Motion Compensation from Short-Scan Data in Cardiac CT

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Motivation

- Cardiac CT imaging is routinely practiced for the diagnosis of cardiovascular diseases like coronary artery disease.
- The imaging of small and fast moving vessels places high demands on the spatial and temporal resolution of the reconstruction.
- Insufficient temporal resolution leads to motion artifacts, whose occurrence might require a second scan increasing the dose applied to the patient.

Temporal Resolution in Cardiac CT

- For the RCA mean velocities $\bar{v}$ varying between $70\,\mathrm{mm/s}$ and $35\,\mathrm{mm/s}$ have been measured.[1,2,3,4)]
- Assume $\bar{v} \approx 50\,\mathrm{mm/s}$ constant during scan

	Single source	Dual source
t_{rot}	250 ms	250 ms
t_{res}	125 ms	63 ms
Displacement	6.2 mm	3.1 mm

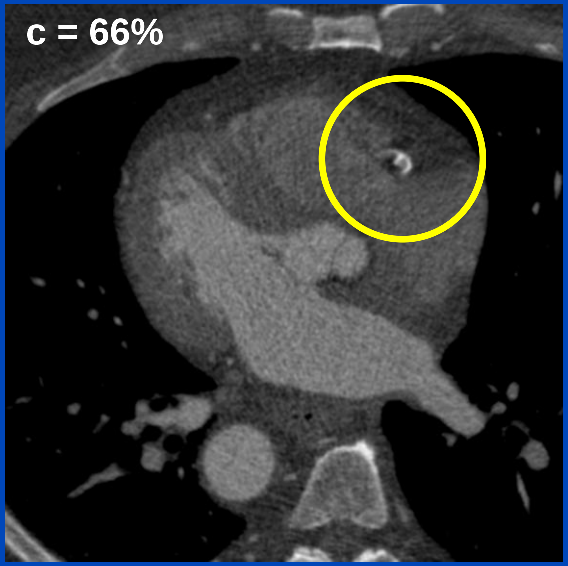
- Large displacement for an object of ~ 1-5 mm diameter.

→ Occurrence of strong motion artifacts especially in case of single source systems!

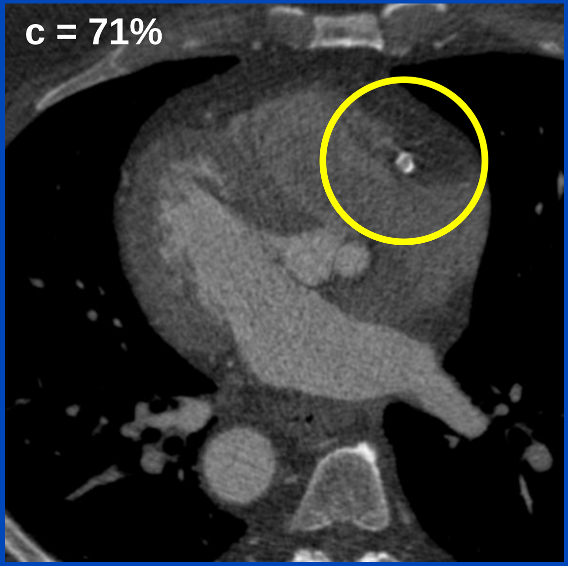
[1)]Husmann et al. Coronary Artery Motion and Cardiac Phases: Dependency on Heart Rate - Implications for CT Image Reconstruction. Radiology, Vol. 245, Nov 2007.
[2)]Shechter et al. Displacement and Velocity of the Coronary Arteries: Cardiac and Respiratory Motion. IEEE Trans Med Imaging, 25(3): 369-375, Mar 2006
[3)]Vembar et al. A dynamic approach to identifying desired physiological phases for cardiac imaging using multislice spiral CT. Med. Phys. 30, Jul 2003.
[4)]Achenbach et al. In-plane coronary arterial motion velocity: measurement with electron-beam CT. Radiology, Vol. 216, Aug 2000.

Aim

- Increase the temporal resolution in cardiac CT in the region of the coronary arteries for data acquired with single source systems.
- Especially beneficial in cases of patients with high or irregular heart rates or non-optimally chosen gating positions.
- In view of dose optimized scan protocols, we want to utilize only the data needed for a single short scan reconstruction.



