

Development Of A New K-Means Clustering Guided Filter For Low Dose Dynamic CT Perfusion

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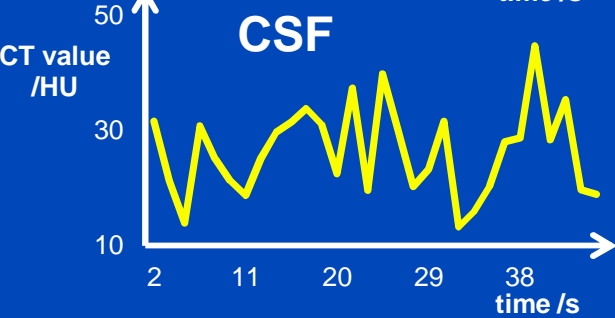
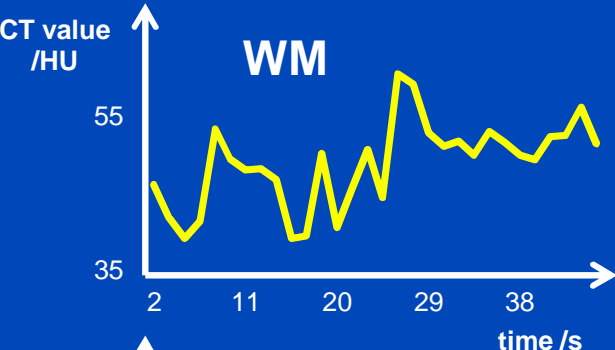
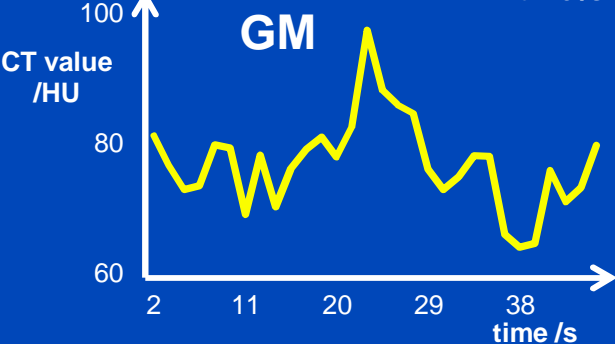
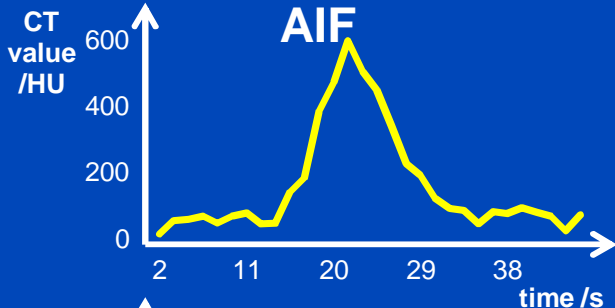
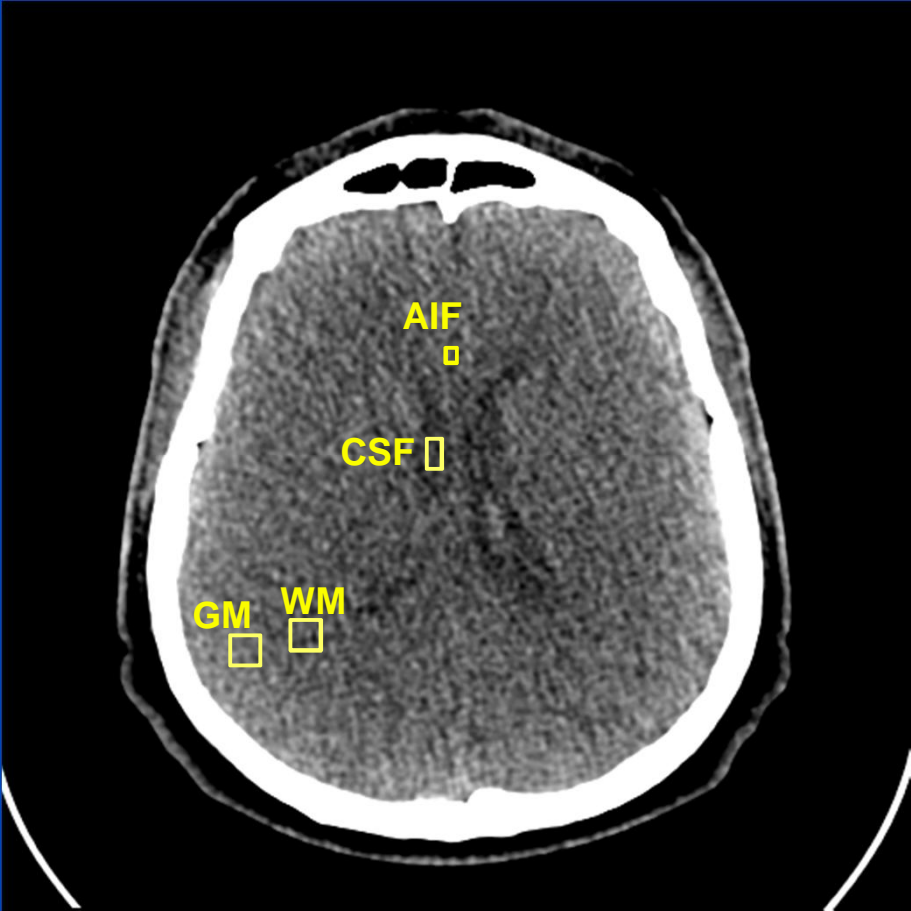
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Introduction

