Fast Dynamic Reconstruction Algorithm with Joint Bilateral Filtering for Perfusion C-arm CT

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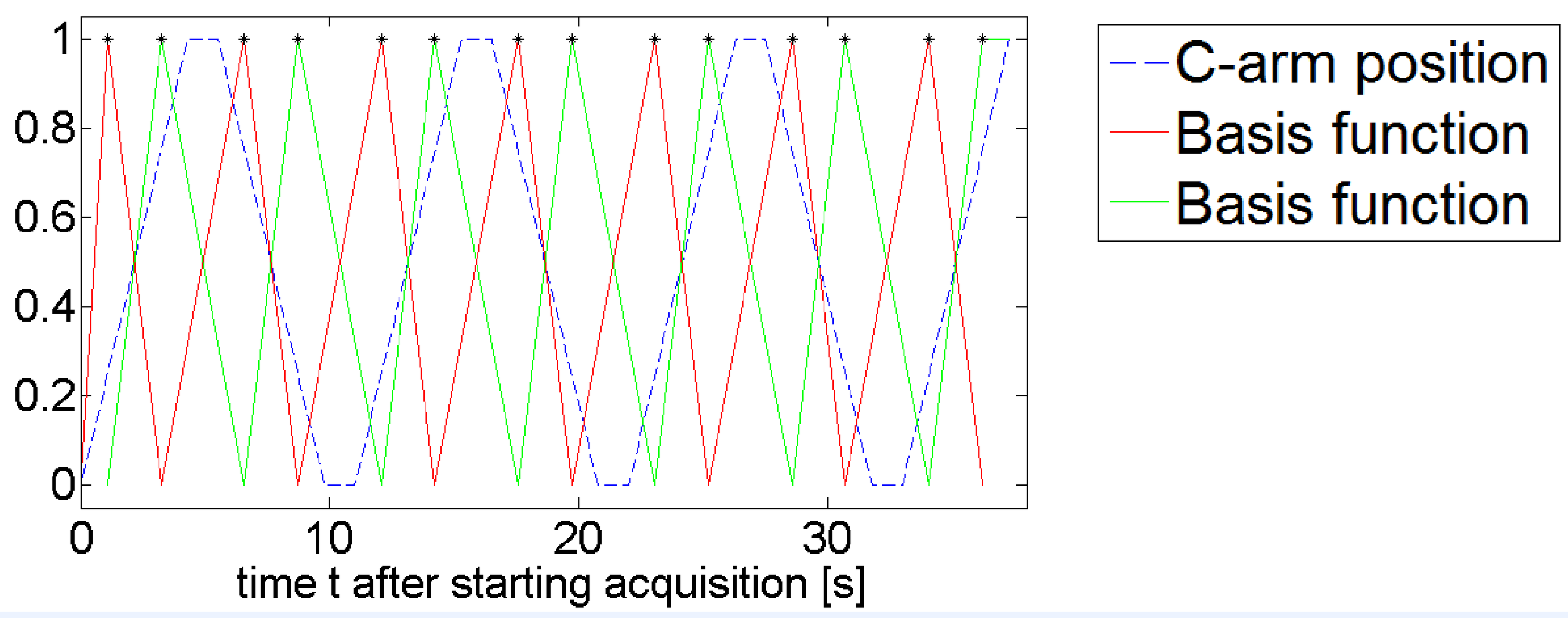
Introduction

- **Perfusion C-arm CT** (PCCT) enables measuring perfusion during **interventional procedures** with **full brain coverage** and **good resolution in all 3 dimensions**
- **Challenges:**
  - **Slow C-arm rotation speed**
  - **Low contrast-to-noise level** in brain tissue

Acquisition & Reconstruction



Dynamic Iterative Reconstruction (DIR):

- Subtract mask projections from contrast-enhanced projections to create contrast-only projection data **p**
- Represent 4D volume **x** describing the contrast time attenuation curves (TACs) as **weighted sum of basis functions** with basis weights **w**:

$$\vec{p} = A\vec{x} \qquad \vec{x} = B\vec{w} \qquad \arg\min_{\vec{w}} \left\| AB\vec{w} - \vec{p} \right\|_2$$