Non-optimally chosen gating position

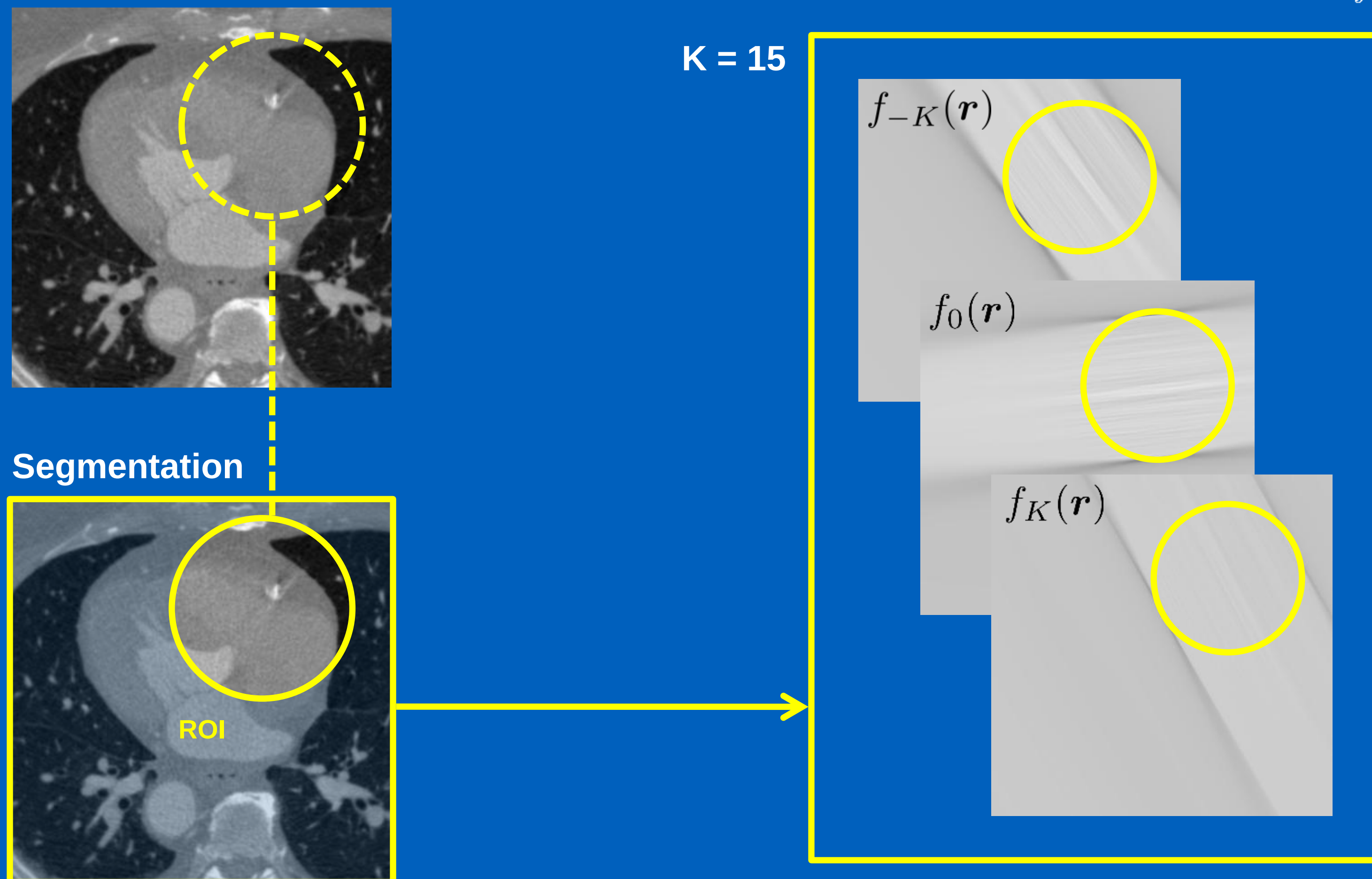


“Best phase”

Initialization of the Algorithm

Initial reconstruction

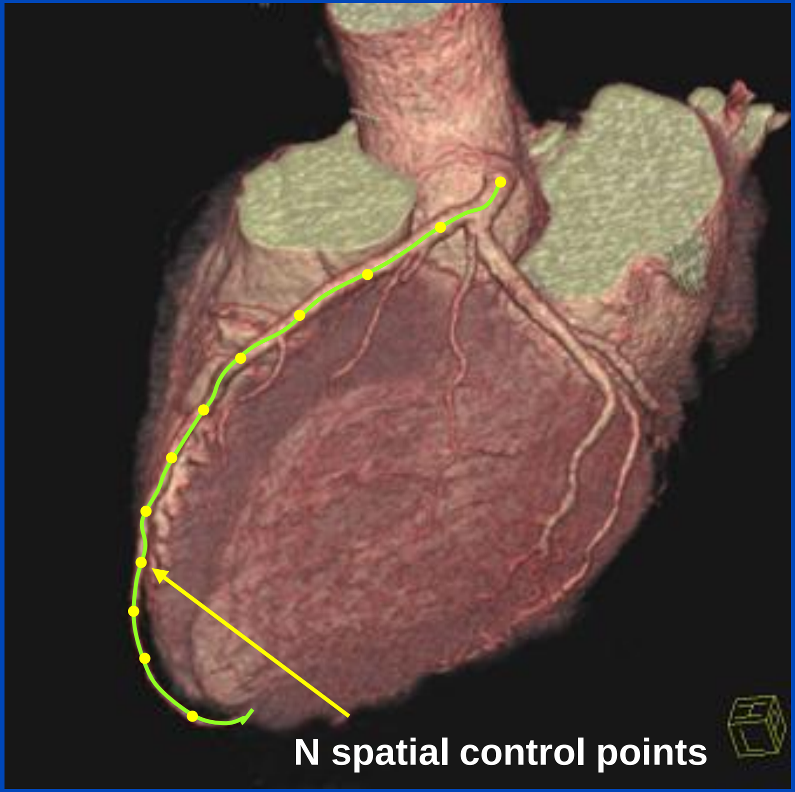
Create $2K + 1$ partial angle images (PAIs) $f_k(\boldsymbol{r})$



