

Dose or Noise Reduction for Dynamic CT Perfusion: 4D Adaptive Time-Intensity Profile Similarity Bilateral Filters (aTIPS-BF)

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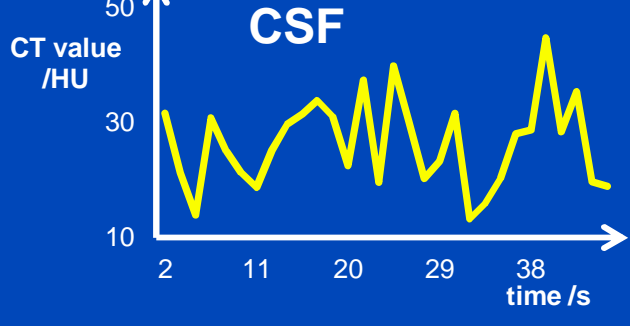
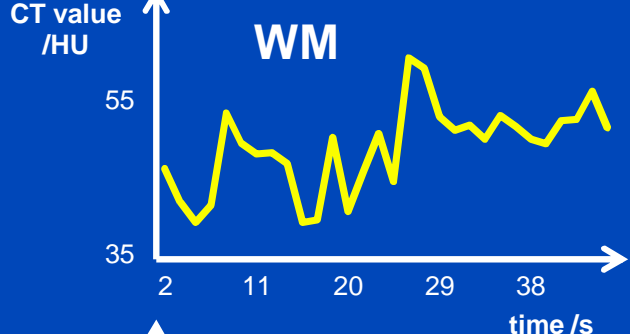
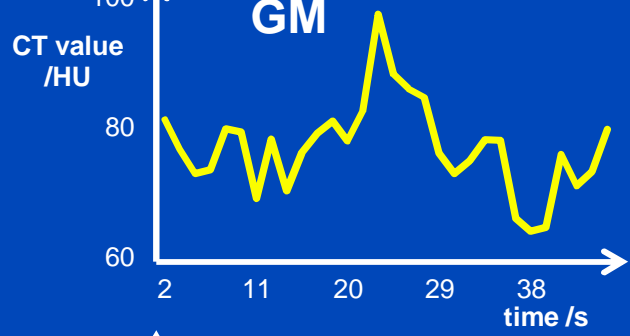
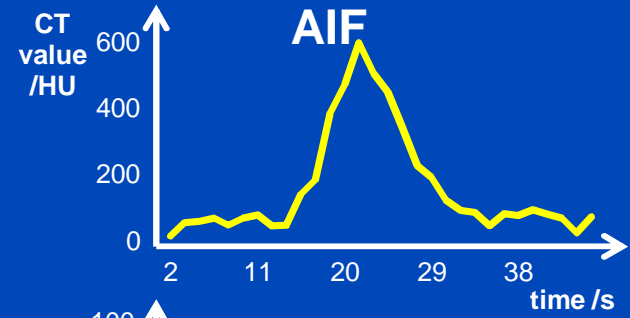
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Introduction

Dynamic acquisition



C = 80 HU, W = 200 HU



Materials and Methods

- **Filters implemented in 4D:**
 - Running average guided bilateral filter → RAGB
 - Time-intensity profile similarity filter → TIPS
 - Multi-band frequency filter → MBF
 - Adaptive time-intensity profile similarity bilateral filter → aTIPS-BF
- **Optimization of parameters**
- **Evaluation of results on CT images**
- **Comparison of functional maps between aTIPS-BF and Gaussian smoothing currently implemented on a commercially available software**

MBF

Multi-Band Frequency (MBF)

MBF:

Split images into spatial low frequency and high frequency components:

$$f^*(\mathbf{r}, t) = \bar{f}_{\text{high}}(\mathbf{r}, t) + f_{\text{low}}(\mathbf{r}, t)$$

$$\bar{f}_{\text{high}}(\mathbf{r}, t) = \frac{1}{2M + 1} \cdot \sum_{m=-M}^M f_{\text{high}}(\mathbf{r}, t + m)$$

RAGB

Running Average Guided Bilateral Filter

$$f^*(\mathbf{r}, t) = \frac{1}{\eta(\mathbf{r})} \sum_{\rho, \tau} w(\tau) w(\rho) w(s) f(\mathbf{r} + \rho, t + \tau)$$

$\eta(\mathbf{r})$ = normalization to unit mass

$$w(\rho) = \frac{1}{\sqrt{2\pi}\sigma_d} e^{-\frac{1}{2}\left(\frac{|\rho|}{\sigma_d}\right)^2}$$

ρ = spatial distance (vector)

$$w(\tau) = \frac{1}{\sqrt{2\pi}\sigma_t} e^{-\frac{1}{2}\left(\frac{\tau}{\sigma_t}\right)^2}$$

τ = temporal distance (scalar)

$$w(s) = \frac{1}{\sqrt{2\pi}V_s} e^{-\frac{1}{2}\left(\frac{s(\bar{f}, \mathbf{r}, \rho, t)}{V_s}\right)^2}$$

The similarity s :

$$s(\bar{f}, \mathbf{r}, \rho, t) = \bar{f}(\mathbf{r}, t) - \bar{f}(\mathbf{r} + \rho, t)$$

The guiding image \bar{f} :

$$\bar{f}(\mathbf{r}, t) = \frac{1}{2M+1} \sum_{m=-M}^M f(\mathbf{r}, t+m)$$

TIPS⁽¹⁾

Time-Intensity Profile Similarity

$$f^*(\mathbf{r}, t) = \frac{1}{\eta(\mathbf{r})} \sum_{\rho, \tau} w(\tau) w(\rho) w(s) f(\mathbf{r} + \rho, t + \tau)$$

The similarity s :

$$s(f, \mathbf{r}, \rho) = \frac{1}{T} \sum_t (f(\mathbf{r}, t) - f(\mathbf{r} + \rho, t))^2$$

⁽¹⁾ A. Mendrik et al. "TIPS bilateral noise reduction in 4D CT perfusion scans produces high-quality cerebral blood flow maps" Phys. Med. Biol. **56** (2011) 3857–3872

aTIPS-BF

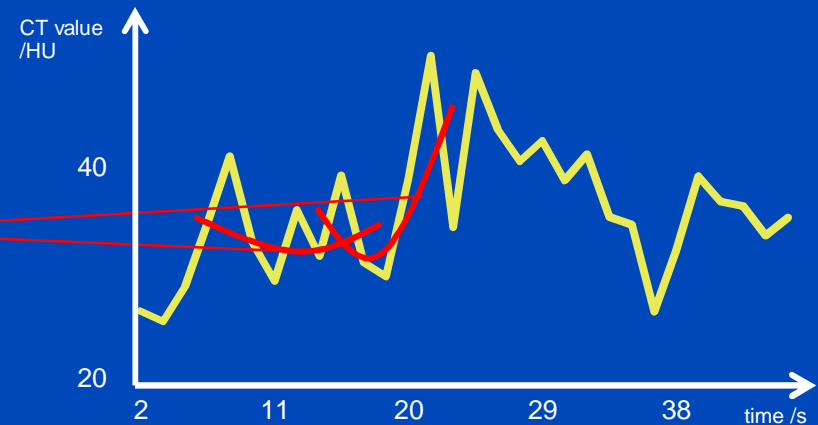
adaptive Time-Intensity Profile Similarity Bilateral Filter

$$f^*(\mathbf{r}, t) = \frac{1}{\eta(\mathbf{r})} \sum_{\rho, \tau} w(\tau, \mathbf{i}, t) w(\rho) w(s) w(\hat{s}) f(\mathbf{r} + \rho, t + \tau)$$

$$w(\tau, \mathbf{i}, t) = \frac{1}{\sqrt{2\pi}\sigma_t(\mathbf{i}, t)} e^{-\frac{1}{2}\left(\frac{\tau}{\sigma_t(\mathbf{i}, t)}\right)^2}$$

$$\hat{s}(f, \mathbf{r}, \rho) = g(f, \mathbf{r}) - g(f, \mathbf{r} + \rho)$$

$$g(f, \mathbf{r}) = w_r \left(\frac{1}{T} \sum_{t=1}^T f(\mathbf{r}, t) \right) + (1 - w_r) f(\mathbf{r}, \text{TTP}_r)$$



Performance Evaluation

For each σ_{xy}, σ_t combination, different performance indexes were calculated.

