Stack Transition Artifact Removal (STAR) in Cardiac CT with Automatic Parameter Selection

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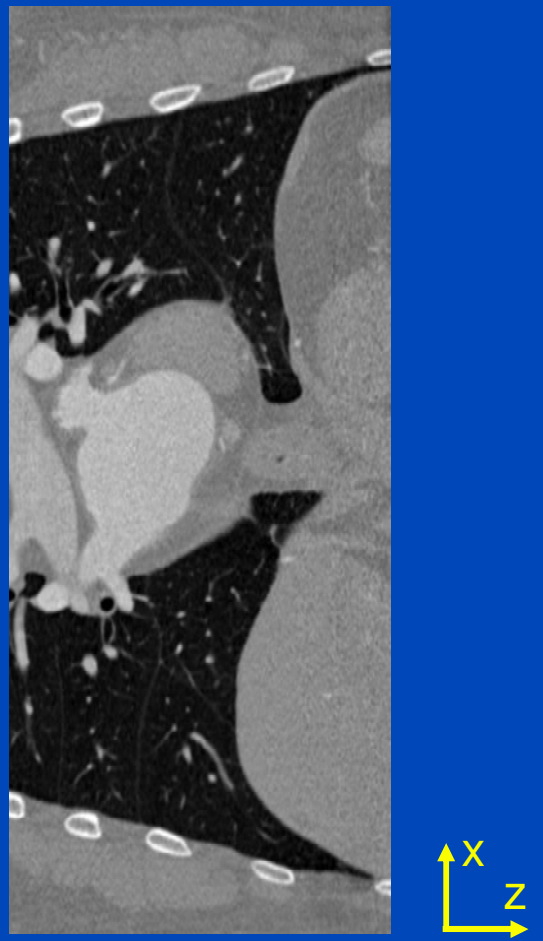
Introduction

- Data of one cardiac phase can be acquired via prospective ECG-gating or extracted from a retrospectively gated data set.
- Cardiac reconstructions can yield sub volumes (stacks) corresponding to different times and, ideally, to the same heart phase.



Introduction

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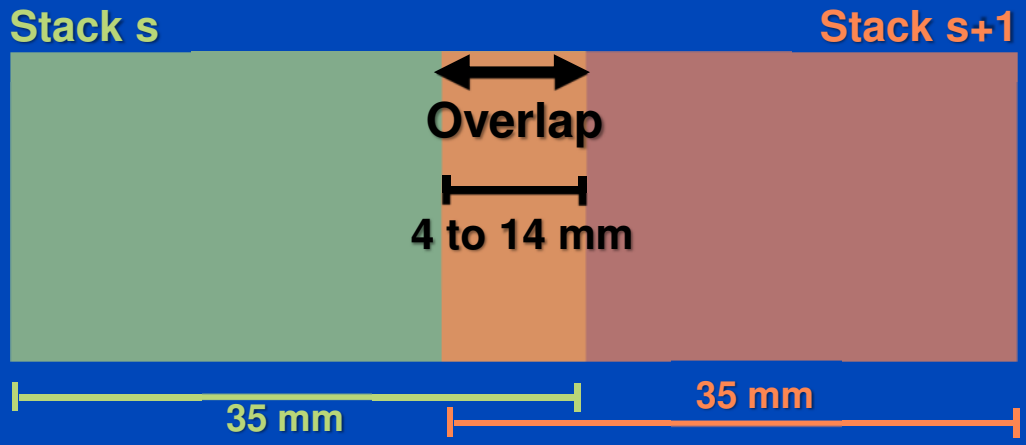
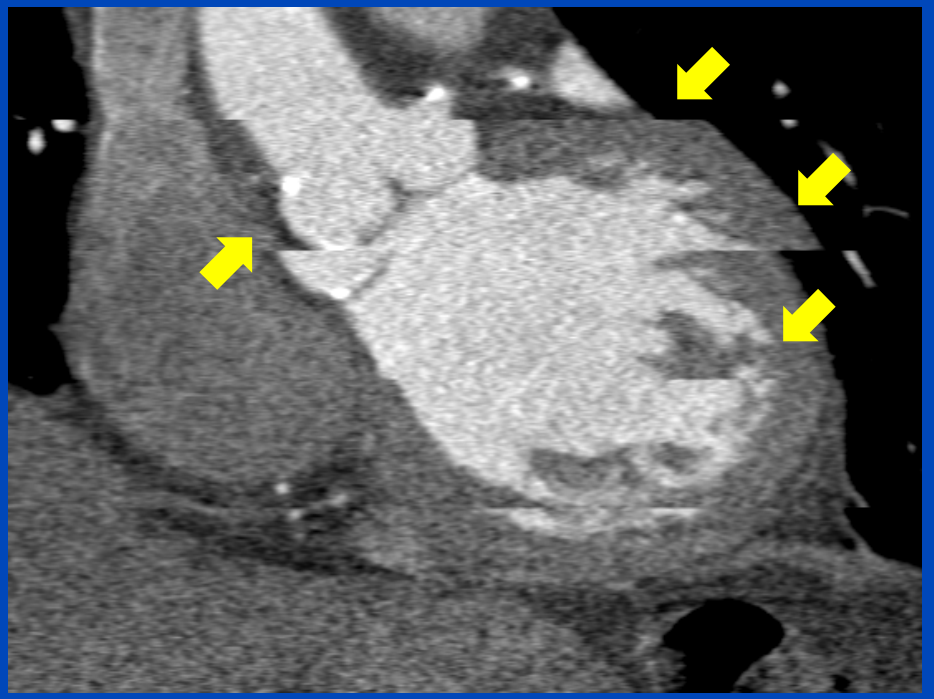
- Cardiac reconstructions can yield sub volumes (stacks) corresponding to different times and, ideally, to the same heart phase.
- The depth of the stacks depends on the longitudinal collimation of the CT scanner.
- The stacks generally have a longitudinal overlap.



Stack Transition Artifacts

- Irregular motion leads to stacks that do not represent exactly the same volume.
- Discontinuities (misalignment) at stack transitions arise when stitching the stacks together to yield the complete CT volume.