In low dose CTP, TACs SNR is very poor.



C = 80 HU, W = 200 HU

Time Intensity Profile Similarity (TIPS)

Original formulation¹:

$$f^*(\mathbf{r}, t) = \frac{\sum_{\boldsymbol{\rho}} w_d(\boldsymbol{\rho}) w_s(\mathbf{r}, \boldsymbol{\rho}) f(\mathbf{r} + \boldsymbol{\rho}, t)}{\sum_{\boldsymbol{\rho}} w_d(\boldsymbol{\rho}) w_s(\mathbf{r}, \boldsymbol{\rho})}$$

Where

$$w_d(\boldsymbol{\rho}) = \frac{1}{\sqrt{2\pi}\sigma_d} e^{-\frac{|\boldsymbol{\rho}|^2}{2\sigma_d^2}}$$

Gaussian weighting Euclidean distance

$$w_s(\mathbf{r} + \boldsymbol{\rho}) = \frac{1}{\sqrt{2\pi}\sigma_s} e^{-\frac{\sum_{\tau=1}^T \frac{1}{T} (f(\mathbf{r}, \tau) - f(\mathbf{r} + \boldsymbol{\rho}, \tau))^2}{2\sigma_s^2}}$$

Gaussian weighting similarity distance*

$$\mathbf{r} = (i, j, k)$$

Voxel index

f^* Filtered image

$$\boldsymbol{\rho} = (\Delta i, \Delta j, \Delta k)$$

Voxel displacement

f Unfiltered image

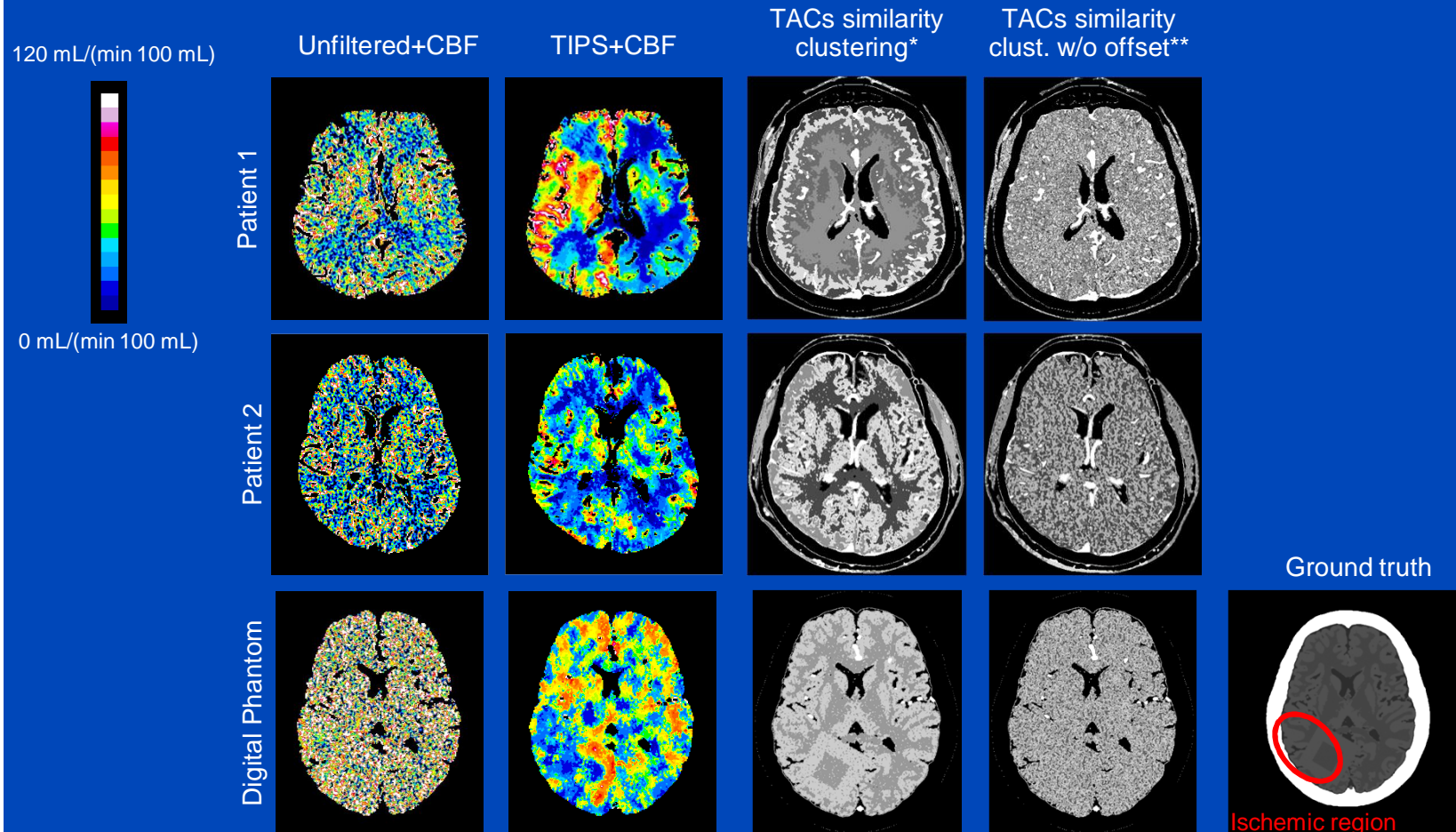
t

Temporal index

¹Mendrik et al. „TIPS bilateral noise reduction in 4D CT perfusion scans produces high-quality cerebral blood flow maps.“ , *Phys Med Biol* (2011).

