Up-To-Date Prior Knowledge via Motion Correction for Low Dose Tomographic Fluoroscopy

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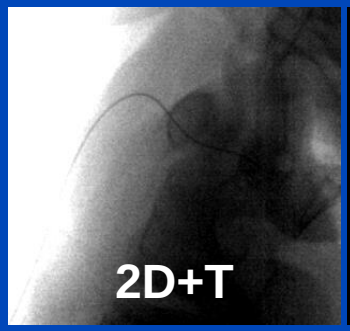
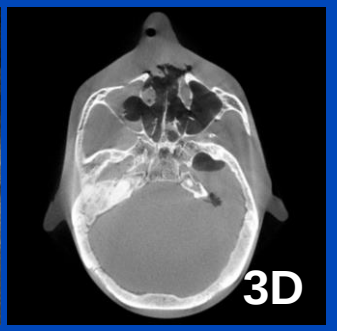
dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Interventional Radiology

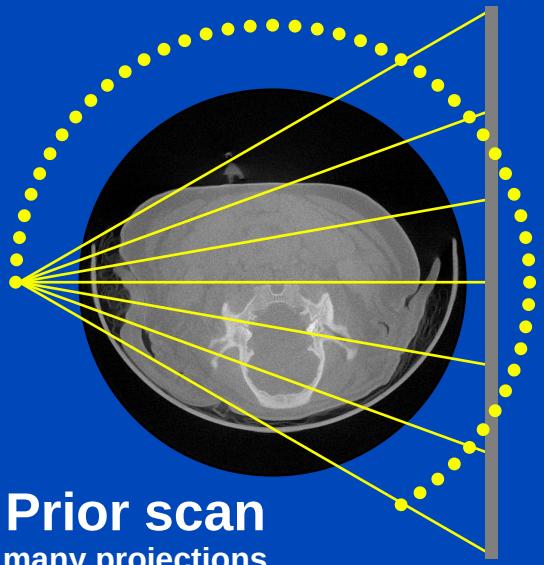
- **Interventional radiology:**
  - Minimally invasive interventions guided by x-ray imaging techniques
  - C-arm systems
- **Projective fluoroscopy:**
  - 2D projections
  - Position of interventional material is often ambiguous.
  - To clarify a 3D volume has to be acquired or trial-and-error approaches are applied.
- **Low dose tomographic fluoroscopy:**
  - 3D volumes
  - For clinical acceptance the dose should be limited to the same level as that of projective fluoroscopy.



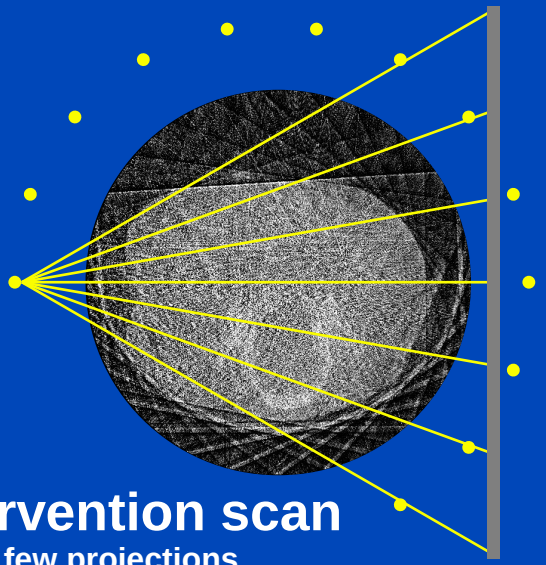


Realization of Tomographic Fluoroscopy

- **Low dose by:**
  - Low tube current
  - Very few projections (pulsed mode)
- **Advantages of intervention guidance:**
  - Repetitive scanning of the same body region.
  - Interventional materials are fine structures (few voxels) of high contrast (metal).