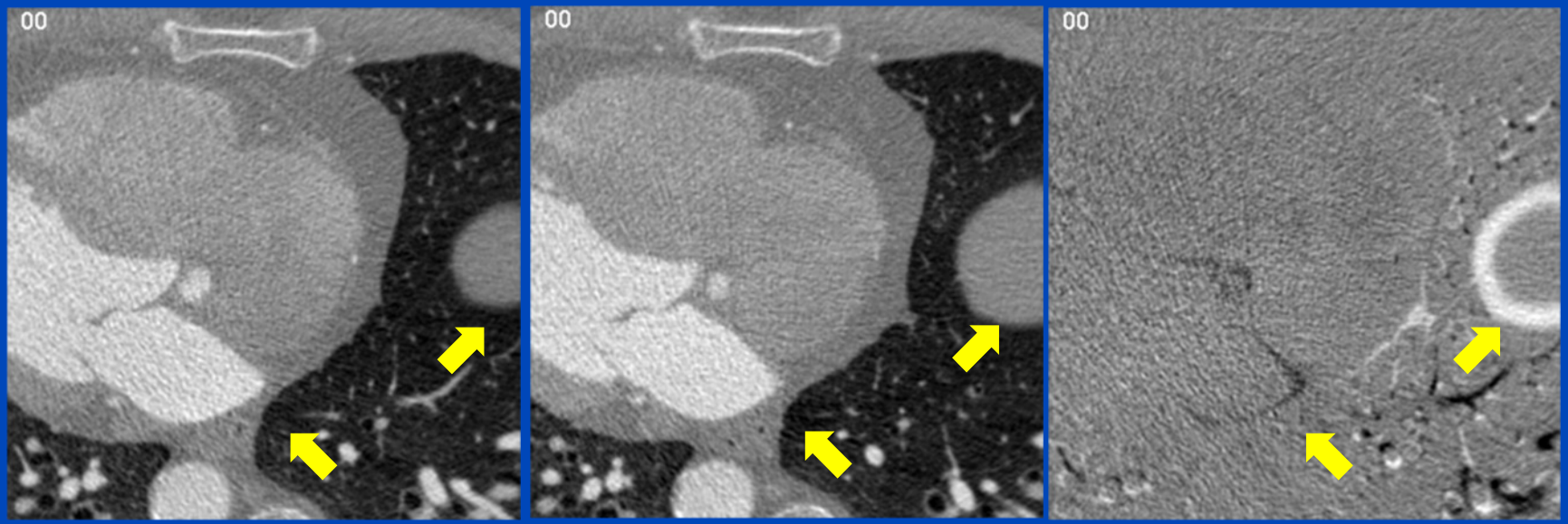


Sagittal slice from a cardiac data set with stack transition artifacts.

Symmetric Registration

- **Perform a registration, where both volumes are transformed.**
- **Given two volumes f1(r), f2(r), compute a DVF d(r) that will match the two.**

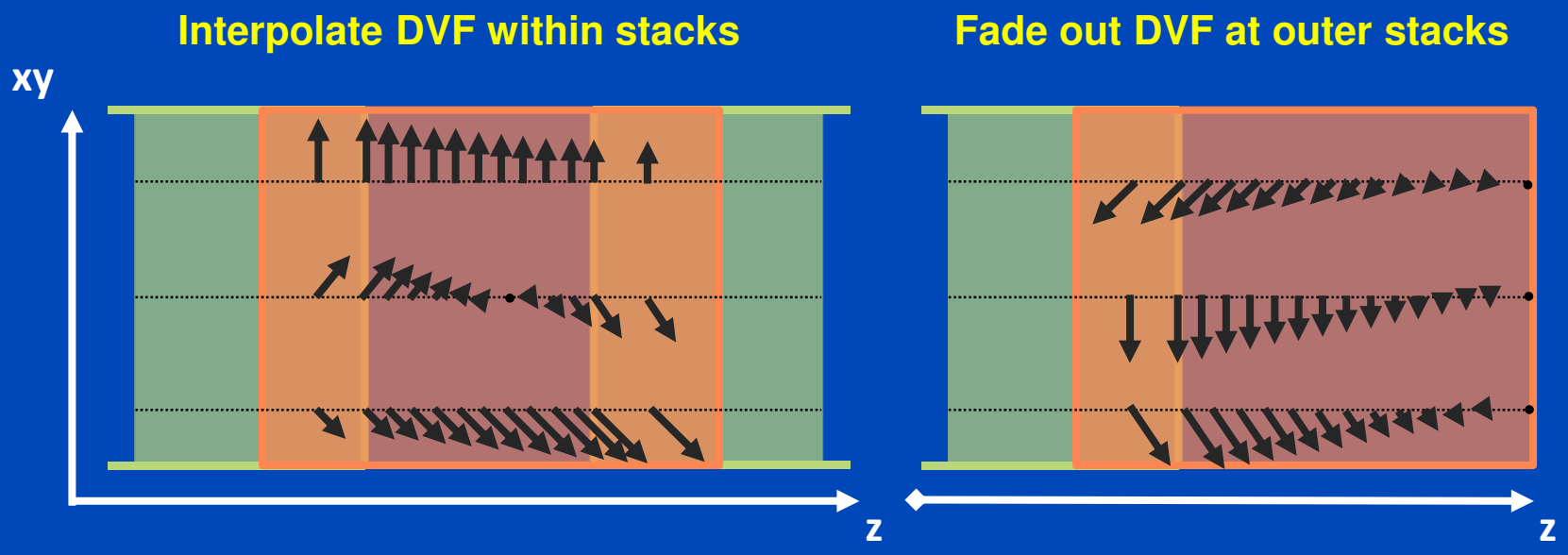
$\hat{f}_1(\boldsymbol{r}) = f_1(\boldsymbol{r} + \boldsymbol{d}(\boldsymbol{r}))$ $\hat{f}_2(\boldsymbol{r}) = f_2(\boldsymbol{r} - \boldsymbol{d}(\boldsymbol{r}))$ $\hat{f}_2(\boldsymbol{r}) - \hat{f}_2(\boldsymbol{r})$