* σ_s Is measured as the average similarity between TACs belonging to a non-enhancing region like the CSF

Time Intensity Profile Similarity (TIPS)



One study² reported that the TIPS tends to result in over-smoothed maps.

*number of clusters $K=5$ for the clinical cases and $K=3$ for the phantom

²Li et al., *Med Phys* 43, 347 (2016).

**the offset was obtained as the temporal average of the images acquired before contrast media arrival

Time Intensity Profile Similarity (TIPS)

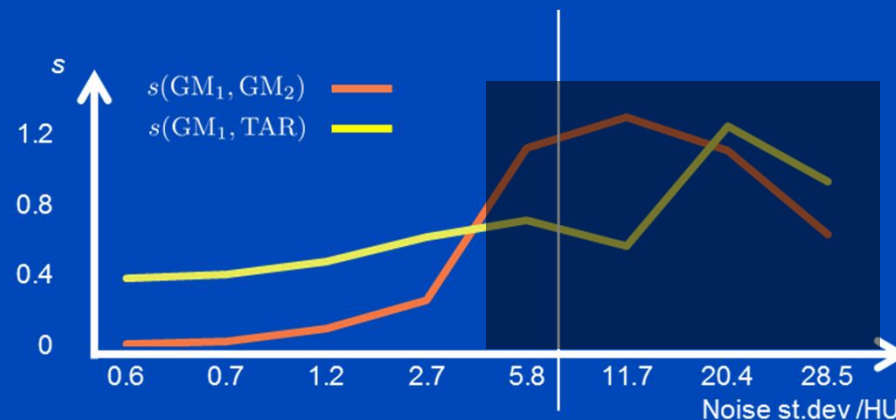
The normalized similarity as defined in the TIPS filter has the following formula*:

$$s(\mathbf{r}_1, \mathbf{r}_2) = \frac{\sum_{t=1}^T (f(\mathbf{r}_1, t) - f(\mathbf{r}_2, t))^2}{2T \sigma_s^2}$$

We can evaluate such similarity:

- $s(\text{GM}_1, \text{GM}_2)$ between two voxels belonging to gray matter,
- $s(\text{GM}_1, \text{TAR})$ between one voxel belonging to gray matter and one to penumbra.

We saw that for increasing noise values, the similarity between two similar voxels, and the similarity between two dissimilar voxels (but with similar average value), tend to be the same.