$$t_{\mathrm{res}} \approx \frac{t_{\mathrm{rot}}}{2} \approx 150\,\mathrm{ms}$$

$$t_{\mathrm{res}} \approx \frac{t_{\mathrm{rot}}/2}{(2K+1)/2} \approx 10\,\mathrm{ms}$$

Algorithmic Concept



Data courtesy of Dr. Stephan Achenbach

- <u>**Motion model**</u>**: Motion is modeled by a motion vector field (MVF)** $\boldsymbol{s}(\boldsymbol{r},t)$ **sub-sampled in time and space, whose time dependence we parameterize by a low degree polynomial (**$P \leq 2$**)**

$$\boldsymbol{s}(\boldsymbol{r},t) = \sum_{p=1}^{P} \boldsymbol{a}_p(\boldsymbol{r})(t-t_0)^p$$

- <u>**Motion compensation**</u> **(MoCo): Apply MVF on** ***2K + 1*** **PAIs** $f_k(\boldsymbol{r})$ **and add them to obtain the motion-compensated reconstruction**

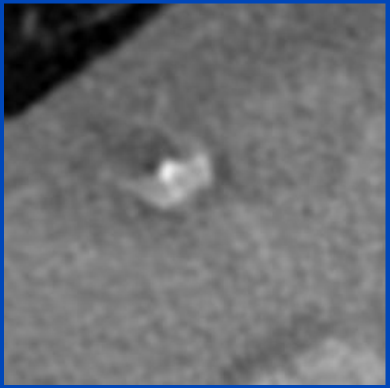
$$f_{\mathrm{MoCo}}(\boldsymbol{r},\boldsymbol{s}) = \sum_{k=-K}^{K} f_k(\boldsymbol{r}+\boldsymbol{s}(\boldsymbol{r},t_k))$$

Algorithmic Concept

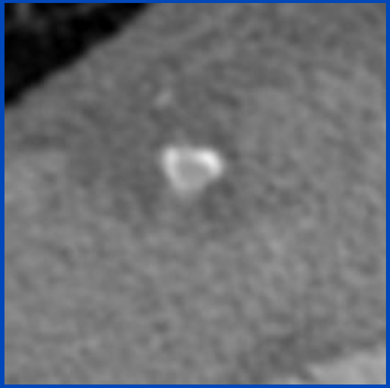
- <u>Motion estimation</u>: The MVFs are subject to the cost function optimization:

$$\hat{s} = \arg \min_{\boldsymbol{s} \in \mathbb{R}^{PND}} E,$$

- As image artifact measuring cost function, we chose the image's entropy.