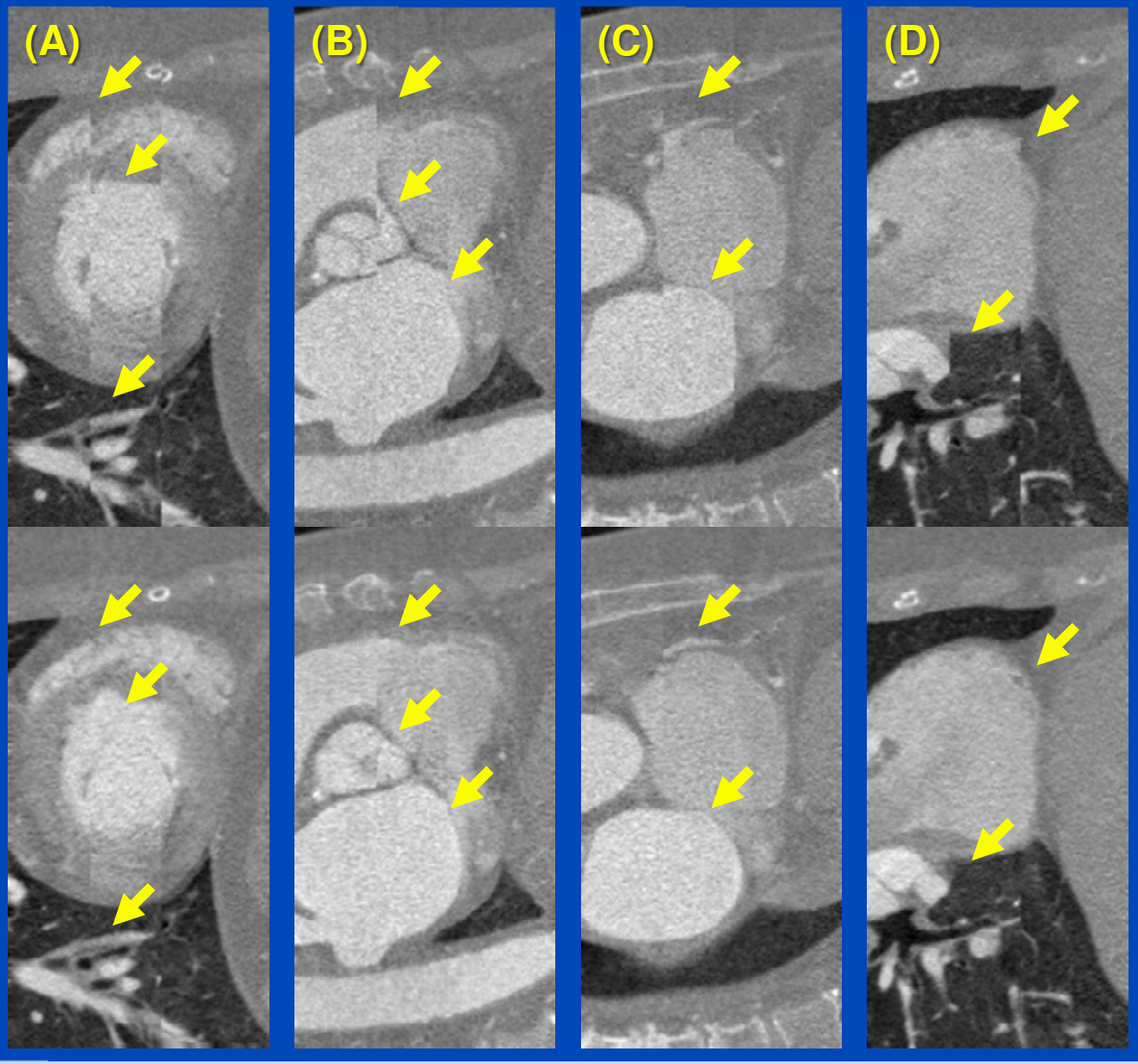
Iterations of the symmetric registration of two 2D slices and the corresponding difference images. The actual STAR algorithm is 3D. *C* = 1000 HU, *W* = 2000 HU.

DVF interpolation

- For each stack a linear interpolation between the upper edge of the lower overlap and the lower edge of the upper overlap is performed.



Results of ECR 2018 and CT-Meeting 2018



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C = 0 HU, W = 2000 HU

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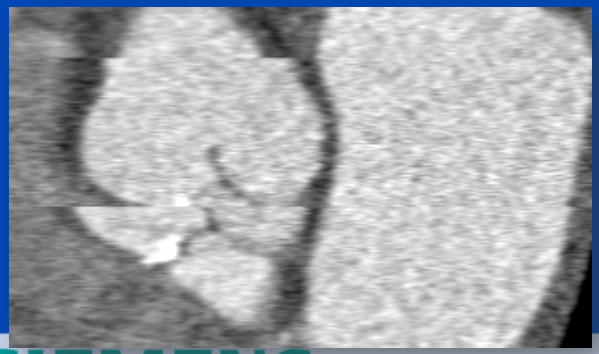
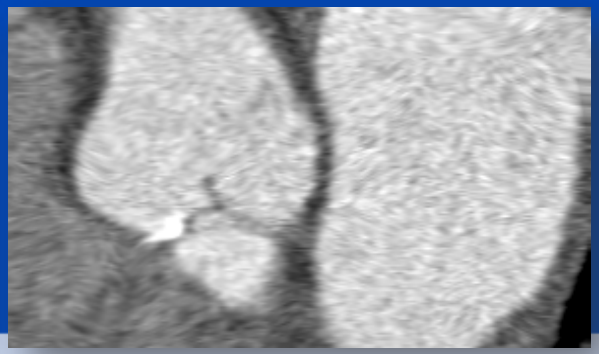
Automatic Parameter Selection

- DVF must be smooth to avoid introducing distortions.
- Smoothness is achieved via Gaussian DVF smoothing.
- The standard deviation σ of the Gaussian filter is essential for registration performance.
- Automatic parameter selection:
  - Perform an initial registration with weak DVF smoothing to find the maximum required DVF magnitude DVF_{max}.
  - Set $\sigma = \max(2\text{ mm}, DVF_{max}/2)$ to guarantee a sufficiently smooth DVF and perform the main registration.
  - This is individually done for each stack transition zone.

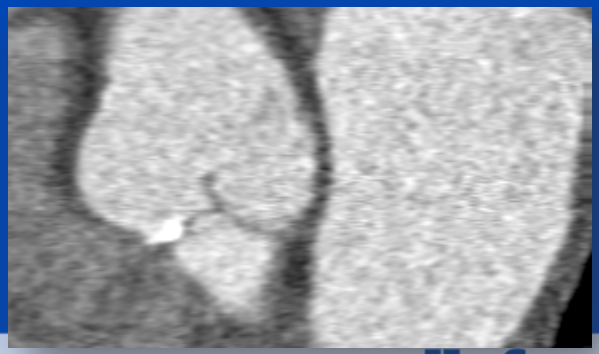
Standard reconstruction with stack transition artifacts