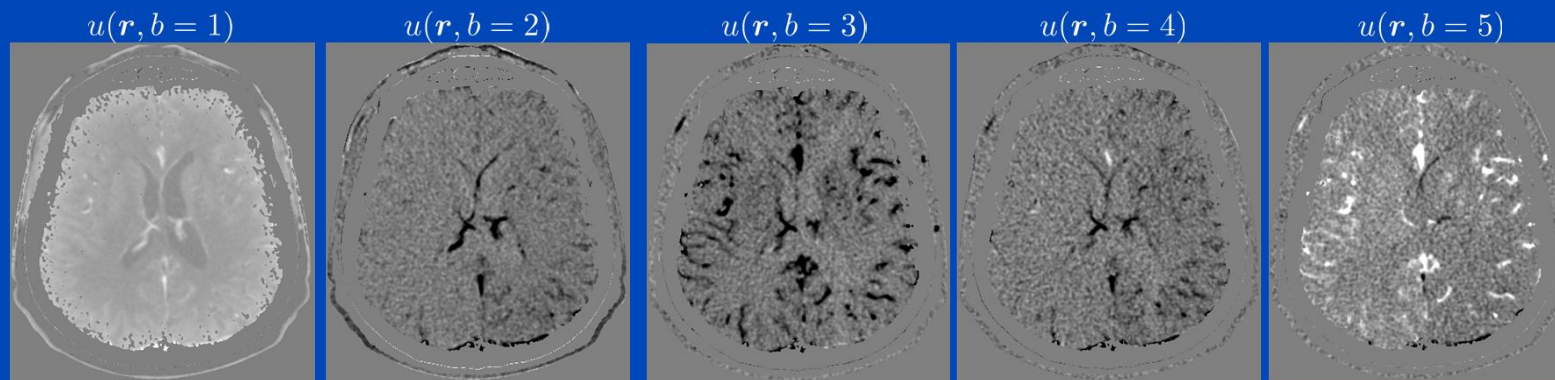


* σ_s is measured as the average similarity between TACs belonging to a non-enhancing region like the CSF

Fuzzy K-Means in Singular Vectors Domain

We propose a new way to calculate similarity between the TACs.

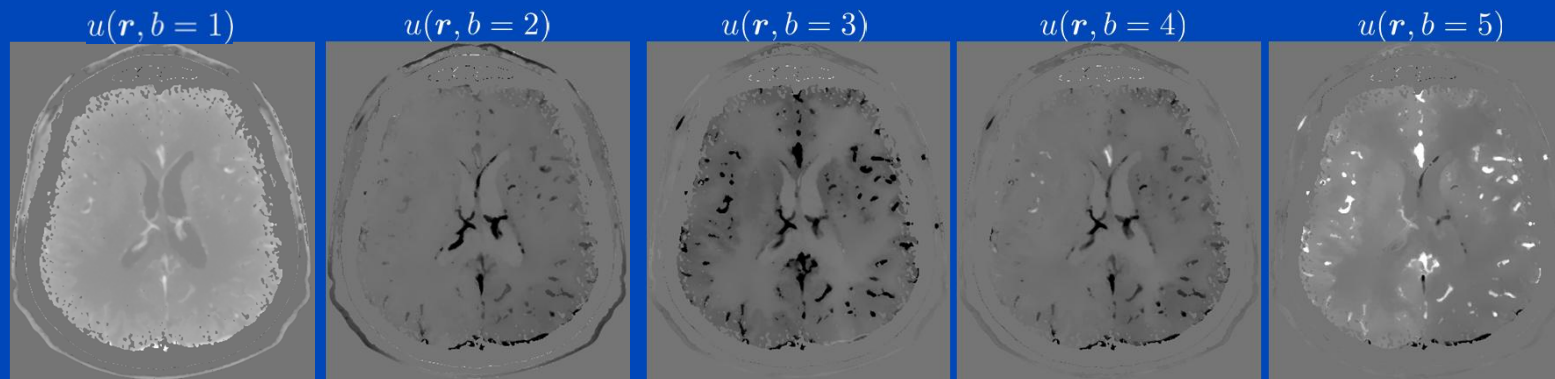
$$f = \begin{pmatrix} f(1,1) & \cdots & f(1,T) \\ \vdots & \vdots & \vdots \\ f(N_v,1) & \cdots & f(N_v,T) \end{pmatrix} \xrightarrow{\text{SVD}} f = U\Sigma V^T$$