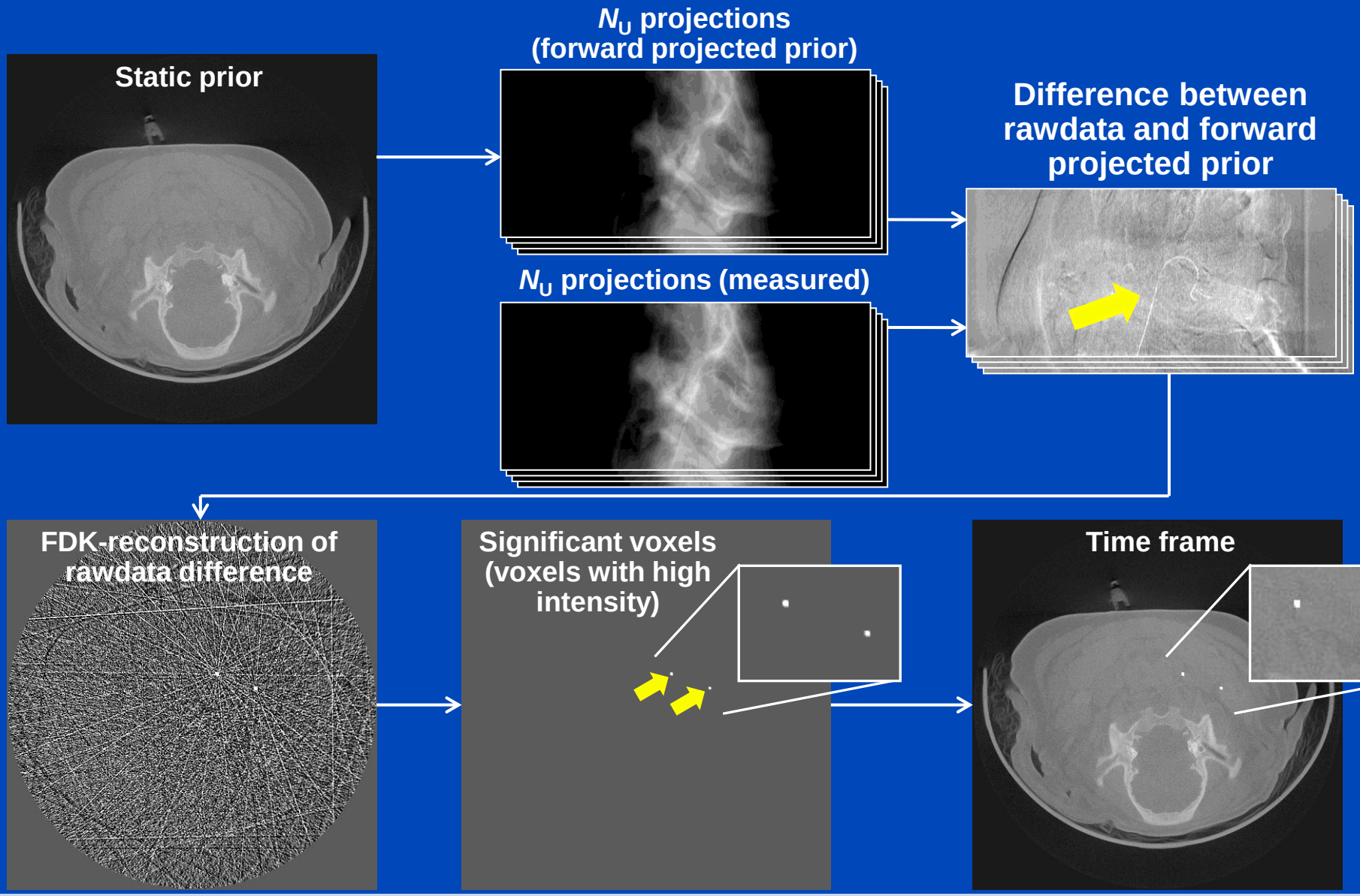


Prior scan
many projections



Intervention scan
few projections

PrIDICT-Algorithm[1]



[1] J. Kuntz, R. Gupta, S.O. Schönberg, W. Semmler, M. Kachelrieß, and S. Bartling, "Real-time x-ray-based 4D image guidance of minimally invasive interventions", Eur. Radiol., 23(6): 1669-1677, Jun. 2013.

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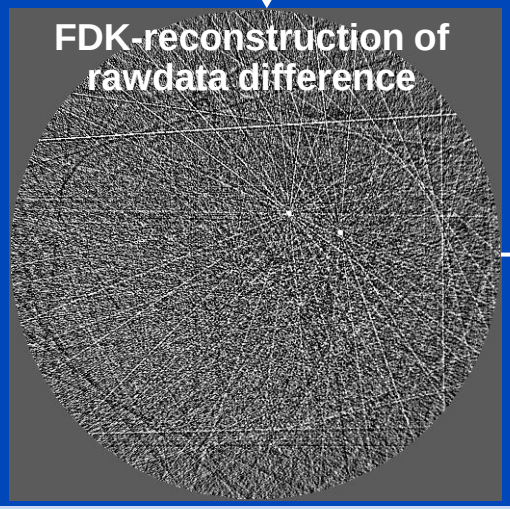
PrIDICT-Algorithm[2]

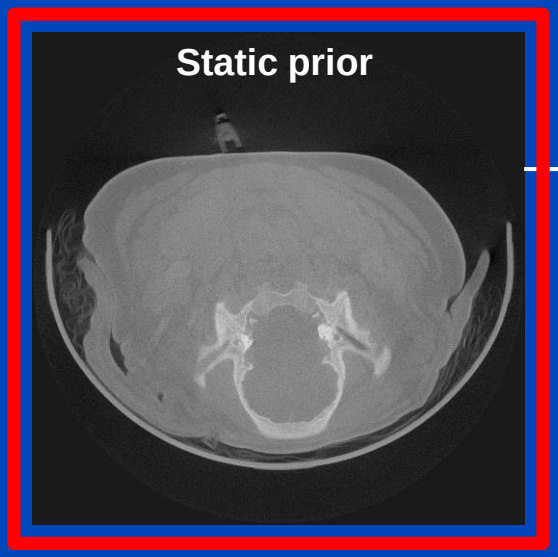
Why Running Prior?