Result with weak smoothing: DVF_{max} = 20 mm



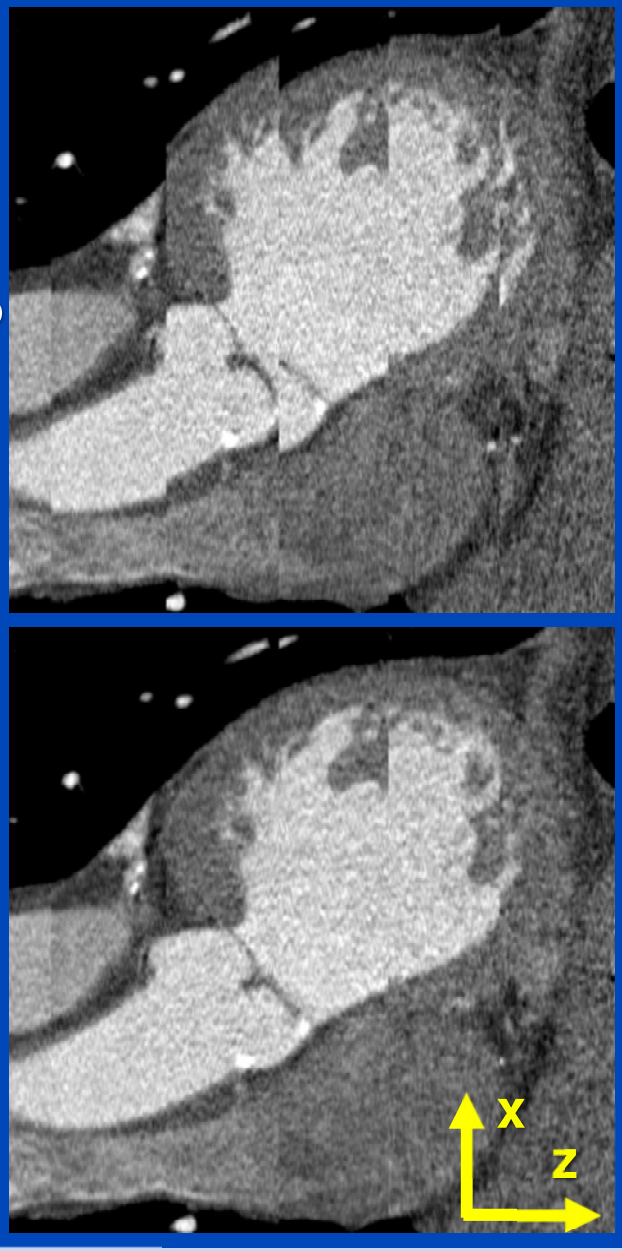
Result with final smoothing: $\sigma = DVF_{max} / 2$ = 10 mm

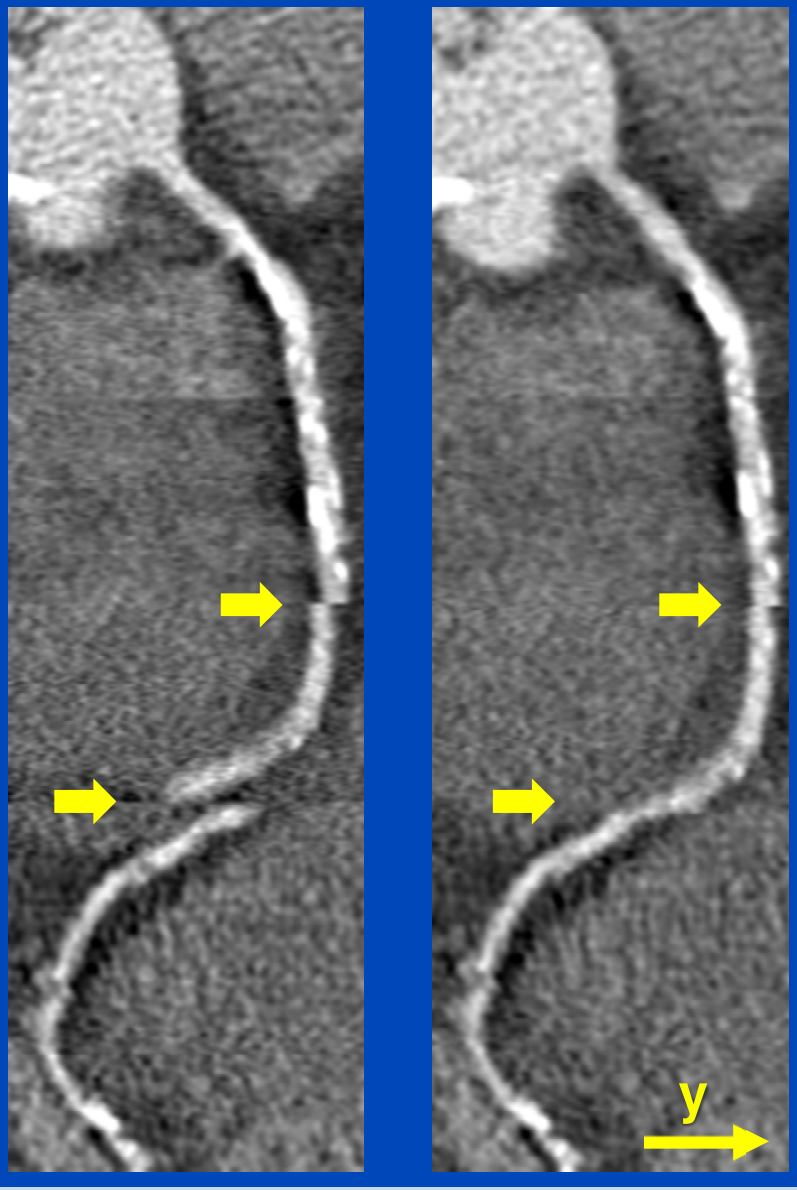


Materials

- Patient data were acquired with a Somatom Definition AS+ (Siemens Healthineers, Forchheim Germany).
- We present 3 patient data sets with stack transition artifacts.
- Recon with 0.4×0.4×0.3 mm pixels and 0.6 mm slice thickness
  - WFBP = standard reconstruction
  - STAR = stack transition artifact reduction
- Collimation = 64×0.6 mm = 38.4 mm
- Rotation time = 285 ms
- Tube current time product = 92 … 125 mAs_{eff}
- Tube voltage = 100 kV
- CTDIvol = 14 … 23 mGy