High entropy

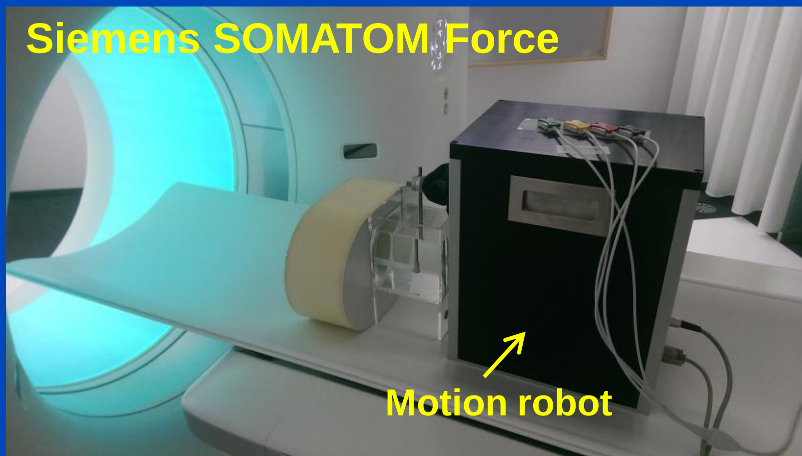


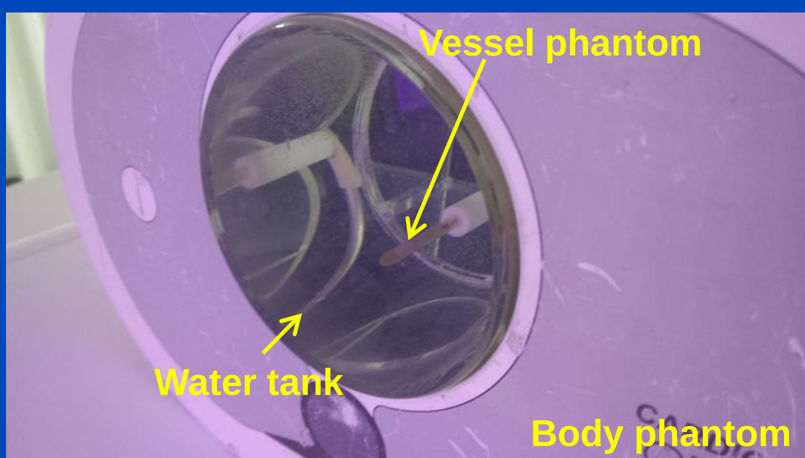
Low entropy

For 3D MoCo, N = 25, P = 2 → 150 parameter

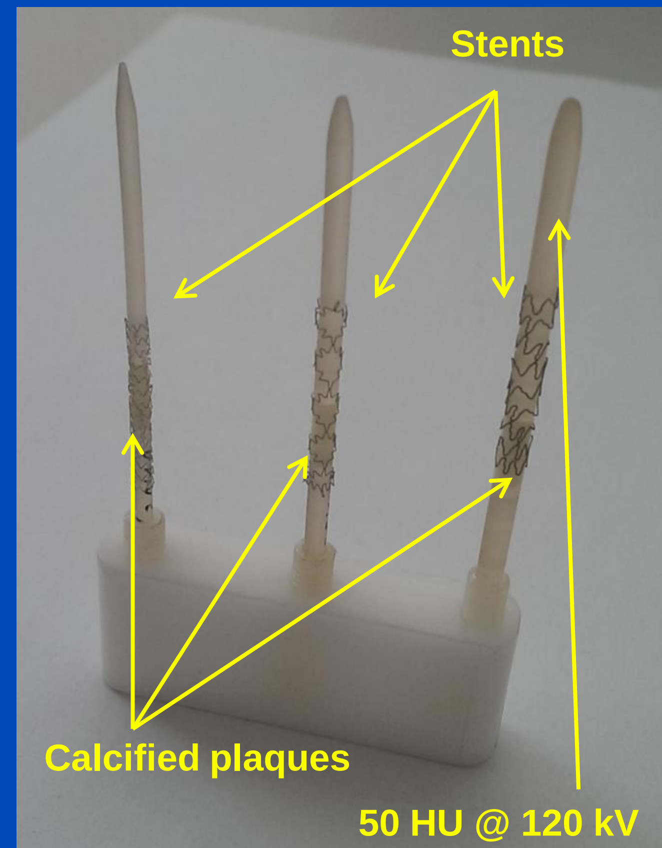
Phantom Measurement

Setup

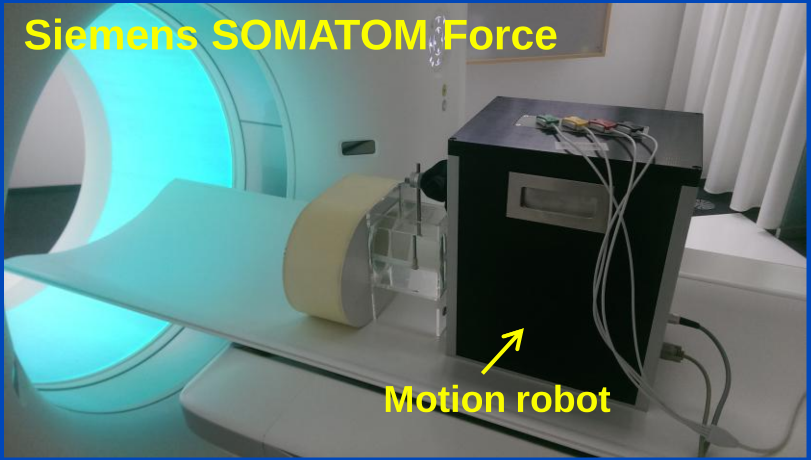


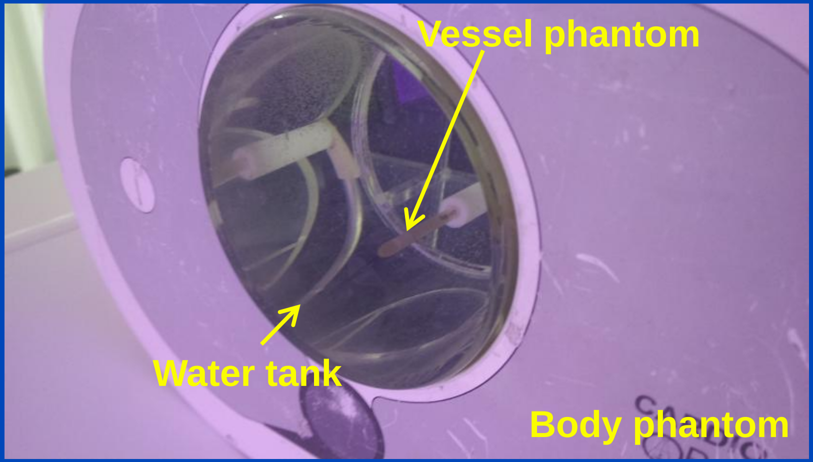


d = 1.5 mm 2.5 mm 3 mm



Phantom Measurement
Setup





Data acquisition

Low pitch spiral scanning: $p \approx 0.2$
→ Reconstruction of multiple cardiac phases possible.
Rotation Time t_{rot} = 250 ms
Heart rate 60, 70, 90 bpm

Reconstruction

For the reconstruction, only the data acquired by detector A have been used!