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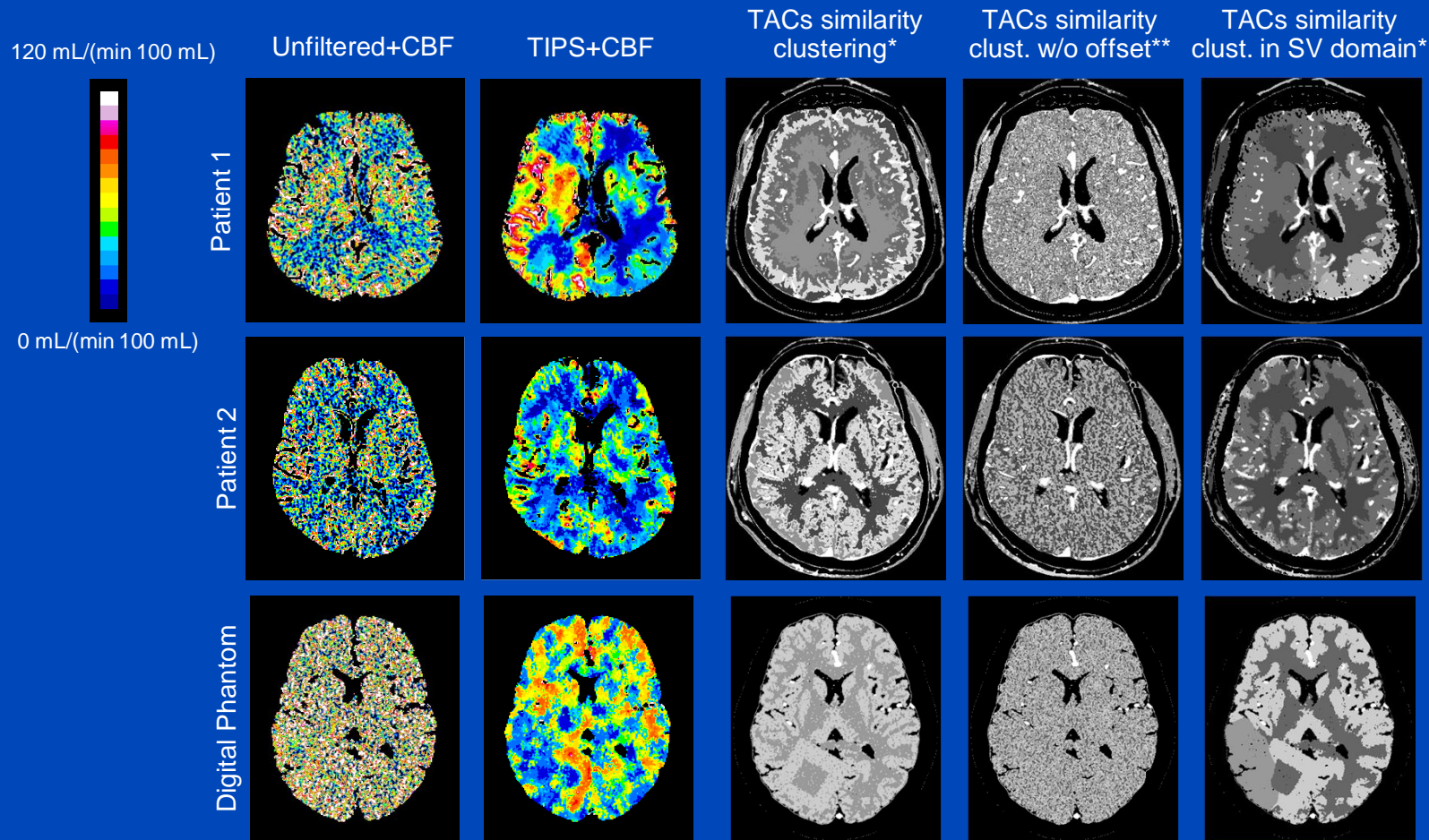