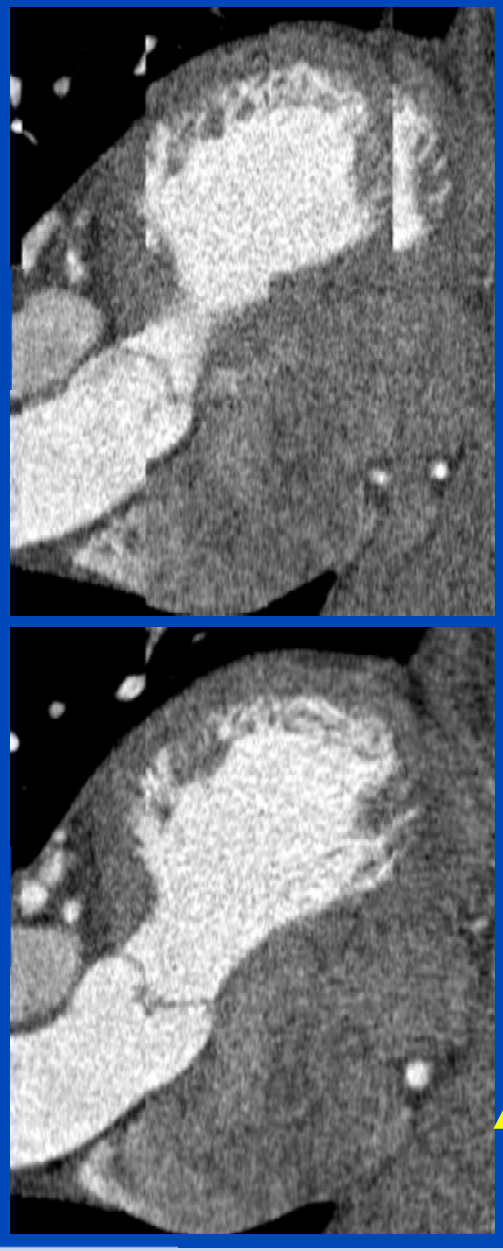
Results

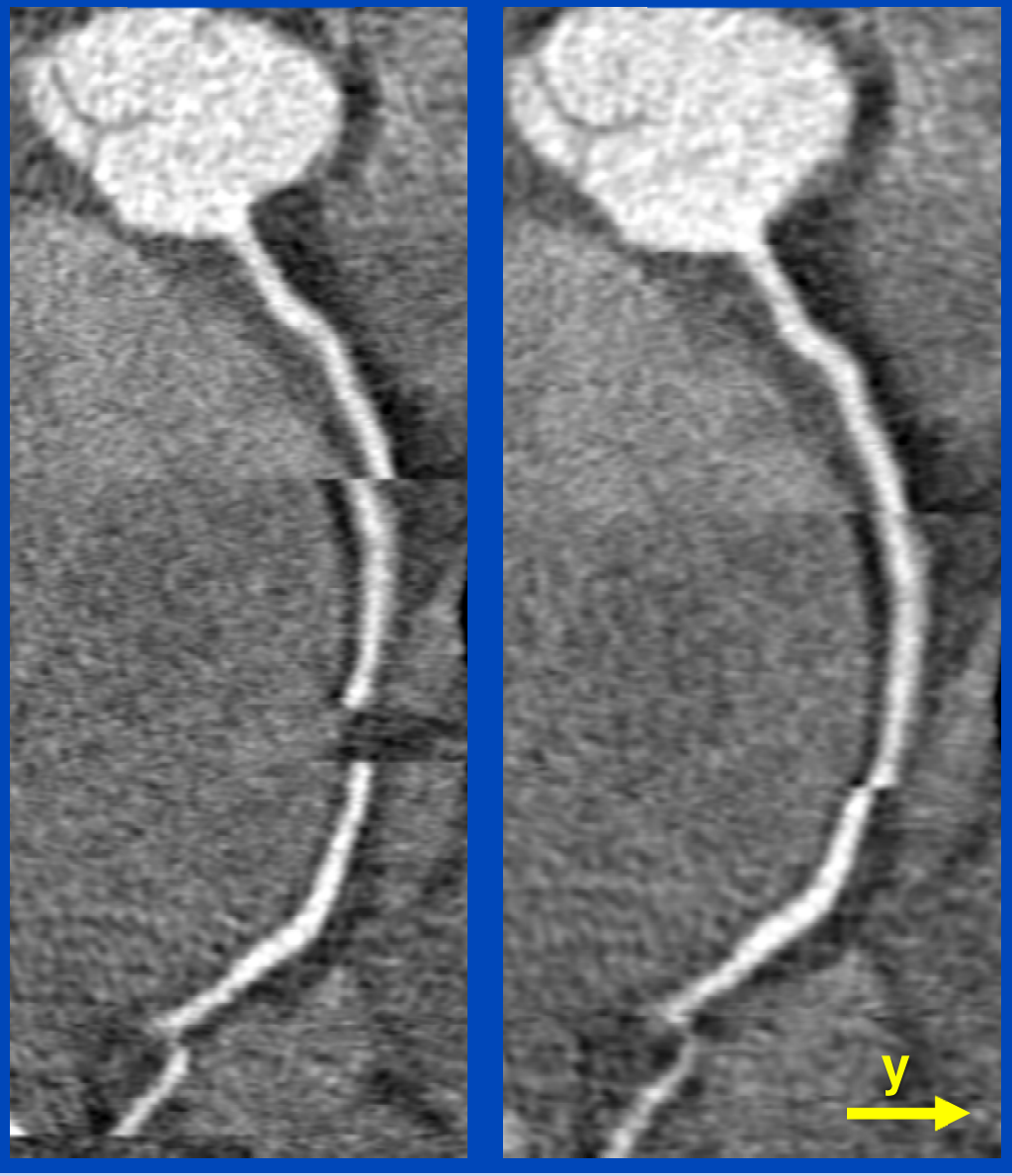




SIEMENS **Case A** σ = 5 … 15 mm, FWHM = 12 … 35 mm C = 200 HU, W = 1000 HU dkfz.

