High Fidelity Vessel Visualization in Diagnostic CT: Low Dose Dynamic CTA via Singular Value Decomposition-Guided Filtering

F. Pisana[1,3], T. Henzler[2], H. Haubenreisser[2], S. Schönberg[2], E. Klotz[3], B. Schmidt[3] and M. Kachelrieß[1]

[1] German Cancer Research Center, Heidelberg, Germany

[2] University Clinic of Mannheim, Germany

[3] Siemens Healthineers, Forchheim, Germany

DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Introduction

- **Dynamic CT angiography (4D CTA) offers a more complete overview of vessels‘ anatomy compared to conventional 3D CT angiography (3D CTA):**
  - **Better estimation of size of stenosis**
  - **Presence of collateral vasculature**
- **The temporal maximum intensity projection (tMIP) displays all the vascular bed.**

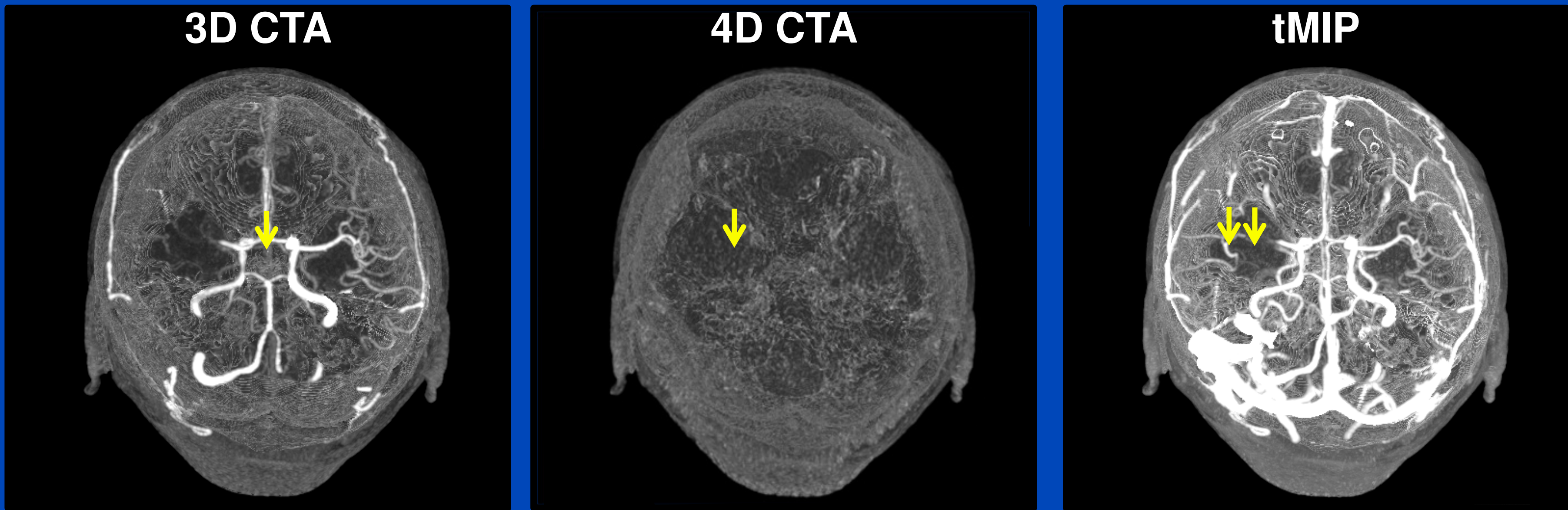


Image courtesy of Siemens Healthineers. Bone mask is subtracted. C = 200 HU; W = 400 HU

Purpose

- 4D CTA results in higher dose compared to 3D CTA.
- Lowering the dose results in higher image noise.
- We thus aim at developing an image filter
  - to preserve vessels‘ anatomy and dynamics,
  - while smoothing the surrounding parenchyma
  - in order to improve vessels‘ contrast-to-noise ratio (CNR).