CNR

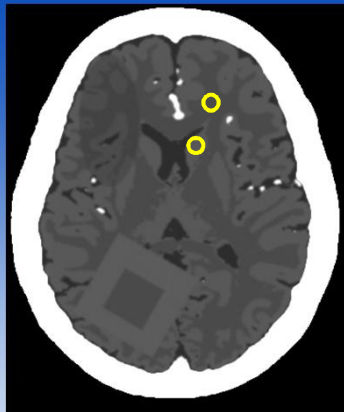
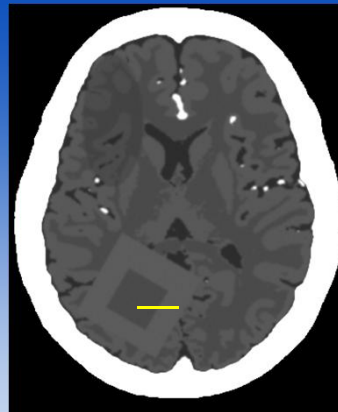


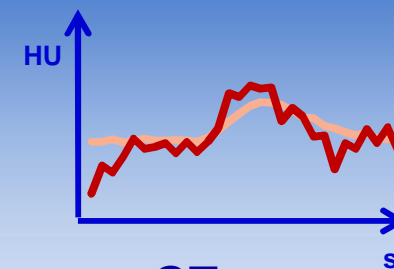
Image
Quality

$FWHM_{LSF}$



Loss of anatomical
details

$RMSE_{GM}$
 $RMSE_{WM}$
 $RMSE_{AIF}$
 $RMSE_{CSF}$



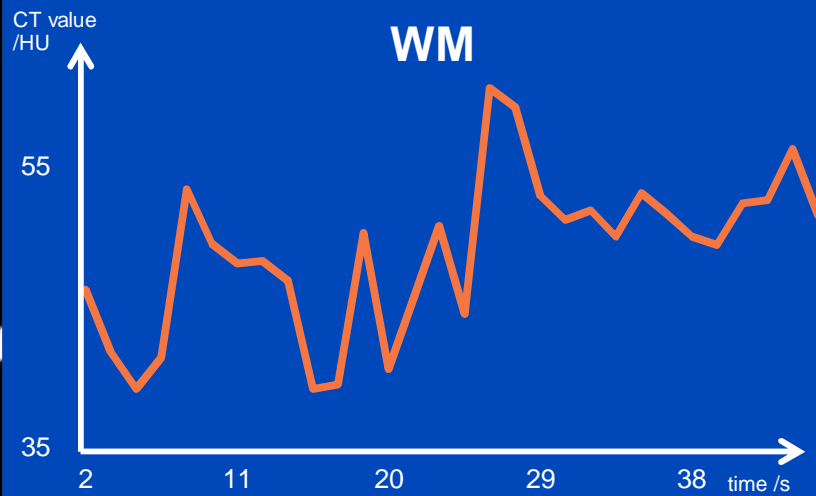
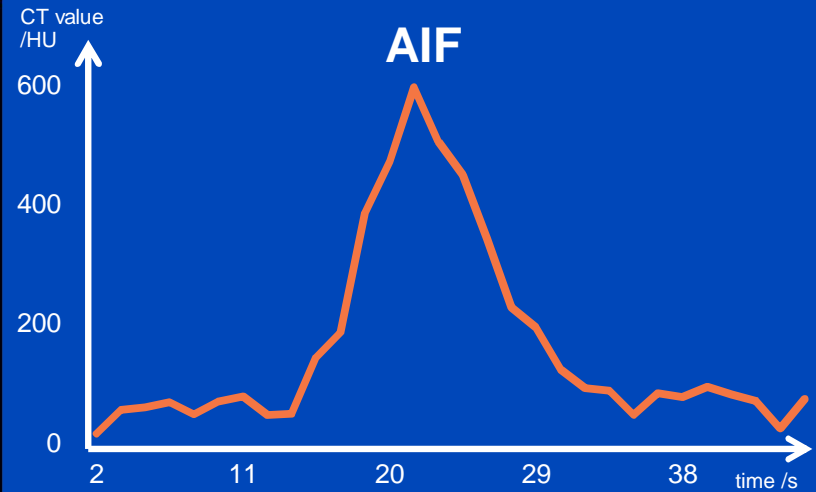
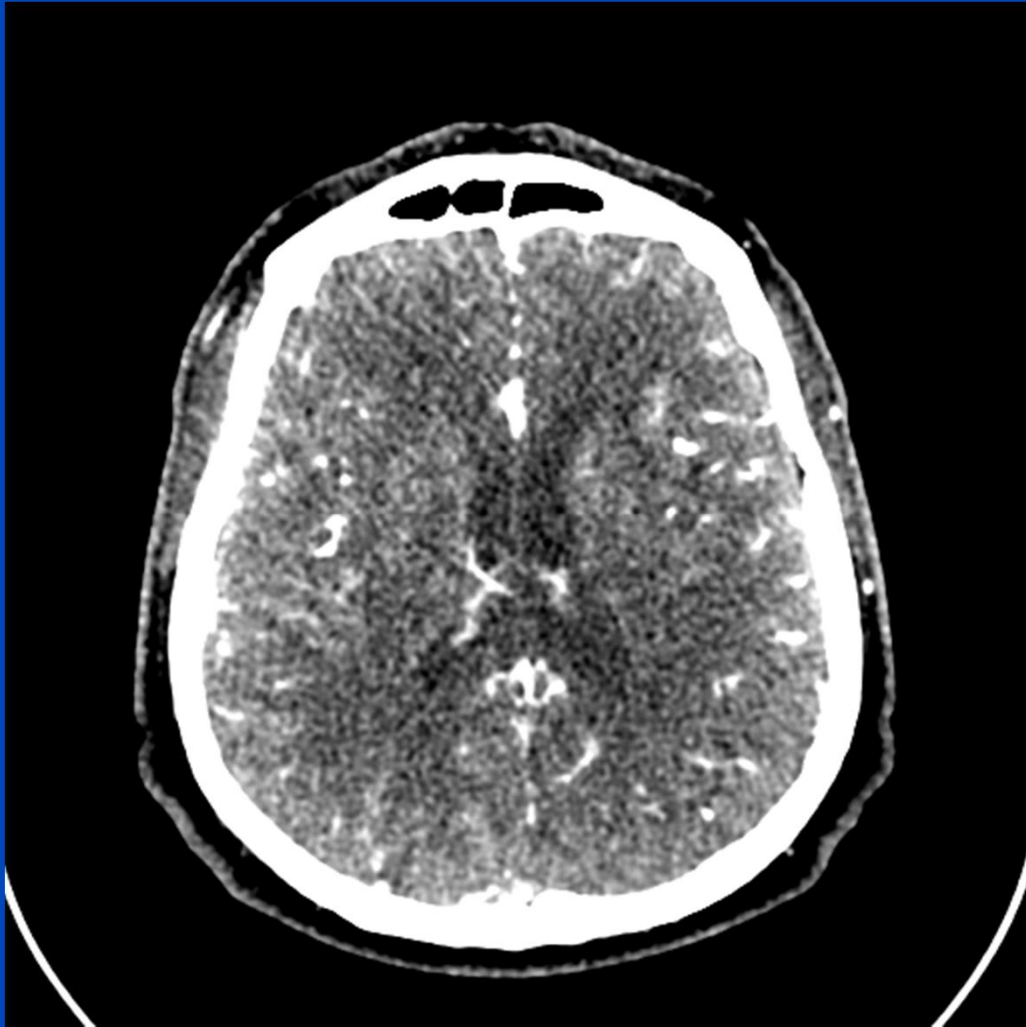
GT
fidelity