Results





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Case B

σ = 5 … 15 mm
FWHM = 12 … 35 mm

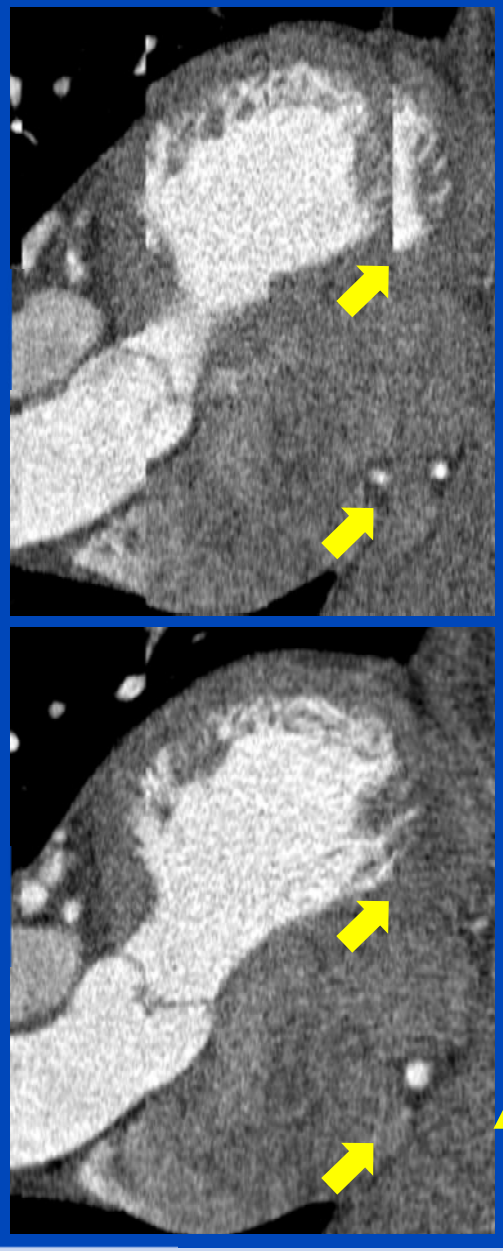
C = 200 HU, W = 1000 HU

dkfz.

Results

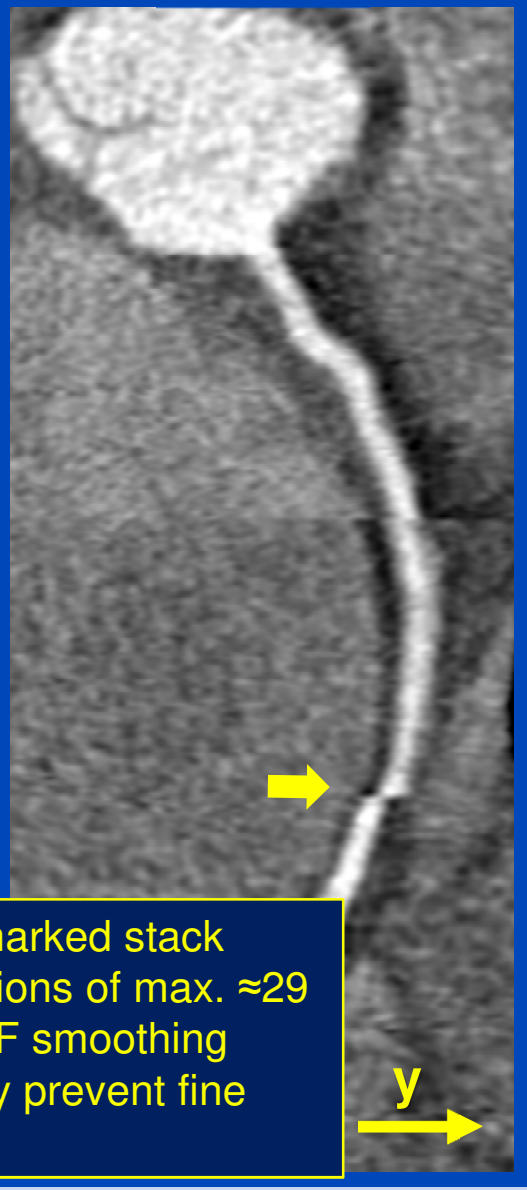
WFBP

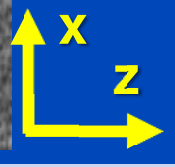
STAR



WFBP

STAR





Large correction at the marked stack transition (here deformations of max. ≈29 mm) lead to a strong DVF smoothing (here σ=11 mm) that may prevent fine corrections

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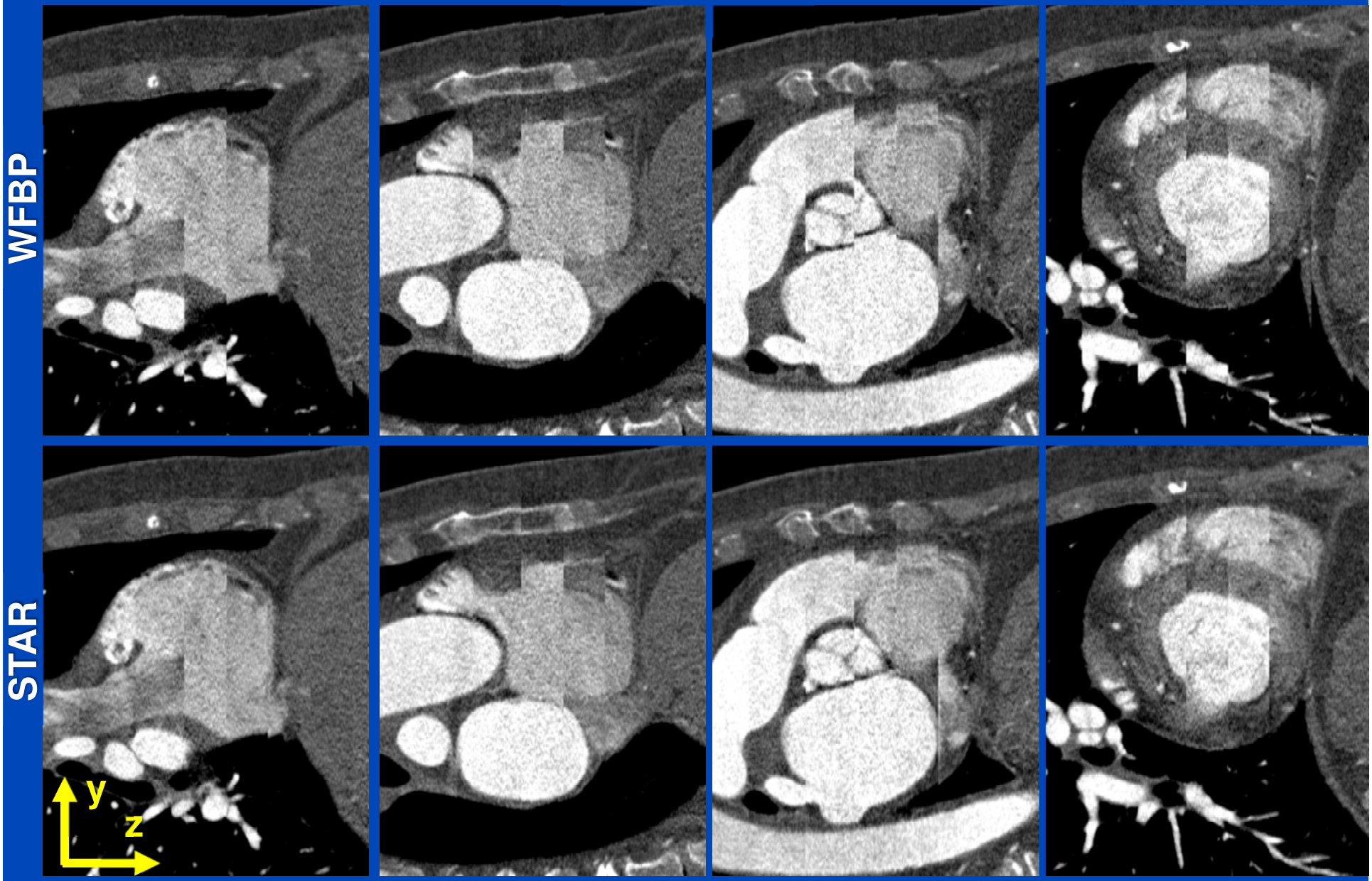
Case B