For the evaluation of the algorithm we choose P = 1.

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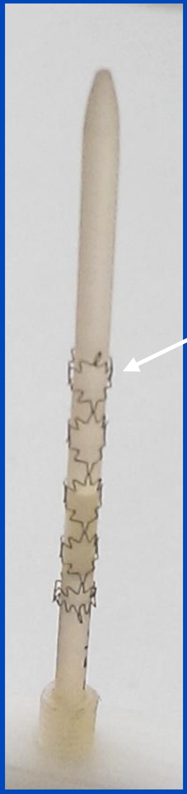
Results
Phantom

70 bpm

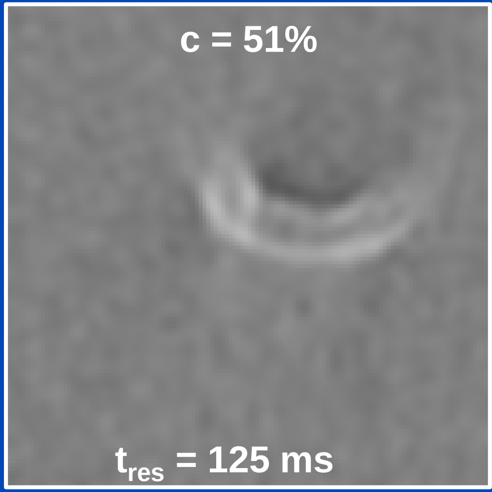
Vessel phantom



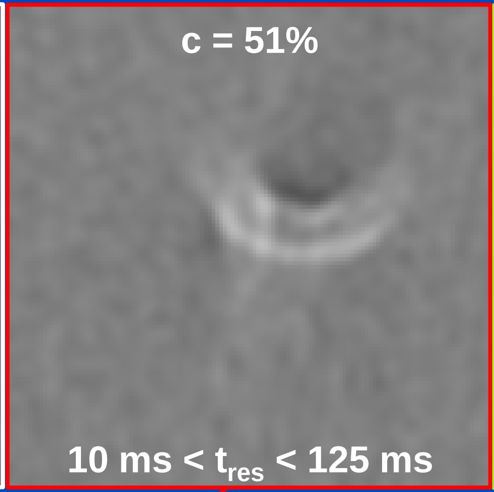
Stent

d = 2.5 mm

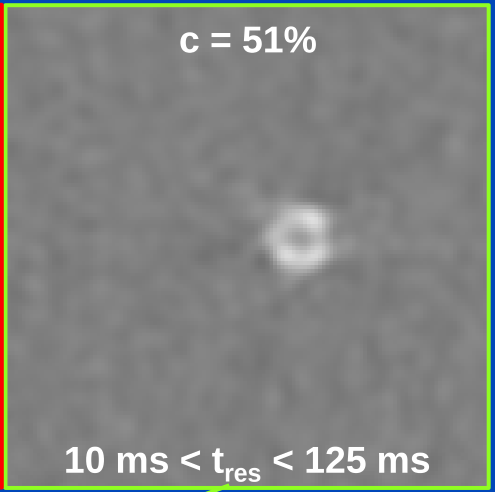
Standard FBP reconstruction

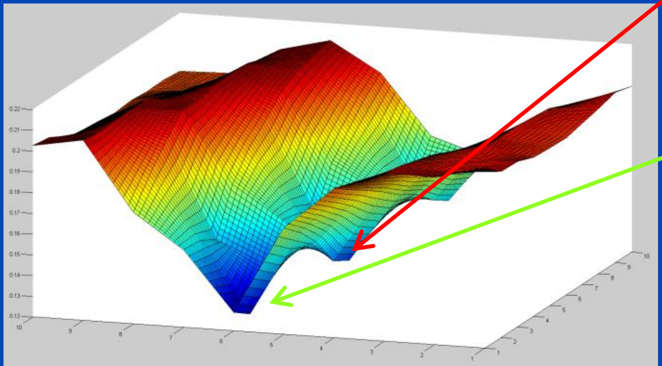


Optimization with Powell's algorithm



Optimization with re-initialization of Powell's algorithm





Optimization might be trapped in local minimum

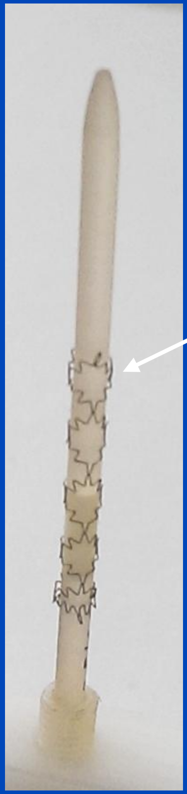
Re-initialization helps to escape from local minima, except for two cases!