Results

(Performances for same spatial resolution)

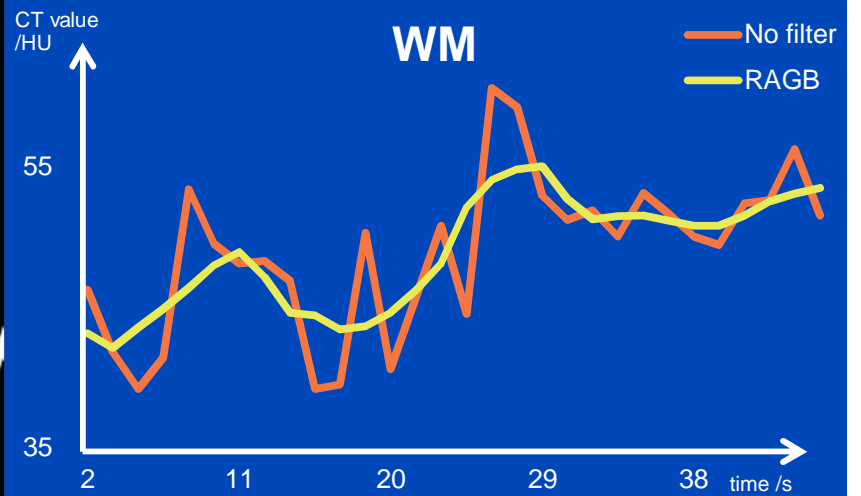
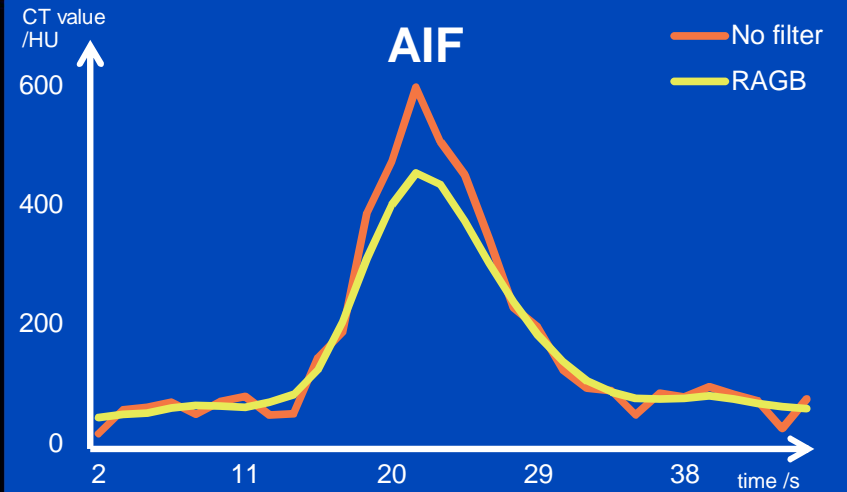
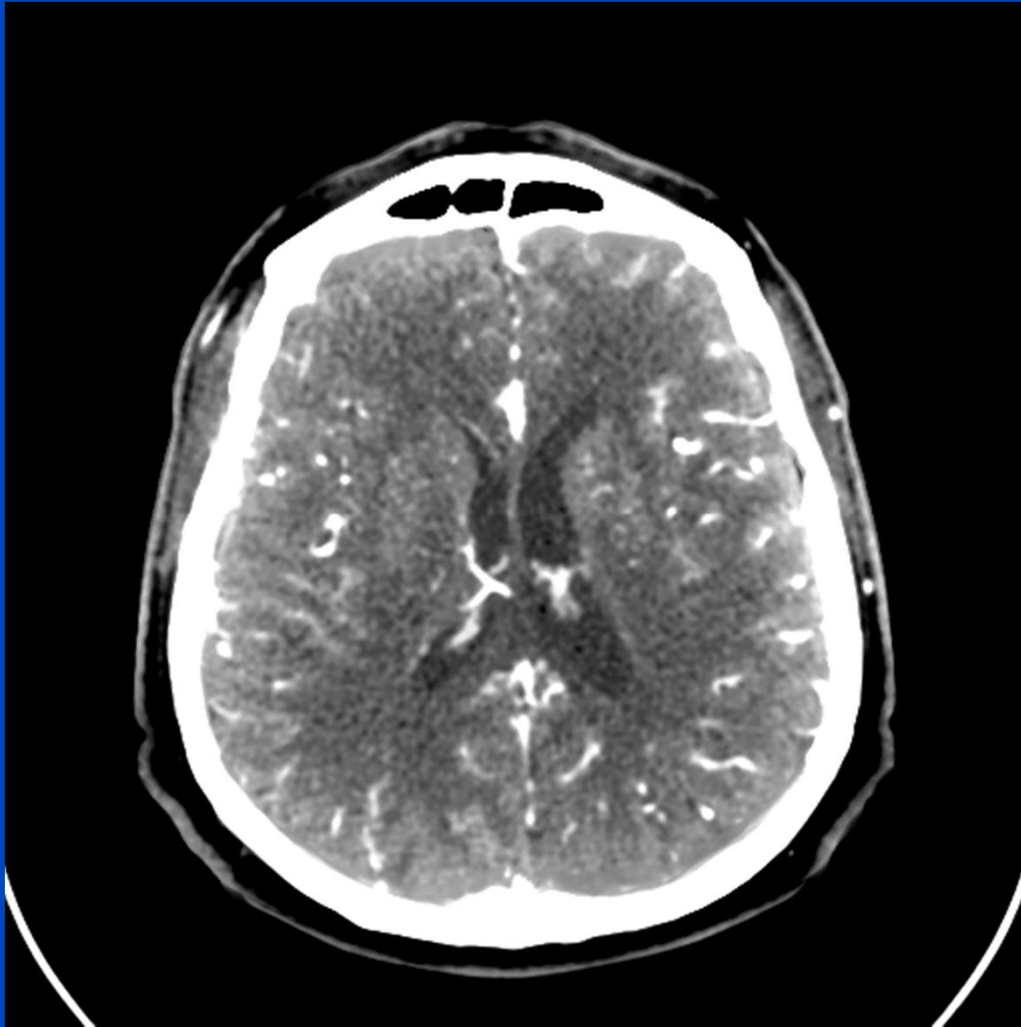
Filter	σ_{xy}	σ_t	CNR	FWHM _{LSF}	RMSE _{AIF}	RMSE _{WM}
RAGB	3.5 mm	1.5 s	0.49	2.05 mm	18.01	1.36
MBF	2.5 mm	1.5 s	0.45	2.05 mm	13.33	1.67
TIPS	0.5 mm	1.5 s	0.61	2.05 mm	12.19	1.6
aTIPS-BF	4 mm	adaptive	0.60	2.05 mm	6.52	0.67