σ = 5 … 15 mm
FWHM = 12 … 35 mm

C = 200 HU, *W* = 1000 HU

dkfz.

Results



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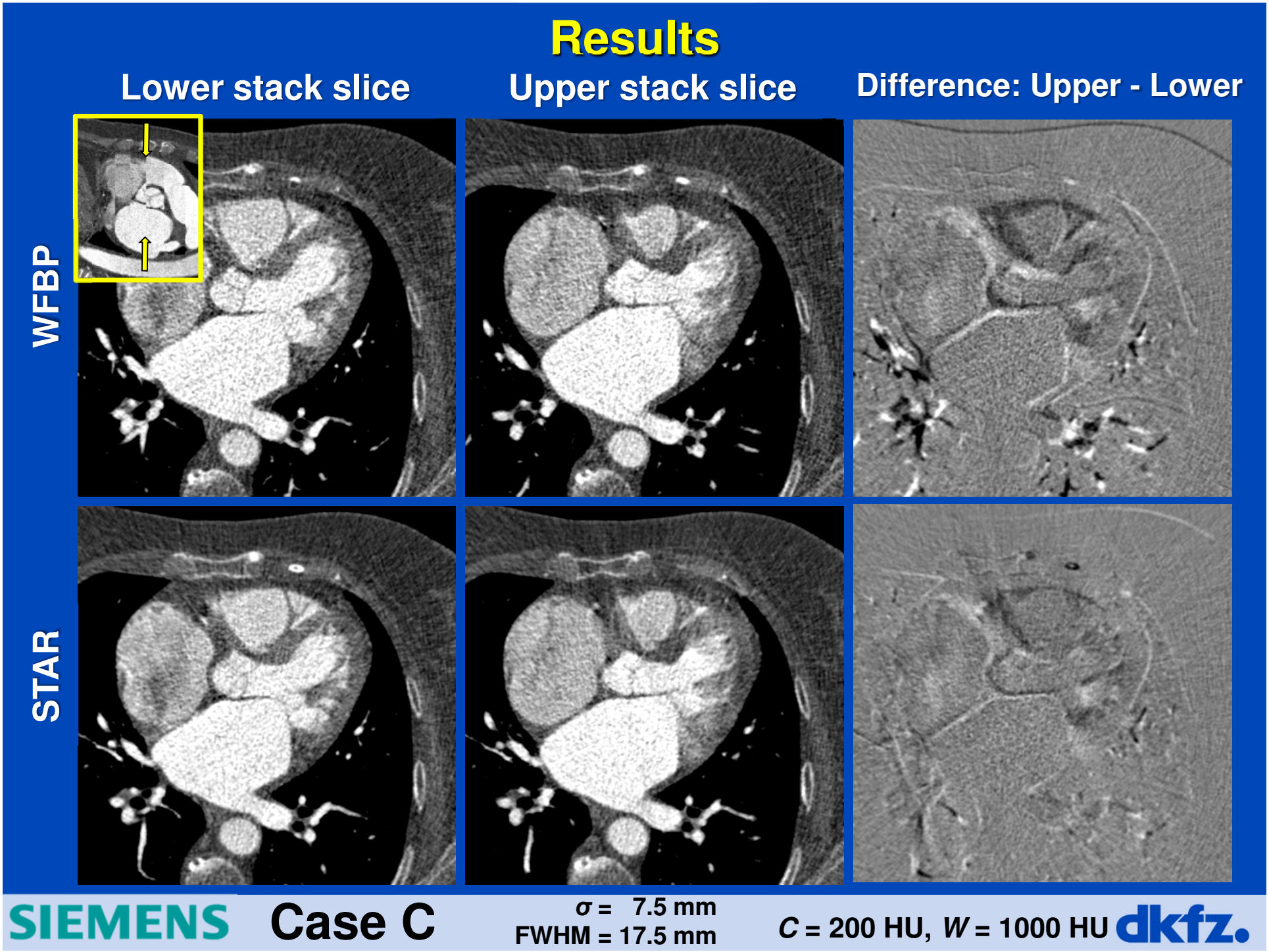
Case C

σ = 4 … 13 mm
FWHM = 9 … 30 mm

C = 200 HU, W = 1000 HU

dkfz.