Baseline Subtraction

1. As a first step, the baseline (defined as the average of all phases without contrast media) is subtracted from the dataset:

$$f(\boldsymbol{r},t) = f(\boldsymbol{r},t) - \frac{1}{t_{\text{base}}} \sum_{\tau=1}^{t_{\text{base}}} f(\boldsymbol{r},\tau).$$

Noise Reduction in Temporal Domain via SVD

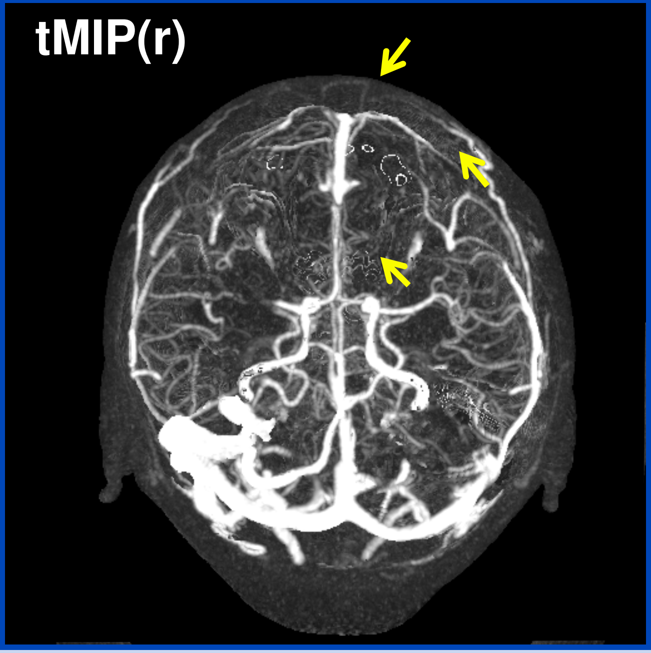
2. After baseline subtraction, the SVD of the dataset is performed in temporal domain. Of the *T* available singular values, only the first 3 main ones are kept to reconstruct a temporally smoothed dataset.

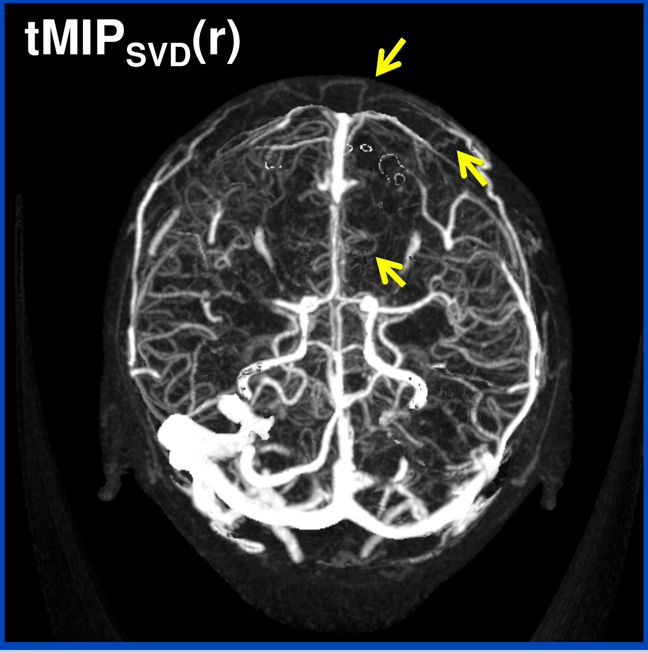
$$f_{\mathrm{SVD}}(\boldsymbol{r},t) = \sum_{i=1}^{3} u_i(\boldsymbol{r})\,\sigma_i\,v_i(t).$$

Creation of a Guiding Volume

3. **The lower noise in temporal domain is reflected in a much better vessels‘ visibility when a temporal MIP is created.**

$$\mathrm{tMIP}_{\mathrm{SVD}}(\boldsymbol{r}) = \max_t(f_{\mathrm{SVD}}(\boldsymbol{r}, t)).$$





C = 200 HU; W = 400 HU

Noise Reduction in Spatial Domain

4. Filter:

$$f^*(\boldsymbol{r},t) = \frac{\int d^3\rho\, w_s(\boldsymbol{r},\boldsymbol{\rho})\, w_g(\boldsymbol{r},\boldsymbol{\rho}) f_{\mathrm{SVD}}(\boldsymbol{r}+\boldsymbol{\rho},t)}{\int d^3\rho\, w_s(\boldsymbol{r},\boldsymbol{\rho})\, w_g(\boldsymbol{r},\boldsymbol{\rho})}$$