No filters



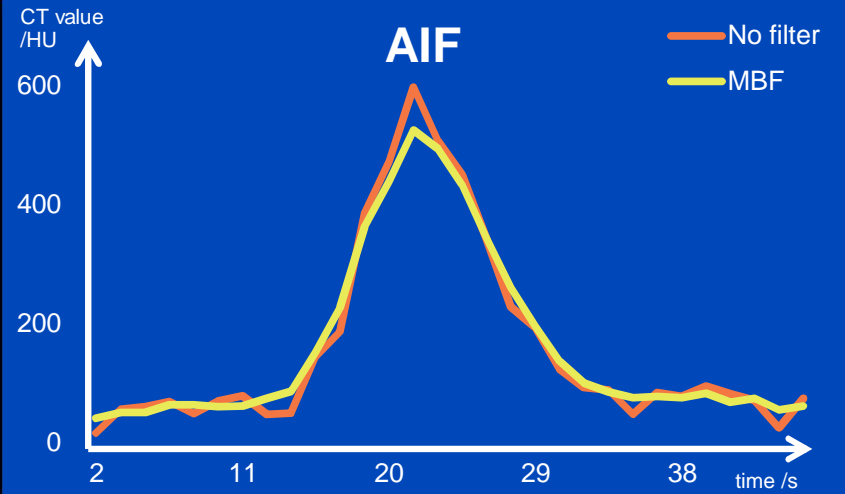
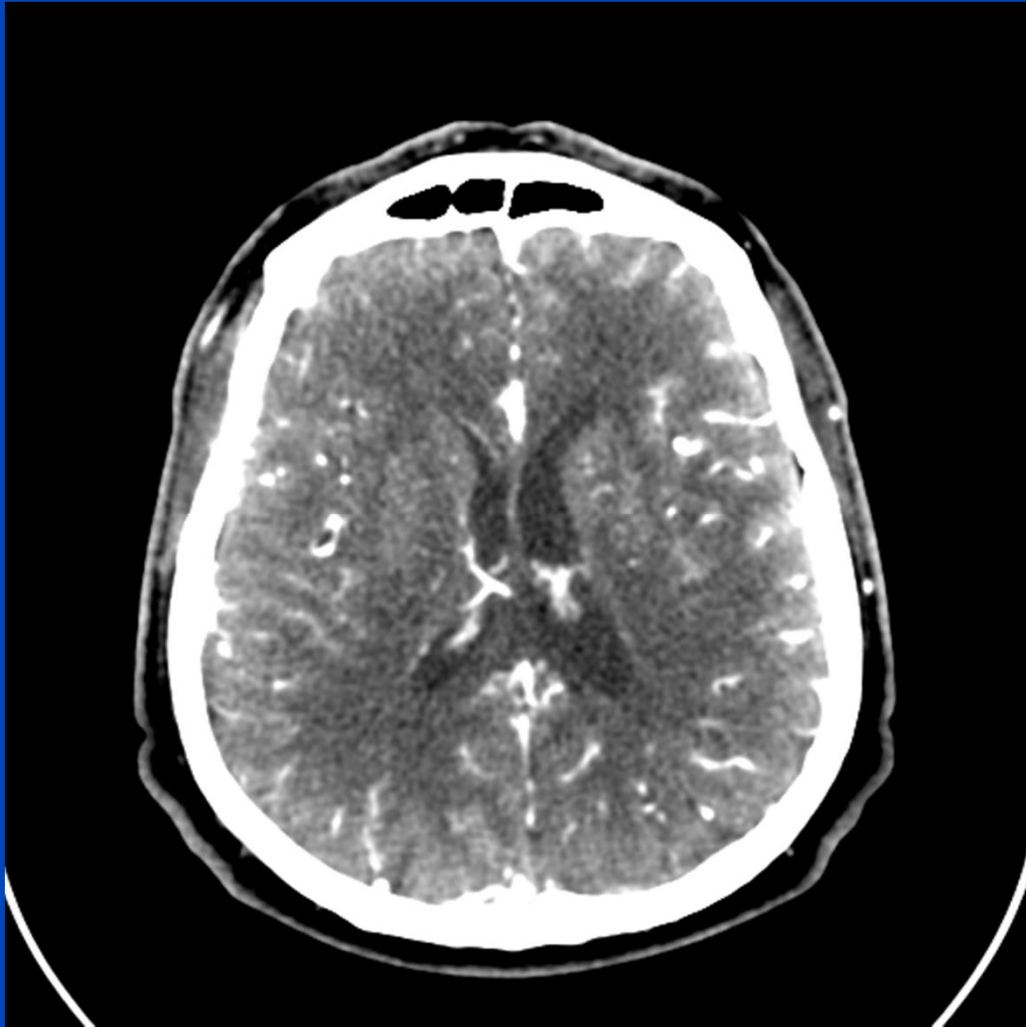
C = 80 HU, W = 200 HU

RAGB



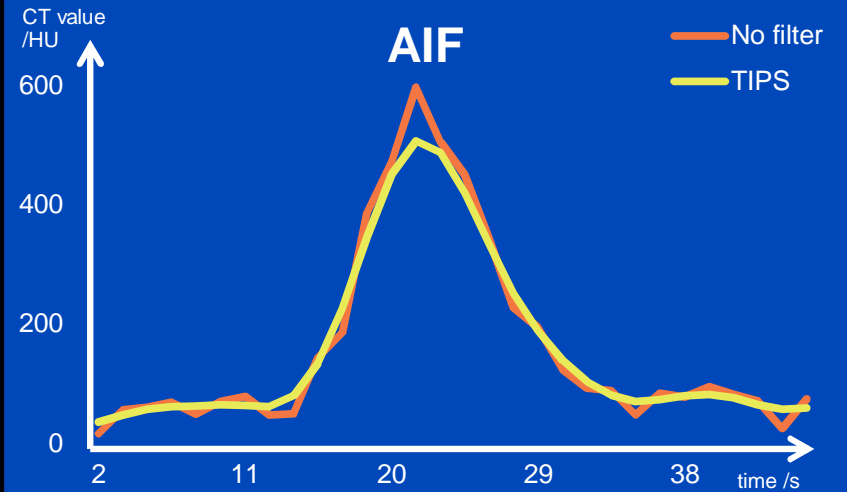
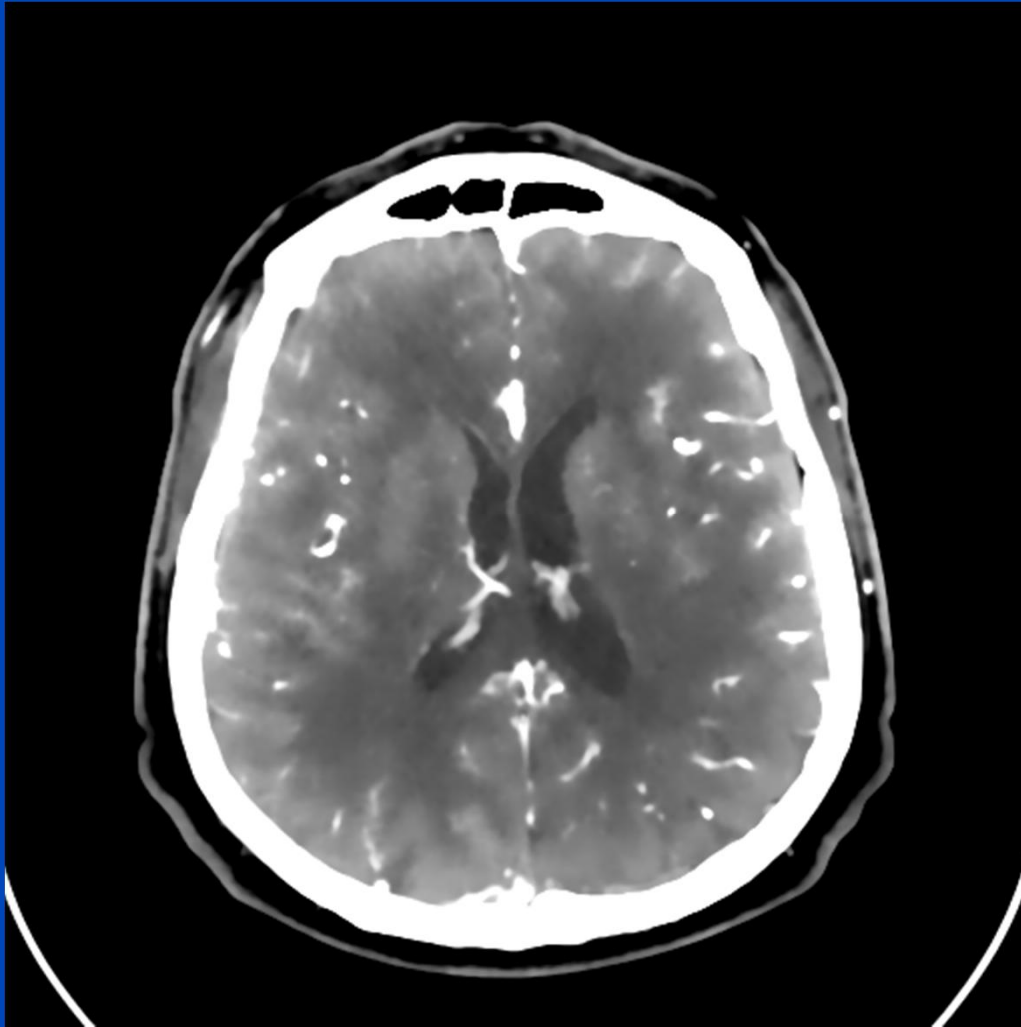
C = 80 HU, W = 200 HU