Results


Lower stack slice
Upper stack slice
Difference: Upper - Lower
WFBP
STAR
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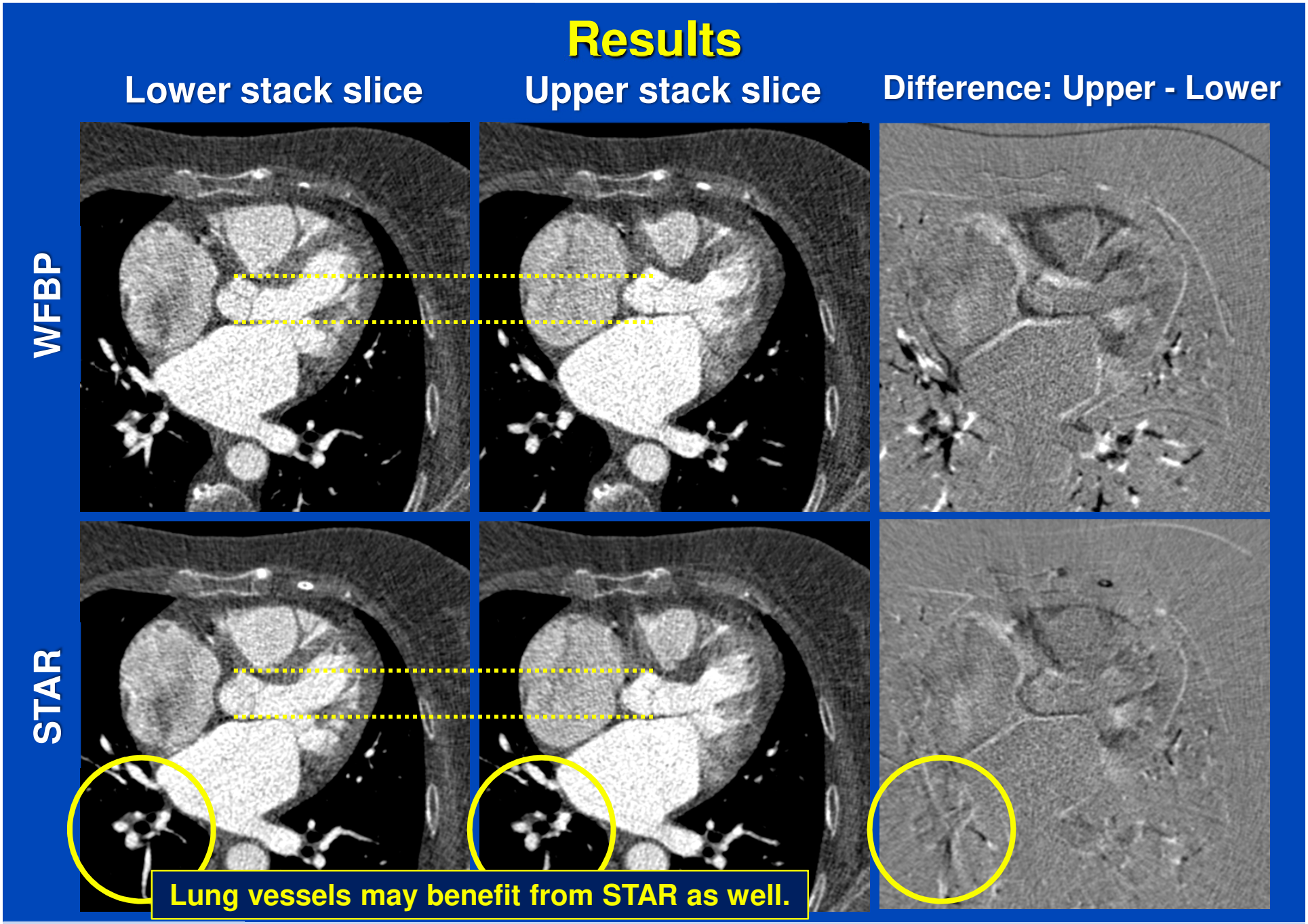
Case C
σ = 7.5 mm
FWHM = 17.5 mm
C = 200 HU, W = 1000 HU
dkfz.

Results



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Case C

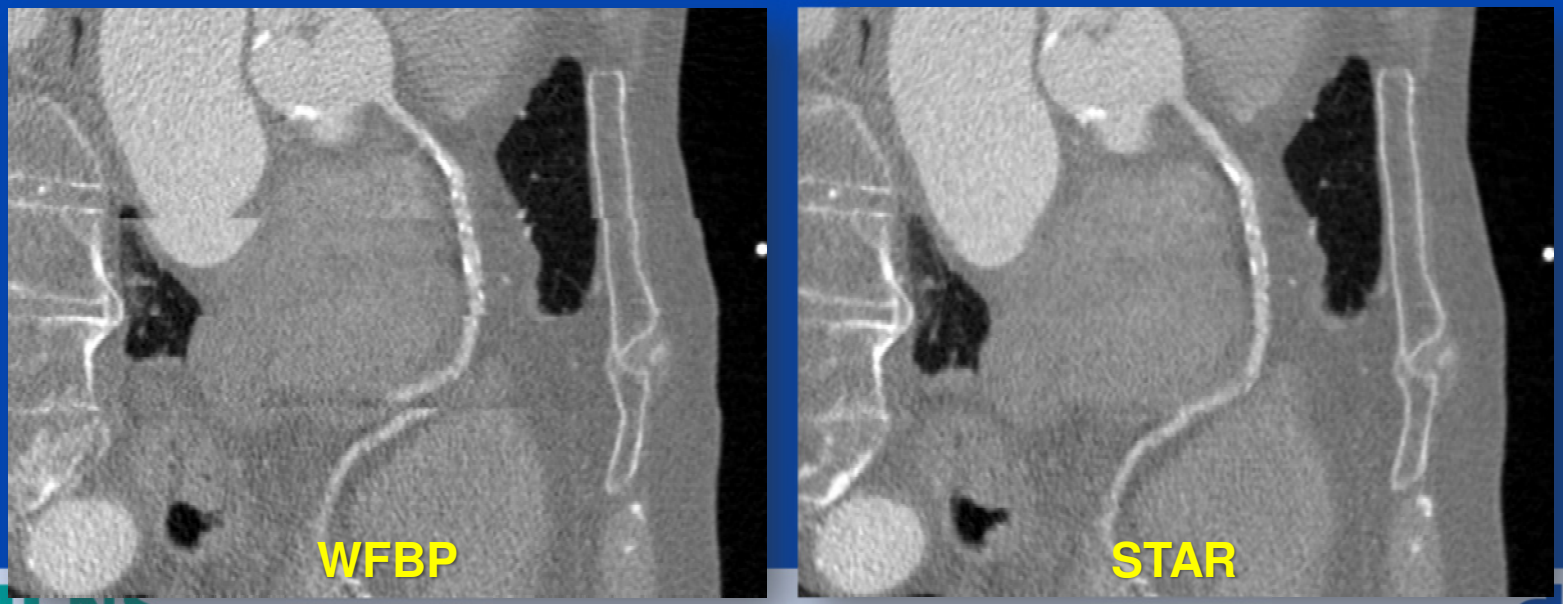
σ = 7.5 mm
FWHM = 17.5 mm

C = 200 HU, *W* = 1000 HU

dkfz.

Conclusions

- STAR is able to considerably improve image quality.
- Some stack transition artifacts may or shall remain:
  - Registration may fail locally if structures are not present in both stacks.
  - Registration shall fail partially if the deformation would require a non-smooth or unrealistic DVF.
- While the smoothness requirement may limit the registration performance, it ensures a “safe” deformation of the volumes.



Thank You!

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This presentation will soon be available at www.dkfz.de/ct.
Job opportunities through DKFZ's international Fellowship programs (marc.kachelriess@dkfz.de).
Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.