TACs similarity[1,2]:
Voxels with similar temporal profiles receive higher weight. Preserves correct dynamic information.

$$w_s(\boldsymbol{r},\boldsymbol{\rho}) = e^{-\frac{\frac{1}{T}\sum_{t=1}^{T}\left(f_{\mathrm{SVD}}(\boldsymbol{r},t) - f_{\mathrm{SVD}}(\boldsymbol{r}+\boldsymbol{\rho},t)\right)^2}{\sigma_s^2}}$$

Bilateral guide:
Further improves edge preservation for the small vessels.

$$w_g(\boldsymbol{\rho}) = e^{-\frac{\left(\mathrm{tMIP}_{\mathrm{SVD}}(\boldsymbol{r}) - \mathrm{tMIP}_{\mathrm{SVD}}(\boldsymbol{r}+\boldsymbol{\rho})\right)^2}{\sigma_g^2}}$$

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

[2]Li et al. "A robust noise reduction technique for time resolved CT.", *Med Phys* 43, (2016).

dkfz.

Brief Summary

1. Compute a truncated temporal singular value decomposition $f_{SVD}(x, y, z, t)$ of $f(x, y, z, t)$.
2. Apply a non-linear filter to f_{SVD}, guided by the temporal MIP and the TACs similarity of f_{SVD}.
3. Enjoy the results.

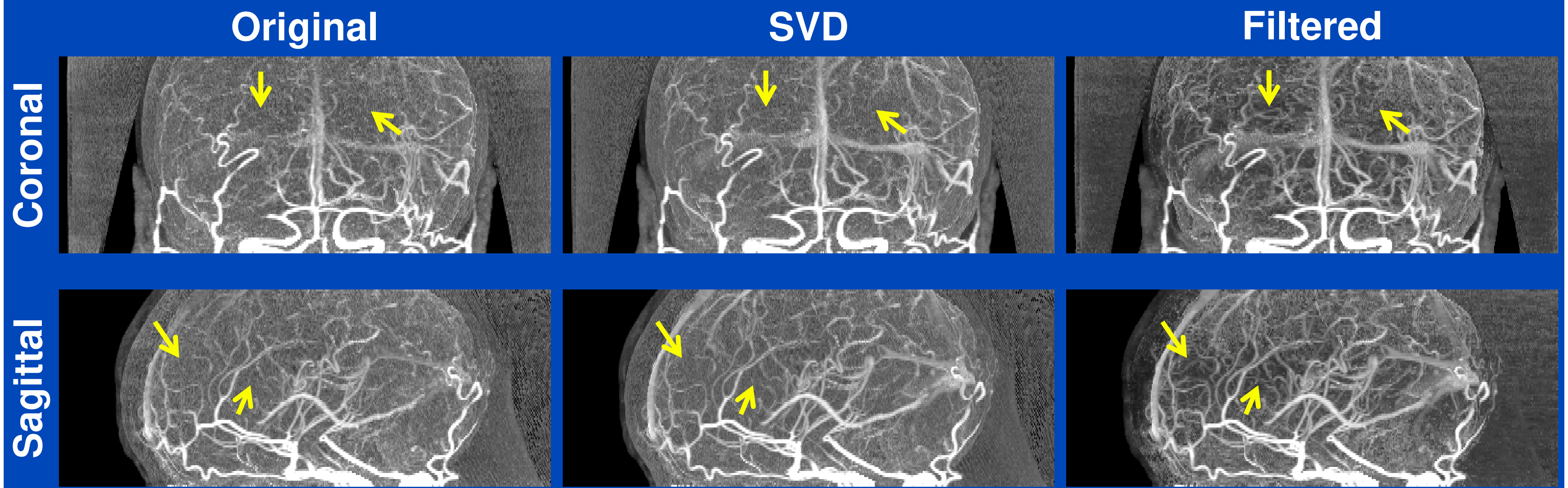
Results

- Data of 5 head patients, suspect of stroke
- Siemens Somatom Force CT scanner

Number of patients	5
Type of patients	Male, suspect of stroke
Mean age	63.32 (±7.04) years old
Median tube voltage	70 kV
Median tube current time product	86 mAs
Median number of phases aquired	34
Mean CNR	3.12 (±1.21)
Mean CNR using our filter	5.4 (±1.8)
Mean effective dose	4.64 (±1.6) mSv
Mean minimal effective dose using our filter	~ 1.43 mSv

Results

- Non-optimized CPU performance is 4 slices/s.
- Vessels‘ CNR is improved in all phases.