MBF



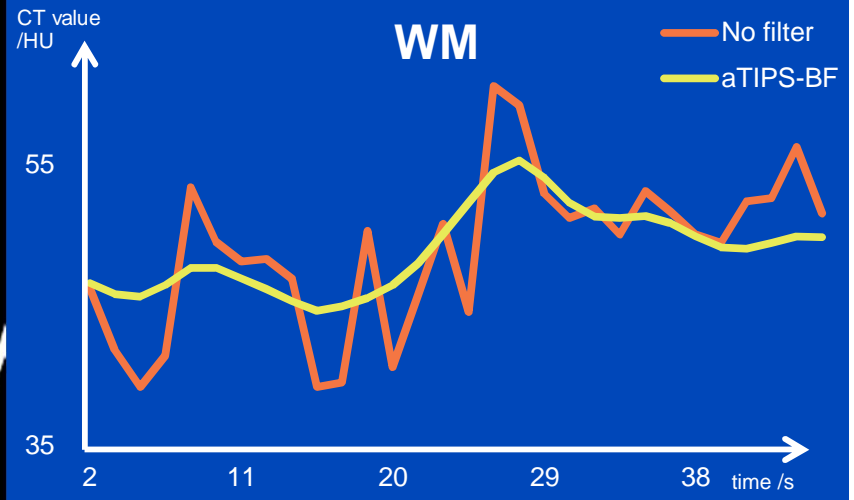
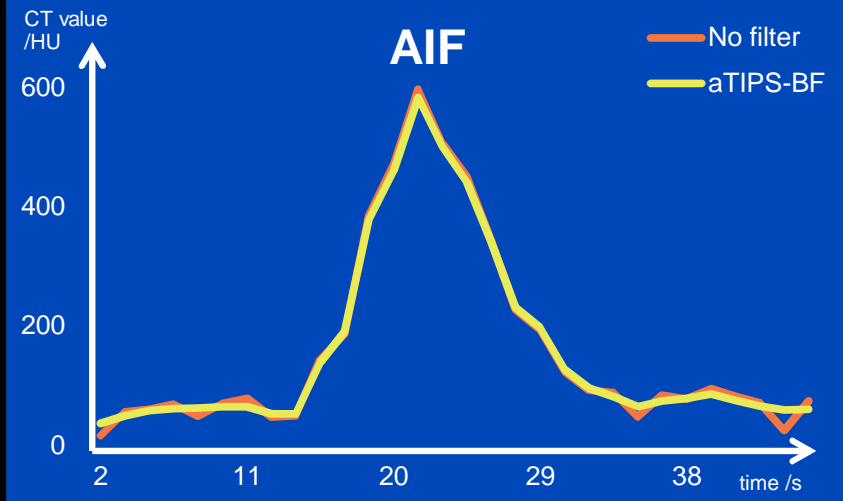
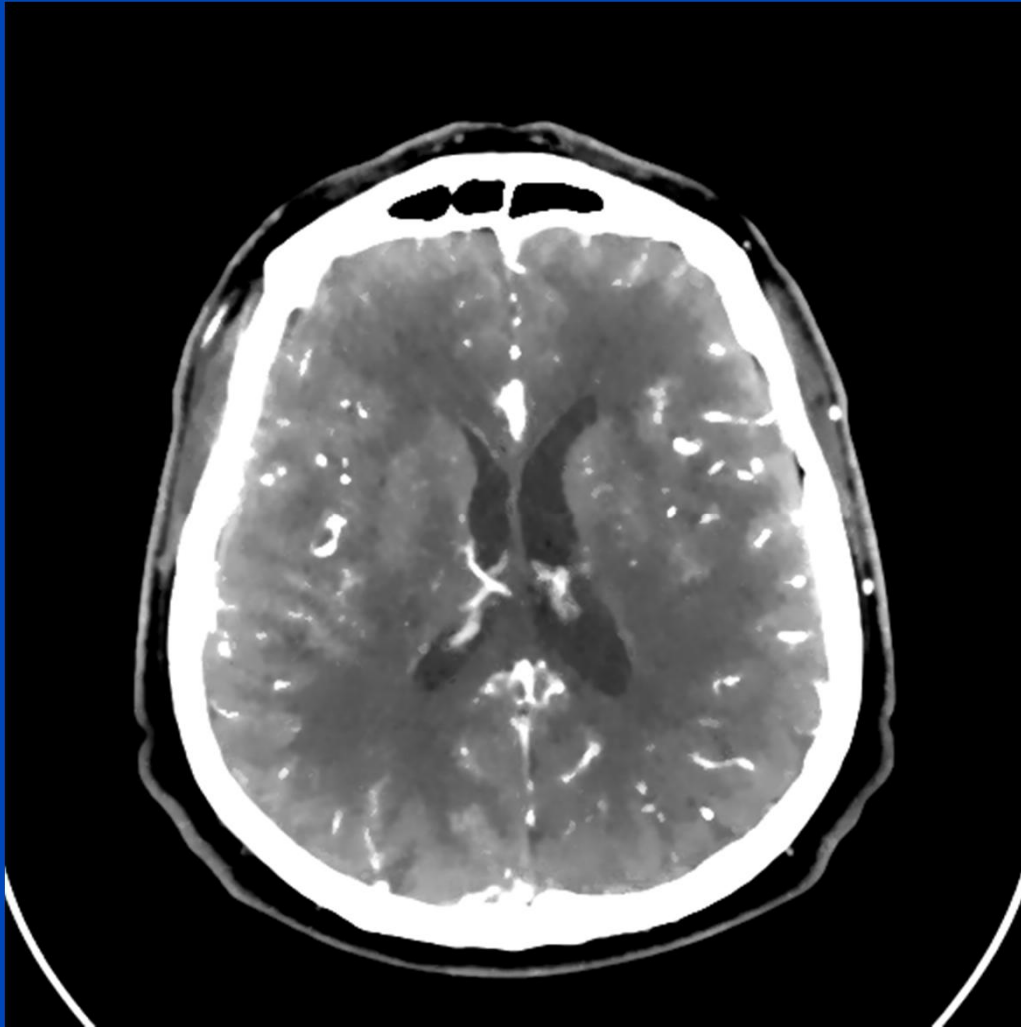
C = 80 HU, W = 200 HU

