# QUANTITATIVE WAVELET DOMAIN IMAGE PROCESSING OF DYNAMIC PET DATA

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## Introduction

Dynamic positron emission tomography (PET) data generally suffer from low signal-to-noise and limited spatial resolution. Kinetic modeling methods used for analyzing these data are often sensitive to noise.

Wavelet-based filters have the potential to reduce noise while preserving spatial resolution due to its ability to provide both space and frequency localization.

Our group has developed a 3D wavelet-based image processing tool for both denoising and enhancement.[1-4] The wavelet-filter (WF) is based on multi-scale thresholding and cross-scale regularization, and utilizes information from the image itself. This data-dependency may lead to non-linearity effects that could hamper quantification of dynamic PET data by kinetic modeling.

The aim of the present study was to investigate the linearity of the WF using dynamic PET data from both phantom and human studies. The study was performed using volume-of-interest (VOI) based analysis with the ultimate goal of achieving improved results in voxel-based analysis.

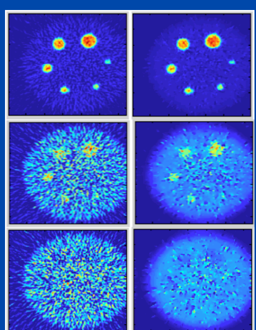

Fig. 1: Three different time frames from a phantom study; unprocessed (left column) and WF processed (right column).

## Acknowledgments

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## Methods - Phantom study

PET scanner: ECAT HR+ (Siemens, Knoxville, TN).
(*Same for human study*)
Phantom: Cylinder (diameter 20 cm) with 6 spherical inserts (diameters 10, 12, 16, 20, 25, 31 mm).
background filled with $^{18}F$ ($T_{1/2}$=110 min)
inserts filled with $^{11}C$ ($T_{1/2}$=20 min).
Data acquisition: 5-min time-frames over 4 hours.
Data processing: Correction for scatter and attenuation
Image reconstruction: Filtered backprojection (FBP) with Shepp filter (Nyquist cut-off).
(*same for human study*)
Image processing: WF with various denoising (D) and enhancement (E) parameters: D/E={1/1, 2/2, 3/3, 5/5}.
Image analysis: Mean image value in each sphere as a function of time.

## Results - Phantom study

As shown in Fig.1, a significant amount of smoothing of the background is achieved with WF, while the spheres definition appear unaffected.

The quantitative analysis (Fig.2) showed that for unprocessed data the lines are straight and parallel when the contrast is positive, while with negative contrast the curves get closer together as a result of contribution from the background. For the WF processed data, with negative contrast, the curves clearly bend, becoming more horizontal, which is an indication of non-linearity.

TABLE III.
WEIGHTED RESIDUAL SUM OF SQUARES AVERAGED ACROSS VOIS AND SUBJECTS

| De-noising | Enhancement | WRSS* |
|---|---|---|
| 0.15 | 0 | 0.987 |
| 0.3 | 0 | 0.880 |
| 0.15 | 15 | 1.284 |
| 0.3 | 15 | 1.172 |

*Normalized to unprocessed data

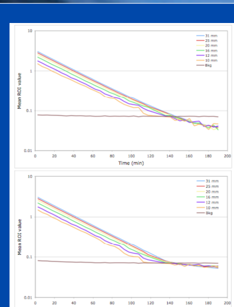

Fig. 2: Mean value in spherical inserts and background in the phantom study as a function of time; unprocessed data (top), WF processed data (bottom).

## Methods - Human study

Subjects: Six healthy volunteers[6].
Tracer: [$^{11}C$]DASB (binds to serotonin transporters)
PET data acquisition: 2 hours from the time of injection
3x20 s, 3x1 min, 3x2 min, 2x5 min, 10x10 min.
Blood sampling: Arterial samples for input function determination.
Data processing: Motion correction,
co-registration to structural MRIs
Image processing: WF with denoising/enhancement parameters:
D/E={1.5/0, 1.5/15, 3/0, 3/15}.
Image analysis: Volumes of interest (VOIs) drawn for various brain regions to generate time-activity curves (TACs).
Kinetic analysis: A 1-tissue compartment model[7] for each VOI.
Quantification: Total volume of distribution, $V_T=K_1/k_2$,
$K_1$ and $k_2$ are first order rate constants describing transfer of tracer between plasma and tissue.

## Results - Human study

Images from the human study (Fig.3) show that with denoising only the 1-min frame becomes visibly much smoother, while the 10-min frame remains almost unaffected: The amount of smoothing depends on the amount of noise in the image. Enhancement results in sharper images (as seen in the 10-min frame), but also leads to noise-amplification (as seen in the 1-min frame).

Fig.4 shows that there is a good correlation between WF processed and unprocessed $V_T$ values. With denoising only there is also a good agreement, but with enhancement included the slope is >1due to improved resolution, resulting in a reduction of partial volume effects.

With denoising only, the residual sum of squares of the kinetic fit was reduced, while with both denoising and enhancement, it increased due to noise-amplification (Table III).

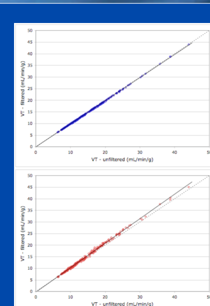

Fig. 4: Correlation between VT values obtained from unprocessed and WF processed data in the human studies; D/E=3/0 (top), D/E=3/15 (bottom). The dotted lines indicate the line of identity.

## Methods - Wavelet filter

The WF algorithm is based on a dyadic wavelet transform[5], using the first derivative of a cubic spline function as the wavelet basis. Each sub-band is processed with a distinct thesholding operator, applied to the modulus of wavelet coefficients. Using cross-scale regularization, detailed signal features within multi-scale sub-bands are recovered by estimating edge locations from coarser levels.

## Conclusions

The results from the phantom study showed that, while linearity was preserved with high contrast, WF processing could lead to non-linear effects in areas with low contrast. The results from the human studies showed that WF processing of real data could lead to quantitatively accurate values while reducing noise and/or enhancing image details.

Having confirmed the linearity of the WF algorithm on a VOI basis, our next step will be to investigate if this method would be beneficial for voxel-based image analysis.

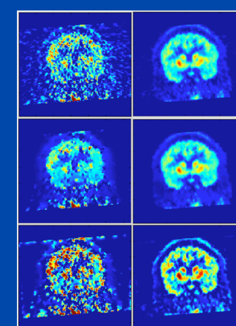

Fig. 3: Coronal sections from a human study, including a 1-min frame (left) and a 10-min frame (right); unprocessed data (top row), WF denoising only (middle row), and WF denoising/enhancement (bottom row).

## References

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