After smoothing the singular vectors, a k-means clustering algorithm was run in this domain, using the following distance measurements from the centroids:

$$d_k(\mathbf{r}) = \frac{1}{5} \sum_{b=1}^5 (u(\mathbf{r}, b) - c_k(b))^2$$

$C = 0, W = 0.02$

Fuzzy K-Means in Singular Vectors Domain



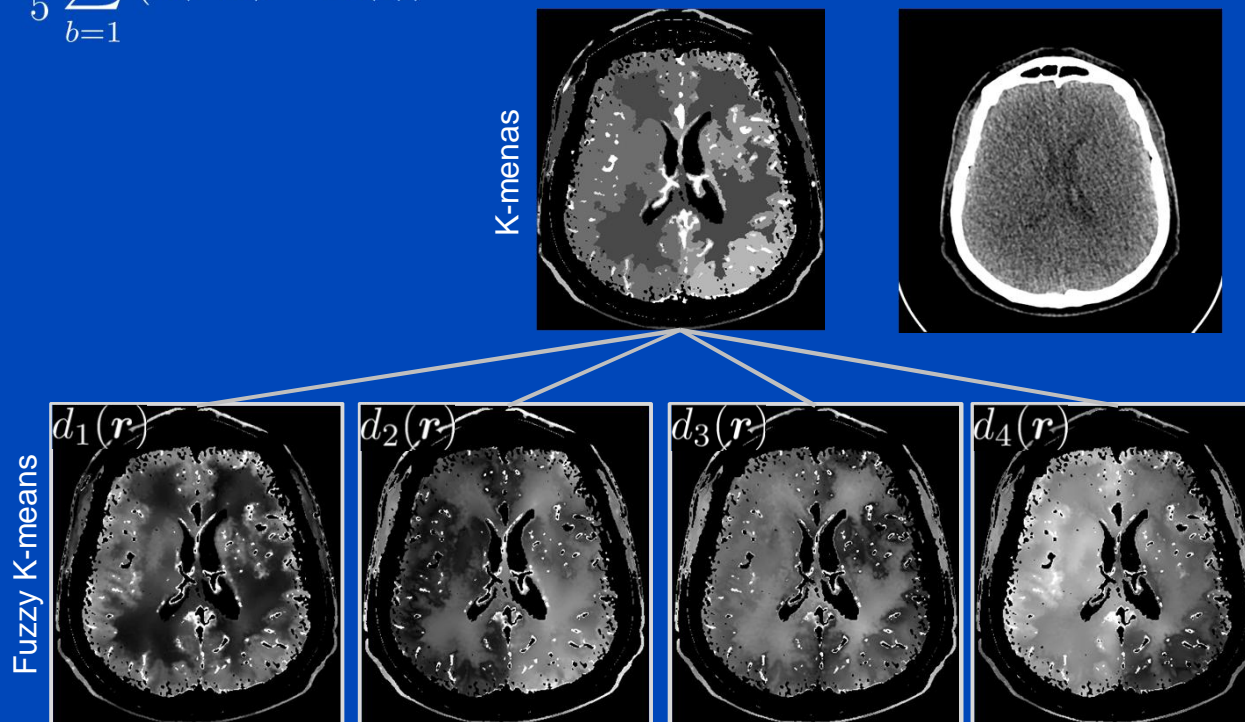
*number of clusters $K=5$ for the clinical cases and $K=3$ for the phantom

**the offset was obtained as the temporal average of the images acquired before contrast media arrival

Fuzzy K-Means in Singular Vectors Domain

We can improve spatial resolution by assigning to each voxel the distance from each cluster (after convergence), rather than the index of the corresponding cluster itself.

$$d_k(\mathbf{r}) = \frac{1}{5} \sum_{b=1}^5 (u(\mathbf{r}, b) - c_k(b))^2$$



C = 0.05, W = 0.1

Fuzzy K-Means Guided Filter (FKMG)

These images contain information regarding how similar are the voxels both anatomically and functionally speaking. We can use such fuzzy clustering to guide a spatial smoothing instead of the TIPS.

$$f^*(\mathbf{r}, t) = \frac{\sum_{\rho} w_d(\rho) w_s(\mathbf{r}, \rho) f(\mathbf{r} + \rho, t)}{\sum_{\rho} w_d(\rho) w_s(\mathbf{r}, \rho)}$$

$$w_s(\mathbf{r} + \rho) = \frac{1}{\sqrt{2\pi}\sigma_i} e^{-\frac{(d_i(\mathbf{r}) - d_i(\mathbf{r} + \rho))^2}{2\sigma_i^2}}$$

Gaussian weighting similarity
distance

Where i is the cluster the voxel \mathbf{r} belongs to.

σ_i is the standard deviation of the distances from the i^{th} centroid of all voxels belonging to the cluster i .