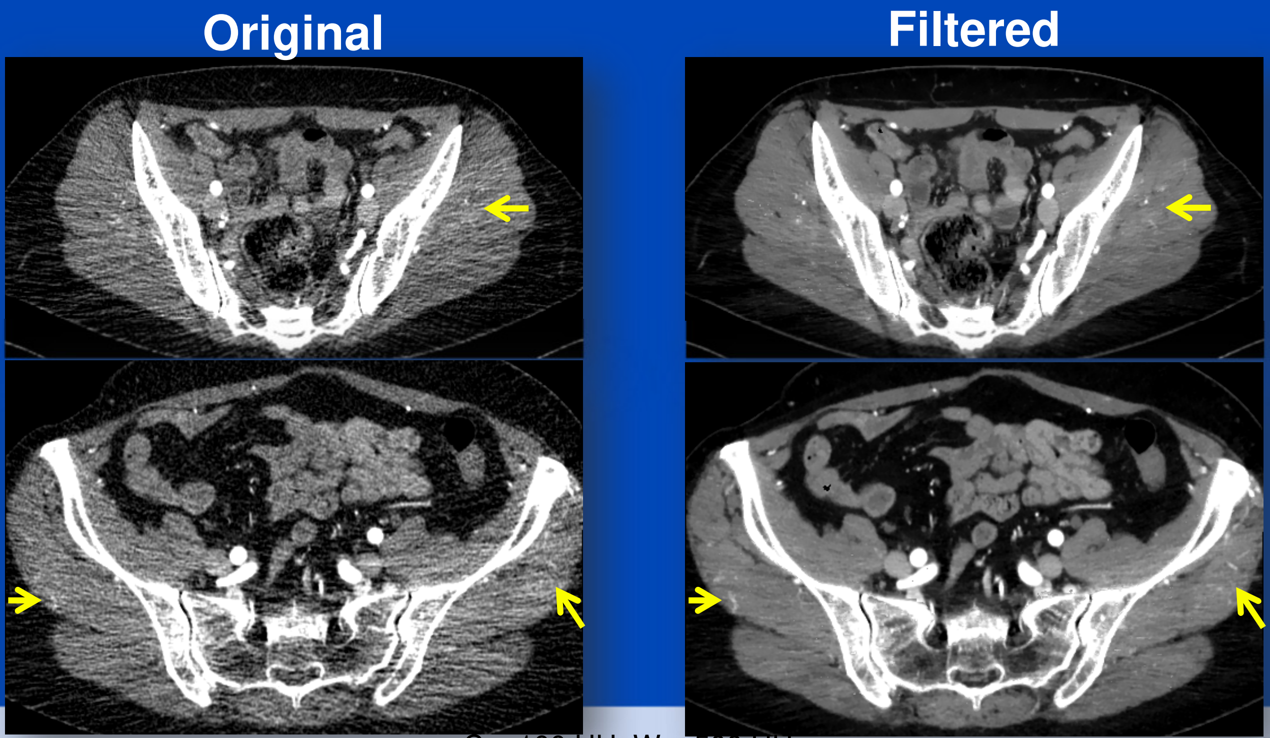


3D MIPs of a late-arterial phase

C = 200 HU; W = 400 HU

Summary and Outlook

- The filter is robust and computationally efficient.
- The mean CNR improvement for small vessels is 80%.
- This corresponds to an x-ray dose or contrast agent amount reduction of up to 69%.
- Application to dynamic CTA of the pelvic region:



C = 100 HU; W = 500 HU

dkfz.

Thank You!

This work was supported by Siemens Healthineers, Forchheim, Germany.

Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.

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

Job opportunities through DKFZ’s international PhD or Postdoctoral Fellowship programs (marc.kachelriess@dkfz.de).