Results

Phantom

70 bpm

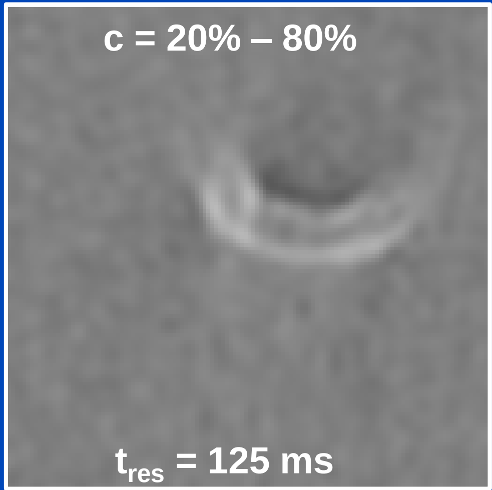
Vessel phantom

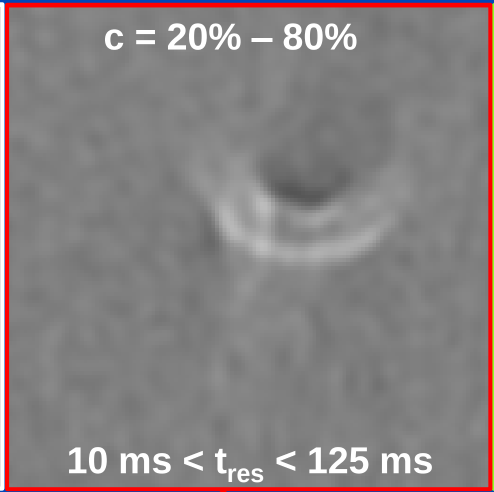


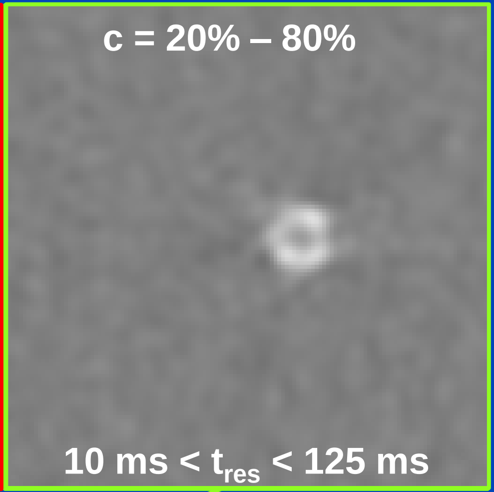
Stent

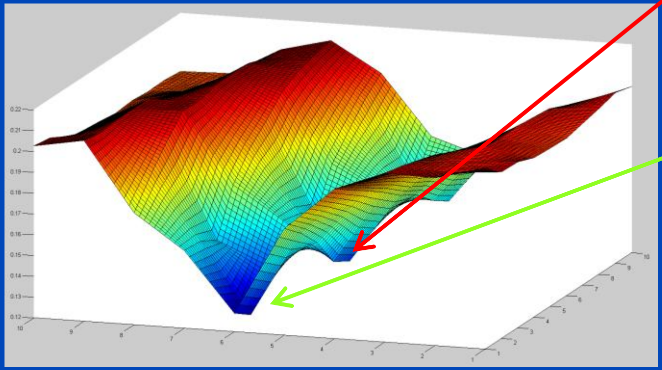
d = 2.5 mm

Standard FBP reconstruction	Optimization with Powell's algorithm	Optimization with re-initialization of Powell's algorithm









Optimization might be trapped in local minimum

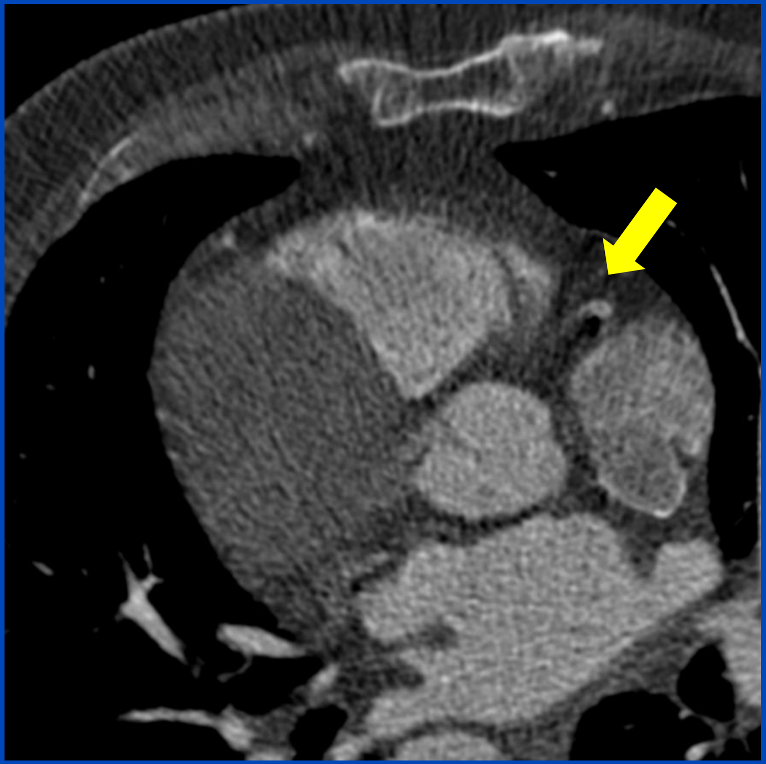
Re-initialization helps to escape from local minima, except for two cases!