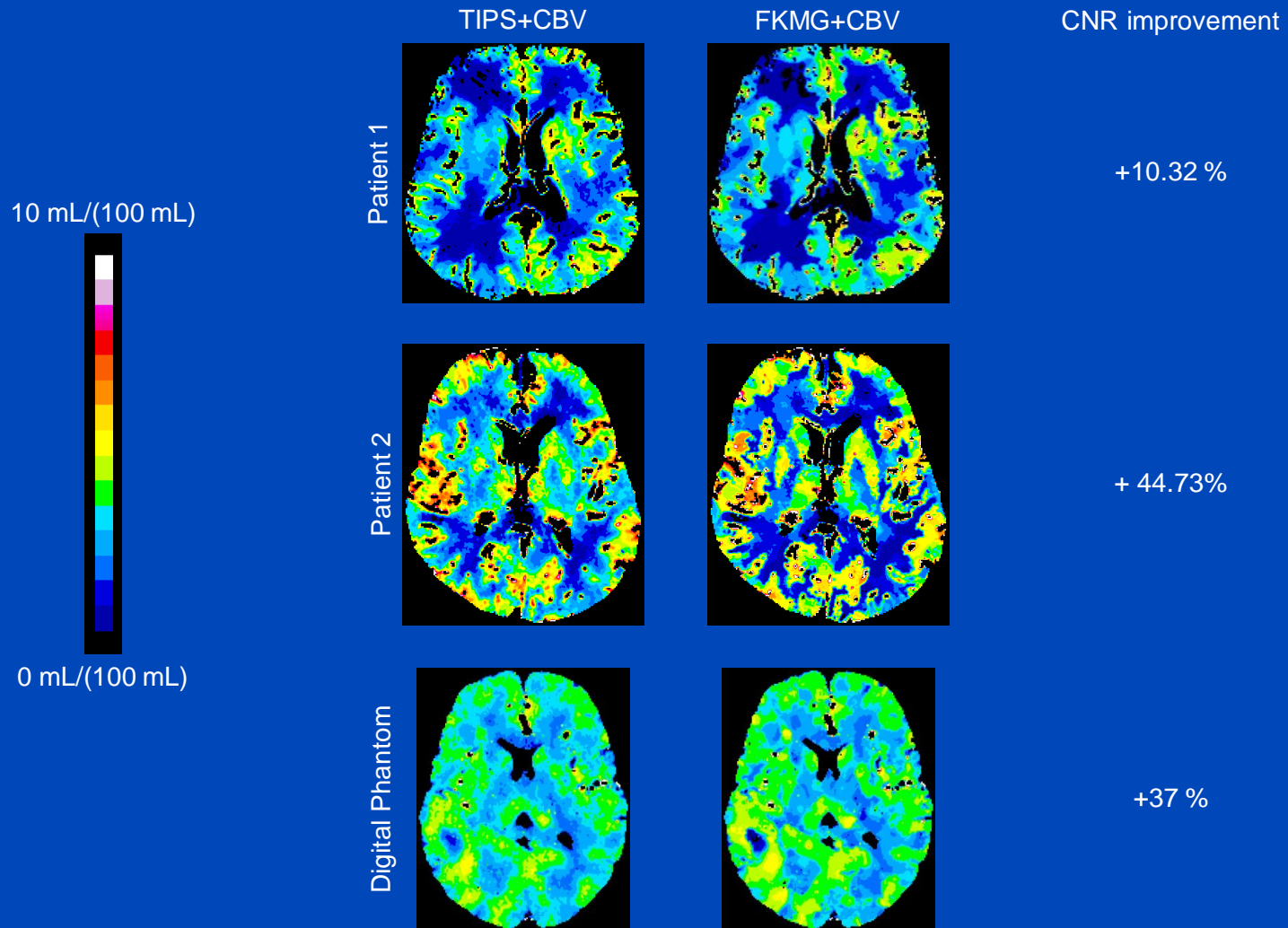
Results - Phantom

We evaluated the average CBF and CBV values in the phantom both for the TIPS and the FKMG filtered datasets. We then compared the measured values with the values obtained from the ground truth (GT) dataset.