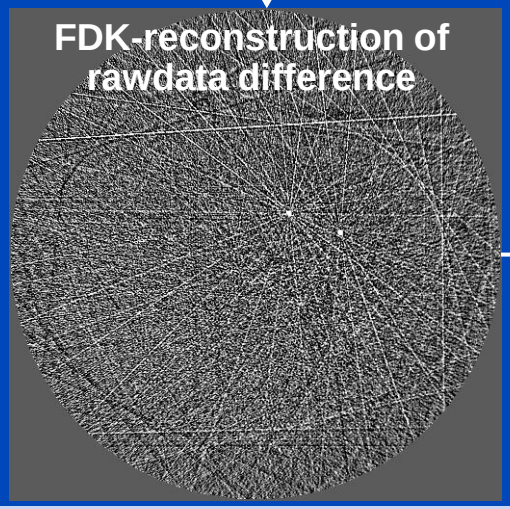
- **Problem with PrIDICT algorithm: Patient motion after prior scan**
- **Aim: Allow for patient motion by updating the prior continuously – for dose reasons without additional projections**
  - **Deformation via registration**
  - **Incorporation of current projections into the prior**



[1] J. Kuntz, B. Flach, R. Kueres, W. Semmler, M. Kachelrieß, and S. Bartling, "Constrained reconstructions for 4D intervention guidance", Phys. Med. Biol., 58(10): 3283-3300, May 2013.

PrIDICT-Algorithm[2]





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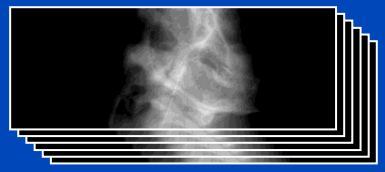
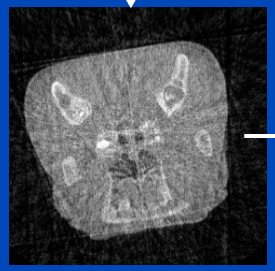
Workflow of Running Prior Technique



Last N_T projections
e.g. 60 projections

FDK

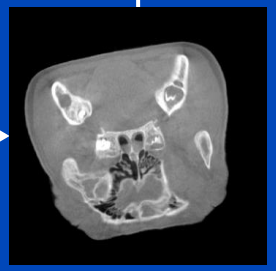


Target image

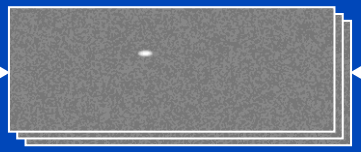
Registration
(affine, Demons)

Current running prior

Forward projections
(same projection angles as last N_U projections)

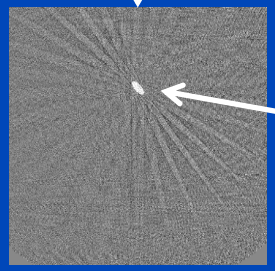


Deformed image



Difference projections

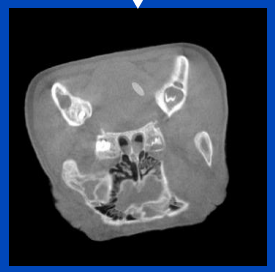
FDK



Difference reconstruction

Last N_U projections
e.g. 15 projections

e.g. subarachnoid hemorrhage



Next running prior

Measurement

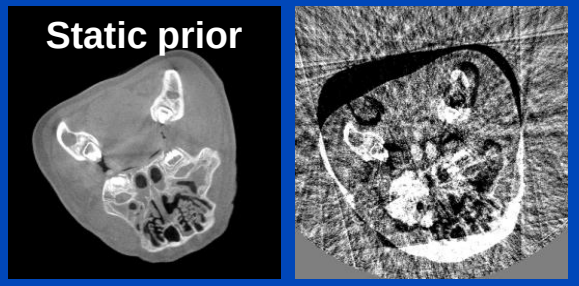
- **System:**
  Volume CT prototype
  - Flat detector on clinical CT gantry
  - Geometry like C-arm systems