Results

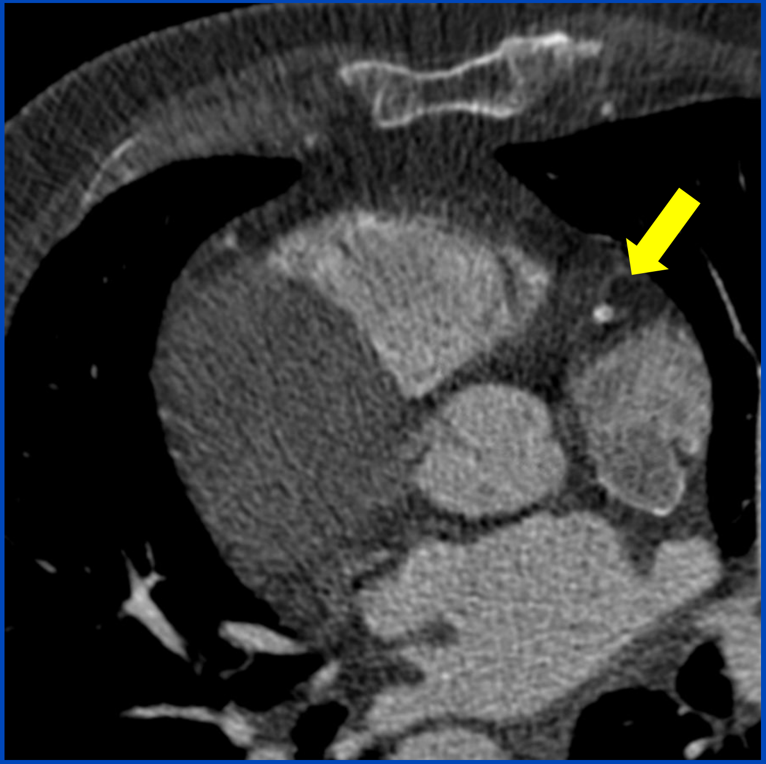
Clinical Case 1

t_{res} = 143 ms, HR = 72 bpm, c = 70% RR

Standard reconstruction



MoCo reconstruction



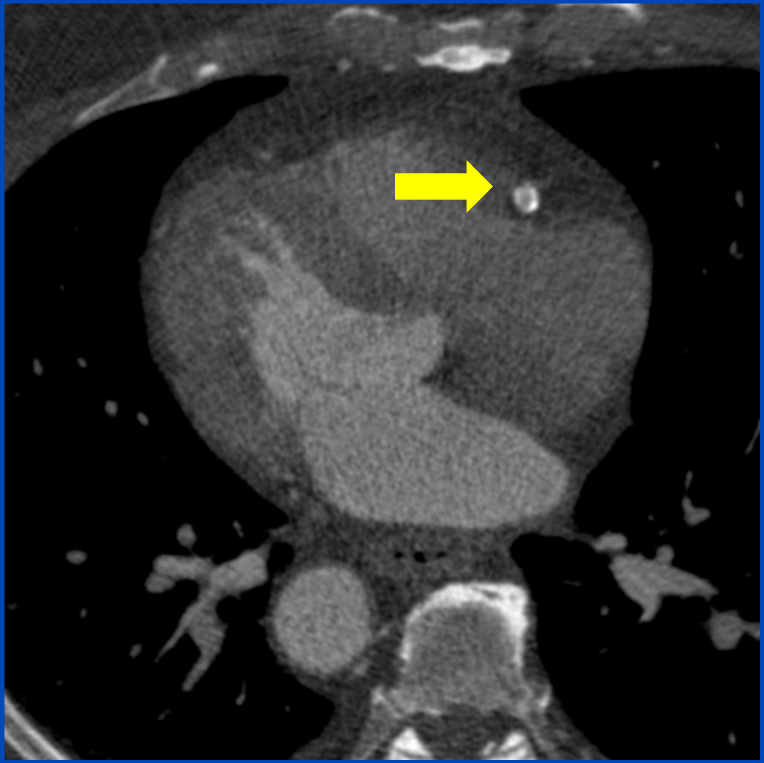
Phase shifted by 5% from the best phase to obtain an image with motion artifacts