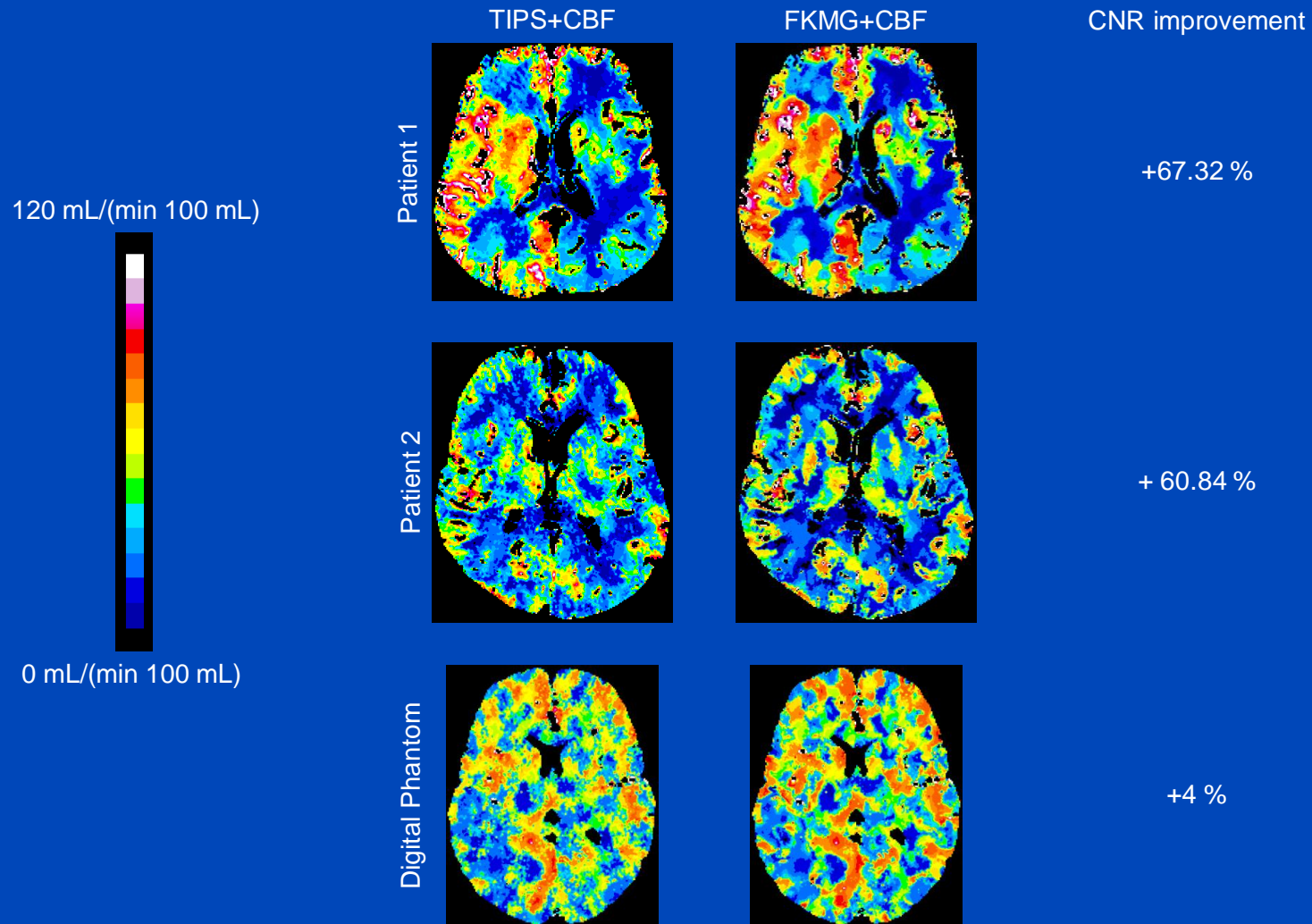
	CBF [mL/(min 100 mL)]			CBV [mL/100 mL]		
	GT	TIPS	FKMG	GT	TIPS	FKMG
GM	60.31	51.5	60	4.4	3.8	4.4
WM	31.62	35.22	30.38	2.9	3.4	3.2
TAR	32.41	25.54	25.64	4.5	4.9	4.9
NVT	18.11	31.72	22.31	1.5	2.5	1.8

It can be seen that the FKMG filter shows values closer to the GT, while the TIPS tends to over-smooth different structures, resulting in lower CNR and potentially over-estimating small ischemic lesions (e.g. NVT).

Results - CBV



Results - CBF



Conclusions

- Similarity between the TACs as defined in the TIPS filter does not reflect functional similarity between voxels, but rather anatomical similarity.
- We developed an algorithm which is able to cluster functionally similar voxels and correctly detect abnormalities, without any prior assumption and more robustly with respect to noise, artifacts and size of the lesions.
- The FKMG filter showed improvements in maps CNR in all cases: on an average 30.6 % for the CBV maps and 44 % for the CBF maps.
- In the phantom study, the FKMG filter showed functional values closer to the ground truth when compared to the TIPS results.

Thank You!

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

Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (www.dkfz.de), or directly through Marc Kachelrieß (marc.kachelriess@dkfz.de).

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