- Solve for **w** with **Landweber iterations** [1]:

$$\vec{w}^{k+1} = \vec{w}^{k} + \beta \cdot B^T A^T \vec{e}^{k} \qquad \vec{e}^{k} = \vec{p} - AB\vec{w}^{k}$$

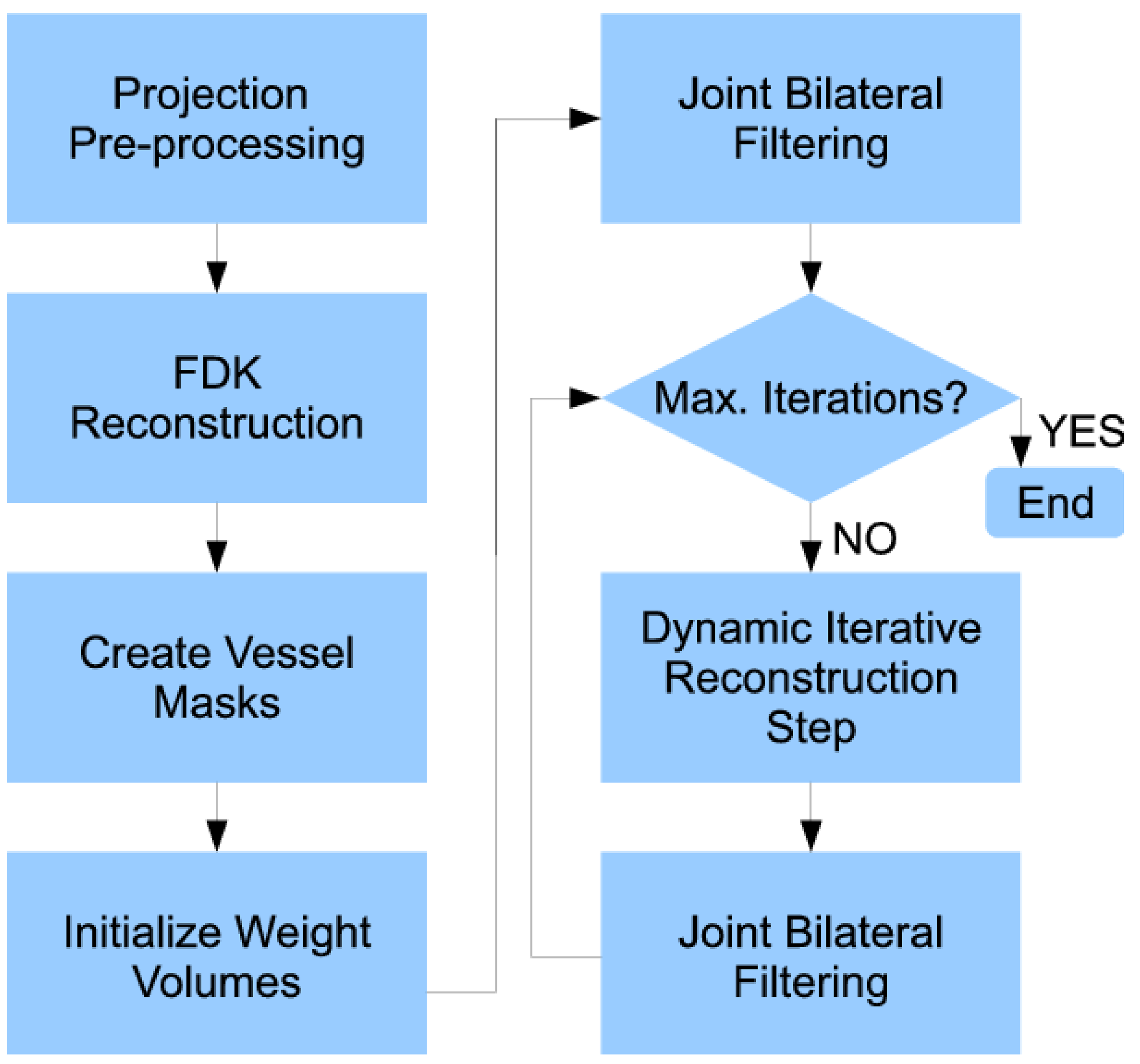
- Use **vessel masking** in back projection to avoid streaking artifacts around vessels:

$$\vec{w}^{k+1} = \vec{w}^{k} + \beta \cdot \left(\vec{m}^{\mathrm{V}} \otimes B^T A^T \vec{e}^{k} + \neg\vec{m}^{\mathrm{V}} \otimes B^T A^T \left(\neg\vec{m}^{\mathrm{P}} \otimes \vec{e}^{k} \right) \right)$$

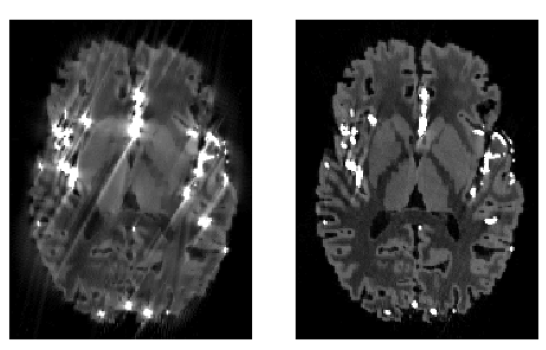
$\vec{m}^{\mathrm{V}}$: volume vessel mask $\vec{m}^{\mathrm{P}}$: projection vessel mask

Noise Reduction with Joint Bilateral Filtering (JBF) [2]:

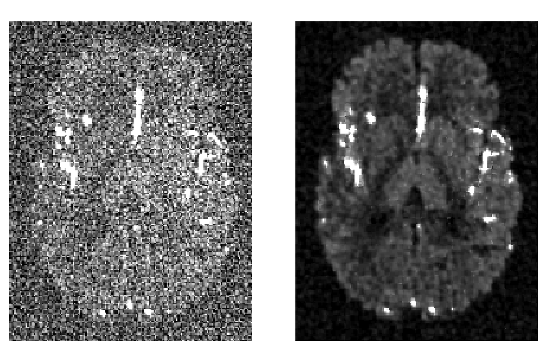
- Temporal maximum intensity projection for range similarity
- Avoids blurring of vessels into brain tissue