Results
Clinical Case 2

t_{res} = 143 ms, HR = 70 bpm, c = 50% RR

Standard reconstruction

MoCo reconstruction

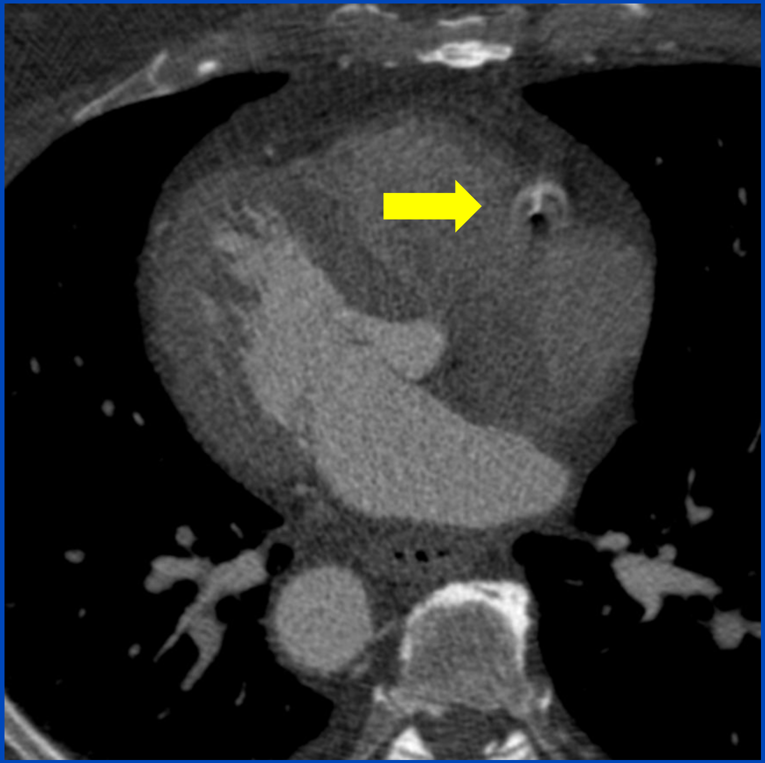


C = 400 HU; W = 1500 HU

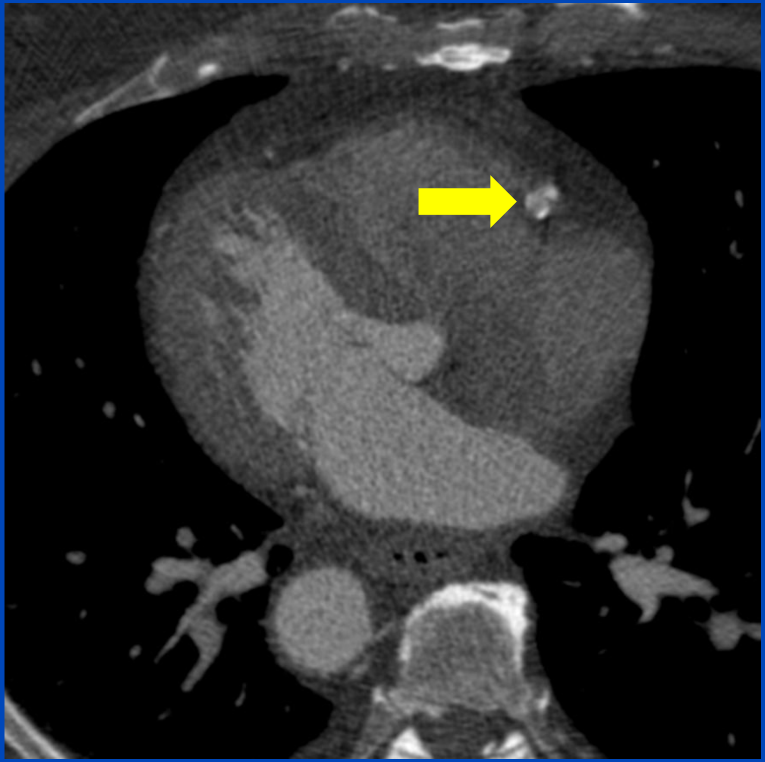
Results
Clinical Case 2

t_{res} = 143 ms, HR = 70 bpm, c = 60% RR

Standard reconstruction



MoCo reconstruction



Summary and Conclusion

- We see an increased sharpness of the coronary arteries in cardiac phases featuring motion artifacts of different severity.
- The computational effort is potentially low because of the simple way the MVFs are applied.
- Potential applications are:
  - Dual source high pitch scan protocols at high heart rates
  - Single source cardiac CT at high heart rates
- More on MoCo:
  - Rank, Kachelrieß. Respiratory MoCo for Simultaneous PET/MR. Mo, Nov 30, 3:10 PM, Room S403A
  - Sauppe, Kachelrieß. Respiratory and Cardiac 5D MoCo for CBCT. Wed, Dec 2, 11:10 AM, Room S403B

Thank You!

This study was supported by Siemens Healthcare GmbH.

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

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