TIPS 4D



C = 80 HU, W = 200 HU

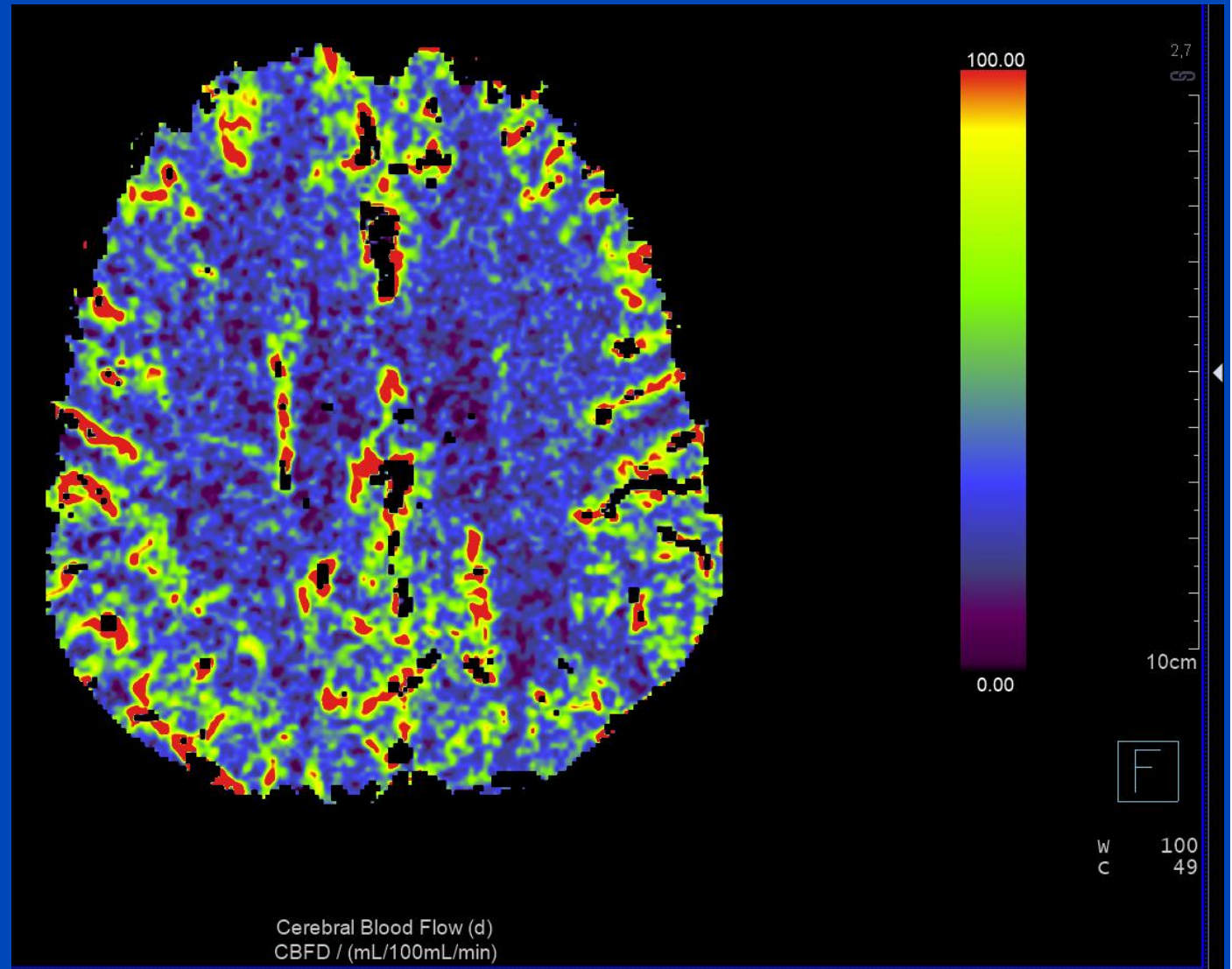
aTIPS-BF



C = 80 HU, W = 200 HU

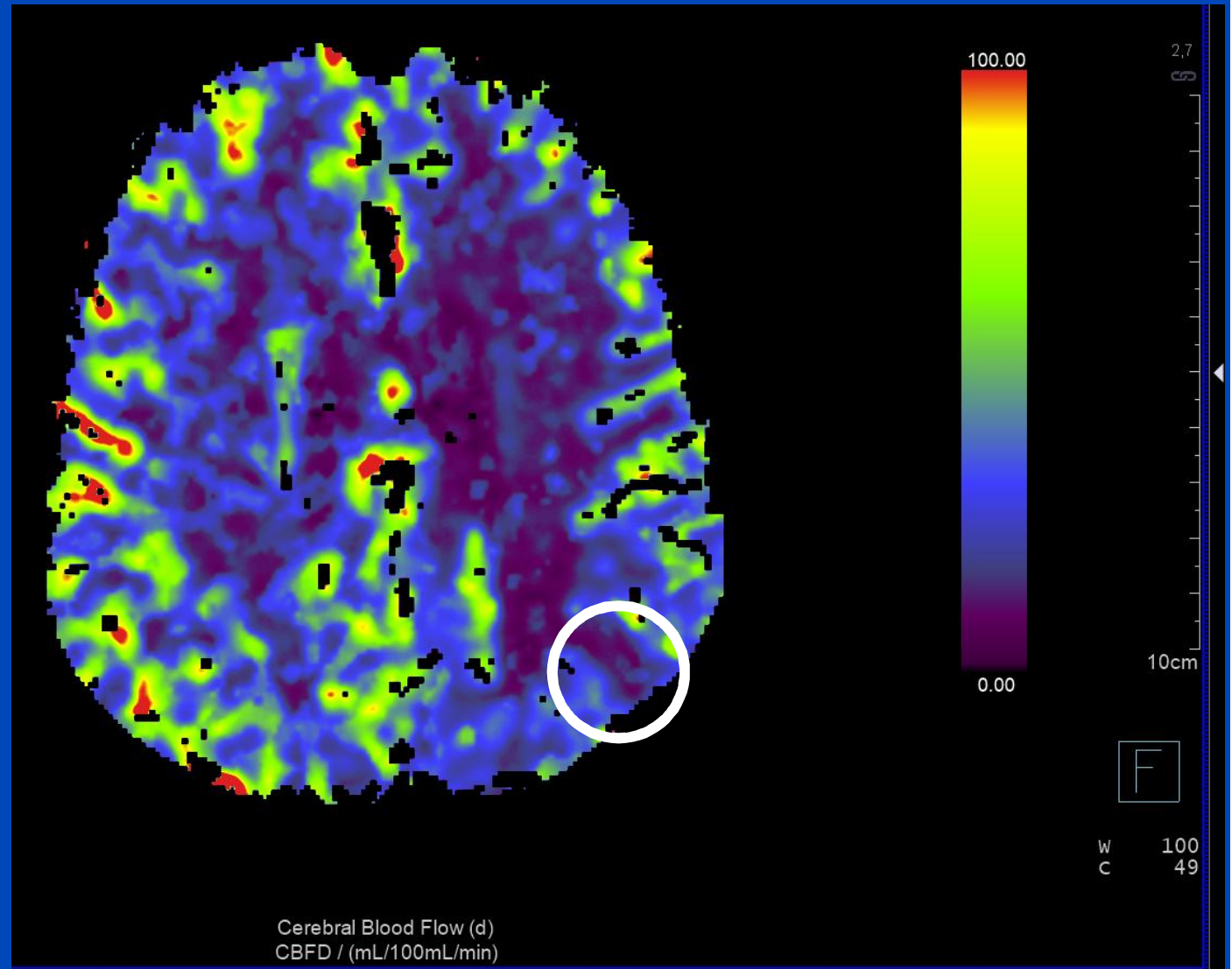
Functional Maps

No filters



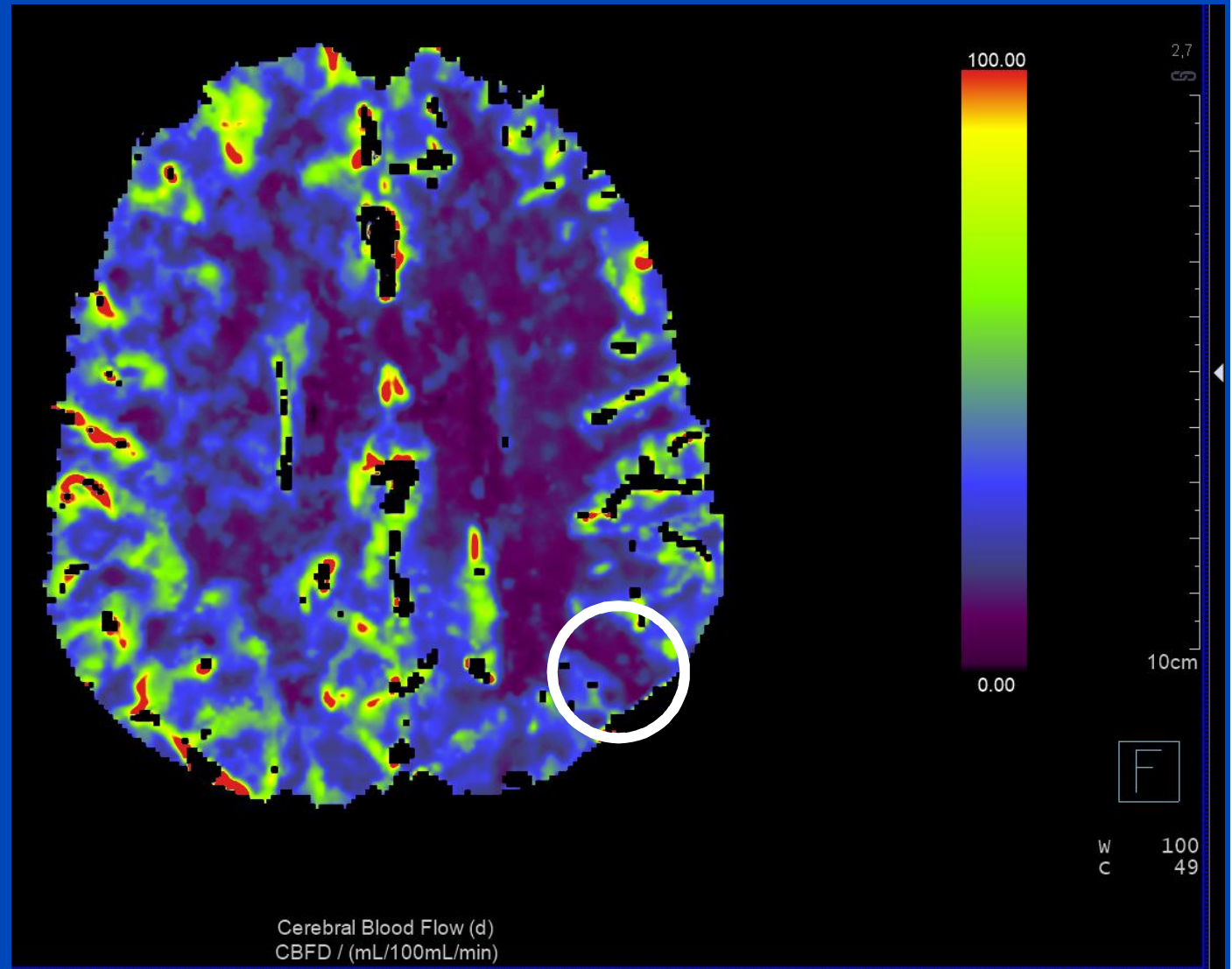
Functional Maps

Gaussian
smoothing



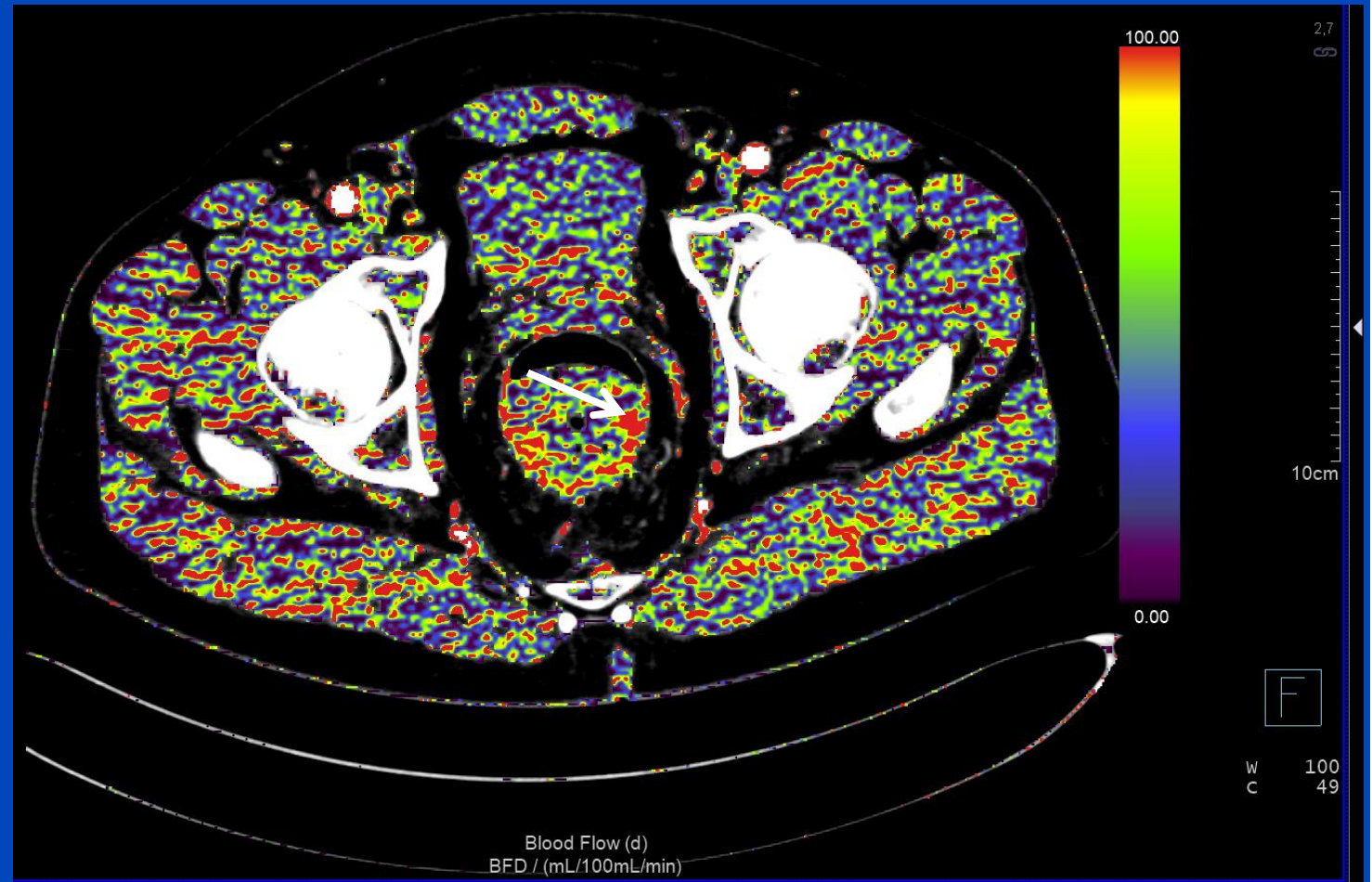
Functional Maps

aTIPS-BF



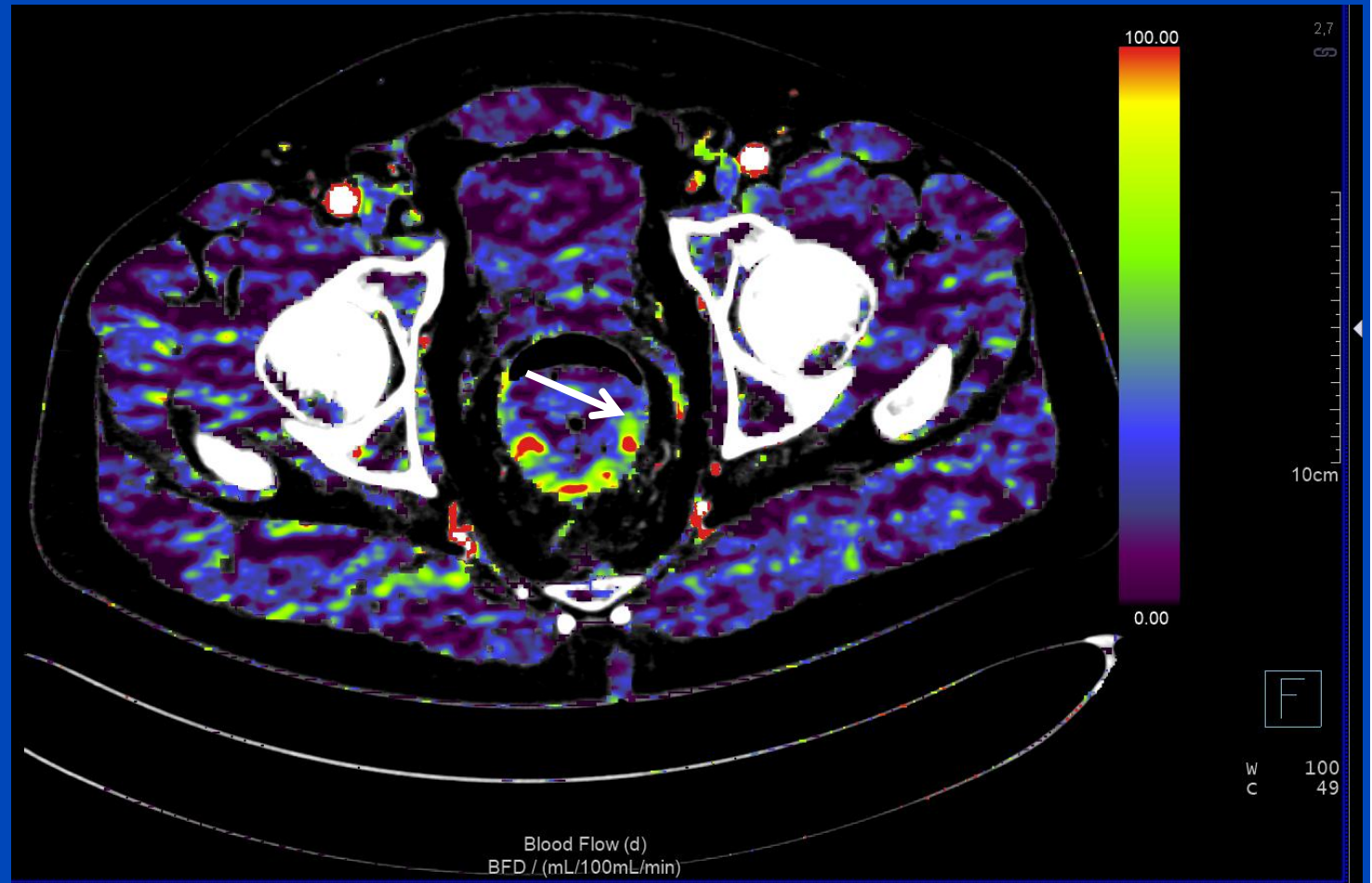
Functional Maps

No filters



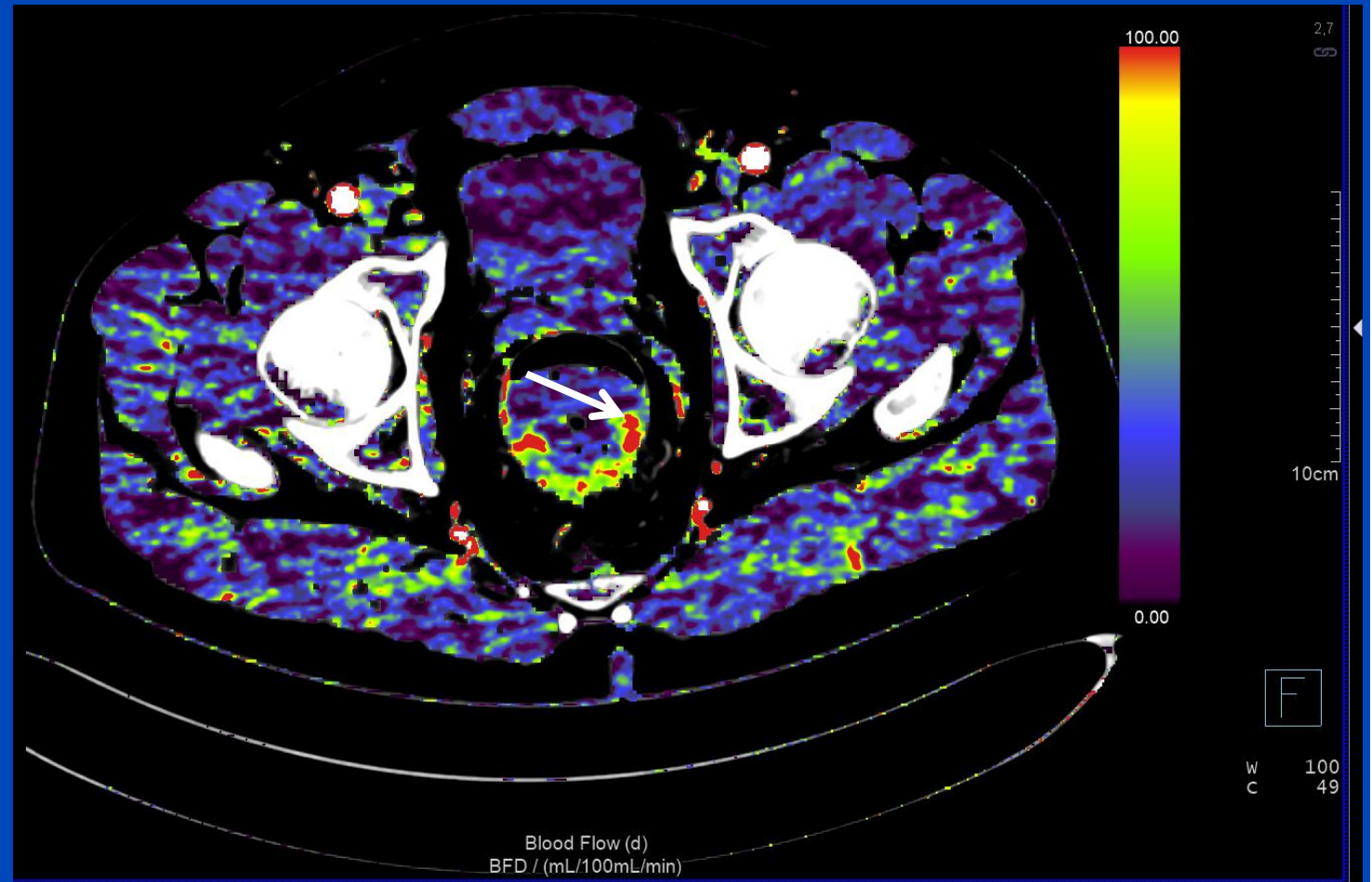
Functional Maps

Gaussian
smoothing



Functional Maps

aTIPS-BF



Conclusions

- **aTIPS-BF filter is an improved version of the TIPS filter. CNR improvements are similar to the TIPS filter, but spatial resolution is higher.**
- **In terms of functional maps, aTIPS-BF shows similar CNR but higher spatial resolution, when compared with a commercially available adaptive Gaussian filter.**
- **Next steps: to introduce a k-means clustering step on noisy dataset in order to improve edge-preserving between different functional classes of voxels (SPIE 2016).**

Thank You!



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Conference Chair

Marc Kachelrieß, German Cancer Research Center (DKFZ), Heidelberg, Germany

**This presentation will soon be available at www.dkfz.de/ct.
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