Dynamic Iterative Reconstruction Algorithm Flow Chart



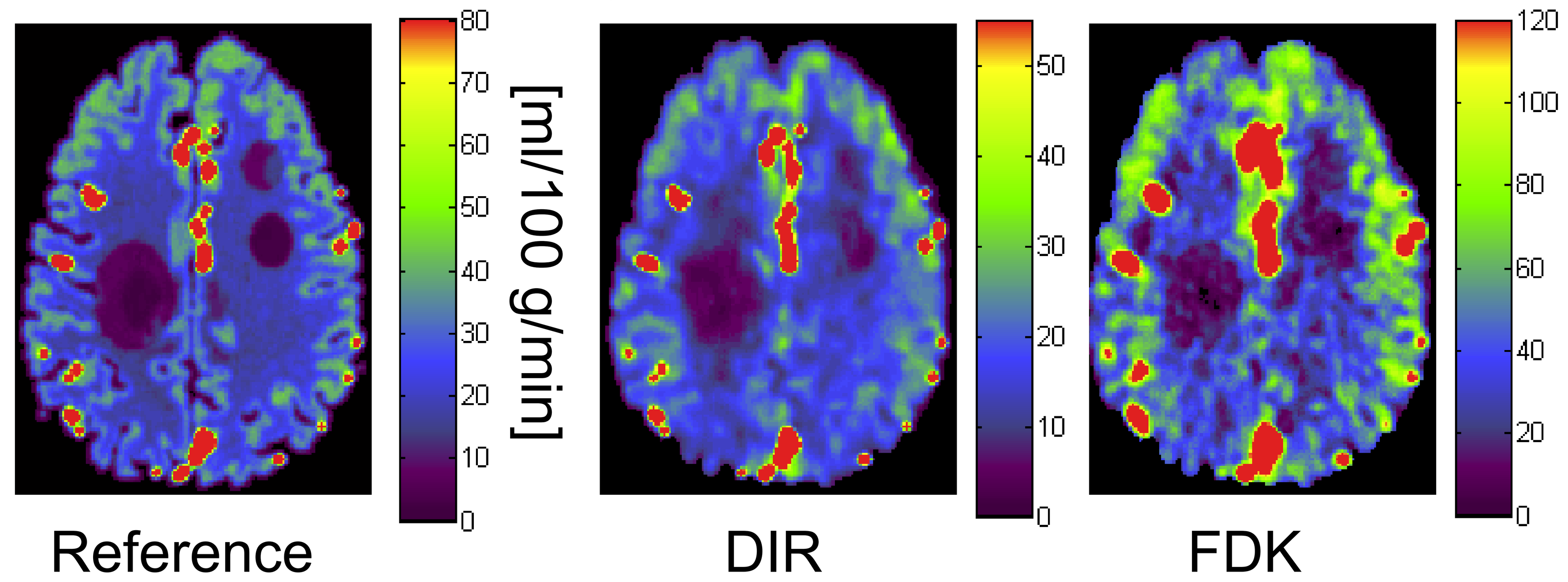
Brain phantom data reconstructed without and with vessel masking



Noisy brain phantom volume and denoised volume filtered with the joint bilateral filter

Results

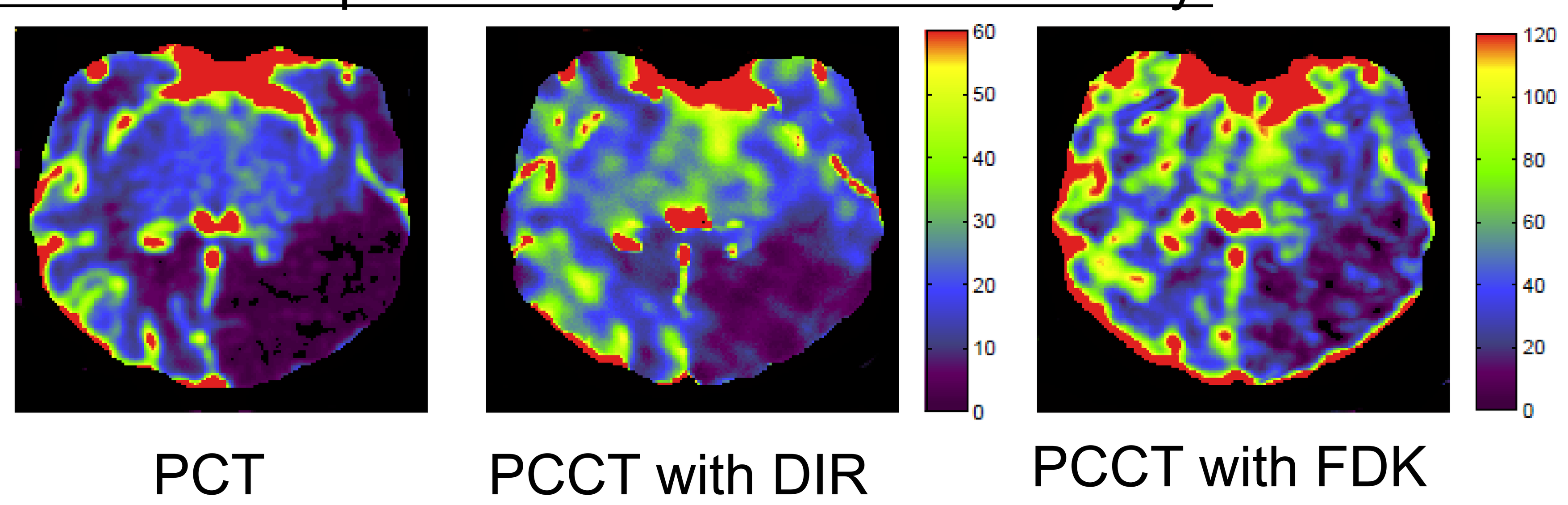
Blood flow maps from digital brain phantom [3]:



	DIR	FDK		DIR	FDK
RMSE AIF [HU]	26	135	PC CBF	0.87	0.81
RMSE Tissue [HU]	2.09	2.74	PC CBV	0.82	0.78

Table 1: Quantitative results from brain phantom study (RMSE: root mean square error of time attenuation curves over time; PC: Pearson correlation between reference and reconstructed maps; CBF: cerebral blood flow; CBV: cerebral blood volume).

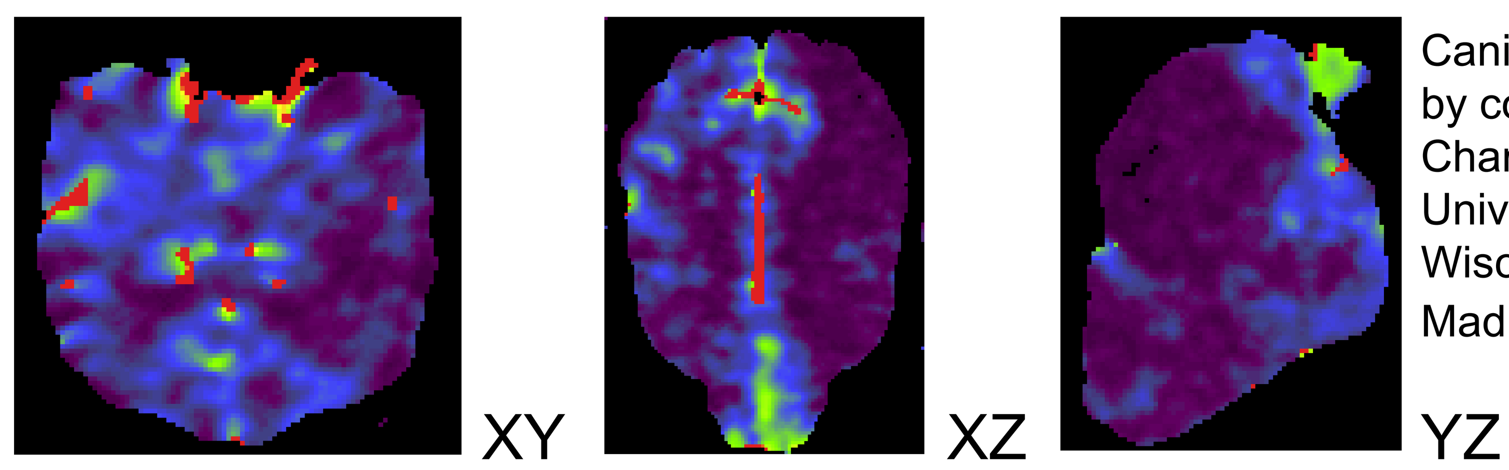
Blood flow maps from canine stroke model study:



	DIR	FDK
PC CBF	0.73	0.61
PC CBV	0.62	0.50

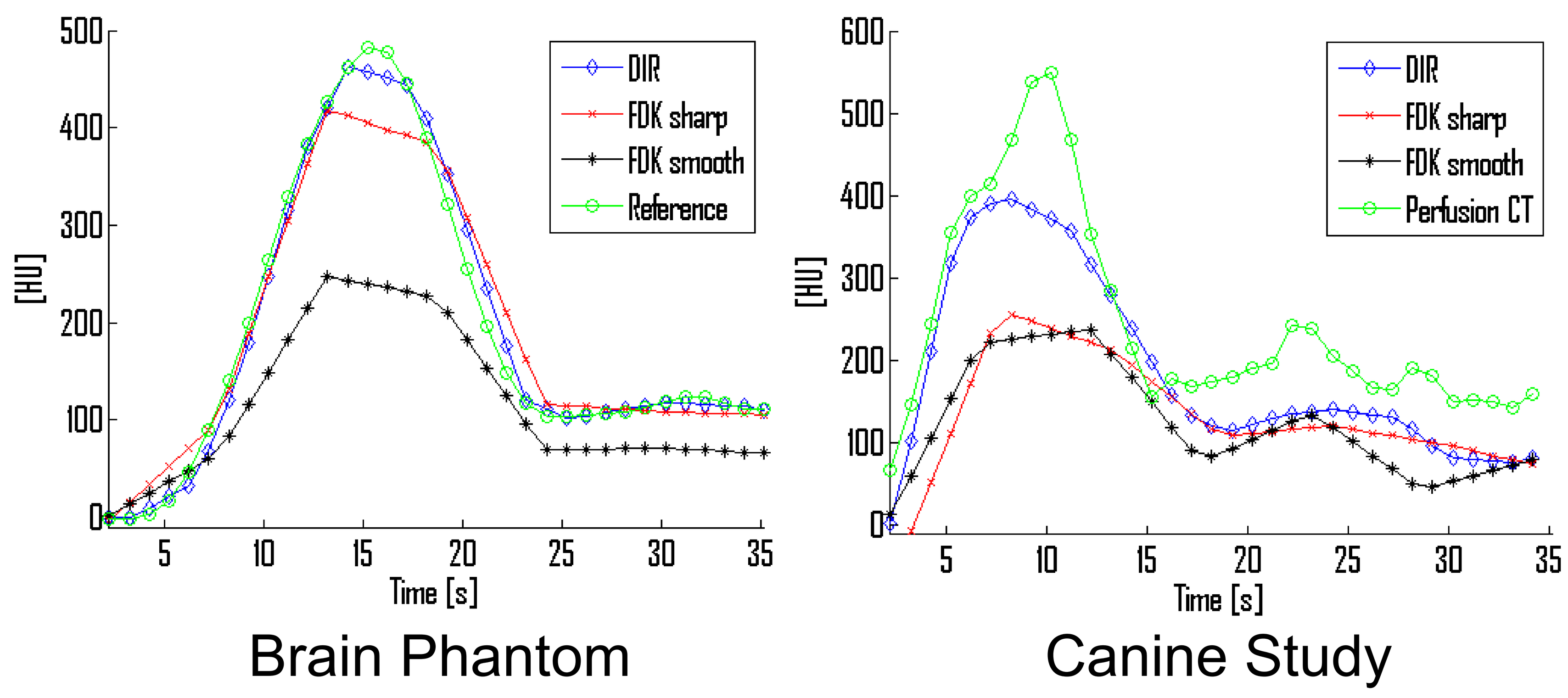
Table 2: Quantitative results from canine stroke model study. Pearson correlation (PC) between co-registered perfusion C-arm CT (PCCT) and perfusion CT (PCT) cerebral blood flow (CBF) and cerebral blood volume (CBV) maps.

3D blood flow maps:



Canine study data by courtesy of Dr. Charles Strother, University of Wisconsin, Madison, USA.

Arterial input functions:



Conclusion

- DIR improves temporal resolution of reconstructed TACs
- JBF for denoising of low contrast tissue TACs without blurring vessels

[1] C. Neukirchen et al., *An iterative method for tomographic X-ray perfusion estimation in a decomposition model-based approach*, Med Phys, vol. 37, 2010.

[2] G. Petschnigg et al., *Digital photography with flash and no-flash image pairs*, Proc. ACM SIGGRAPH, 2004.

[3] A. J. Riordan et al., *Validation of CT brain perfusion methods using a realistic dynamic head phantom*, Med Phys, vol. 38, 2011.