Experimental setup

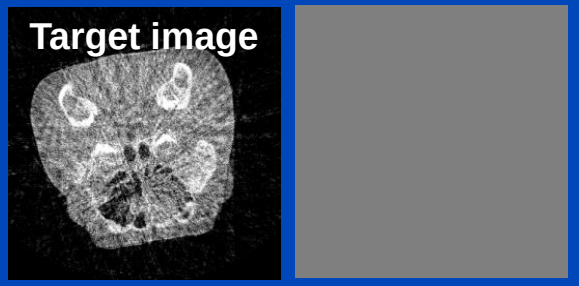
- **Prior scan:**
  - Before intervention
  - N_{360} = 600 projections per 360°
  - 80 kV, 342 mAs
  - T_{rot} = 19 s/360°
  - 1 single rotation

- **Intervention scan:**
  - During intervention
  - N_{180} = 15 projections per 180°
  - 80 kV, 0.6 mAs/projection
  - T_{rot} = 2 s/180°
  - Many rotations (depending on time needed for intervention)
  - Guide wire inserted into the carotid of the pig‘s head during the scan

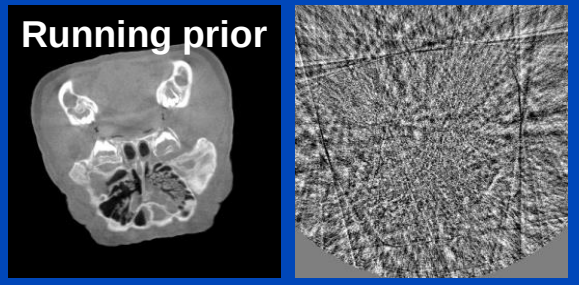
Difference to target image



Position before intervention



Position during intervention



Position after deformation

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Animal Experiments

- During the intervention the pig was anesthetized via an injection of a combination of
  - 8 mg/kg body weight of Stresnil,
  - 1 mg/kg body weight of Midazolam/Dormicum and
  - 20 mg/kg body weight of Ketamin/Ketanest.
- While anesthetized the pig breathed free.
- All animal experiments were approved by the governmental animal ethics committee (Regierungspräsidium Karlsruhe).

Dose Aspects

- No automatic exposure control in Volume CT
- Dose measured in CTDI head phantom
- Dose for prior scan:
  - $CTDI_w$ = 10 mGy
  - $CTDI_w$ values in literature for 3D volumes acquired with flat detector: 9-70 mGy[3-8]
- Dose during the intervention:
  - $CTDI_w$ = 7.8 mGy/min at 7.5 frames/s
  - Skin entrance dose rates for projective fluoroscopy in literature in the range of „less than 1 mGy/min up to several Gy/min“[9], explicitly mentioned values: 5-90 mGy/min[10-17]

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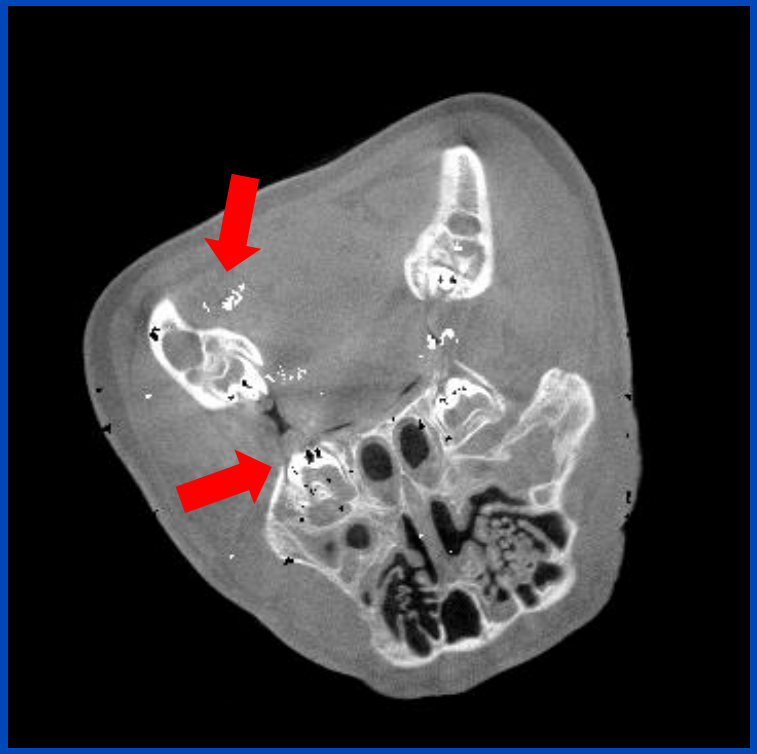
Static Prior vs. Running Prior I

PrIDICT using static prior



Artifacts resulting from motion

PrIDICT using running prior

No artifacts

C = 0 HU, W = 1500 HU

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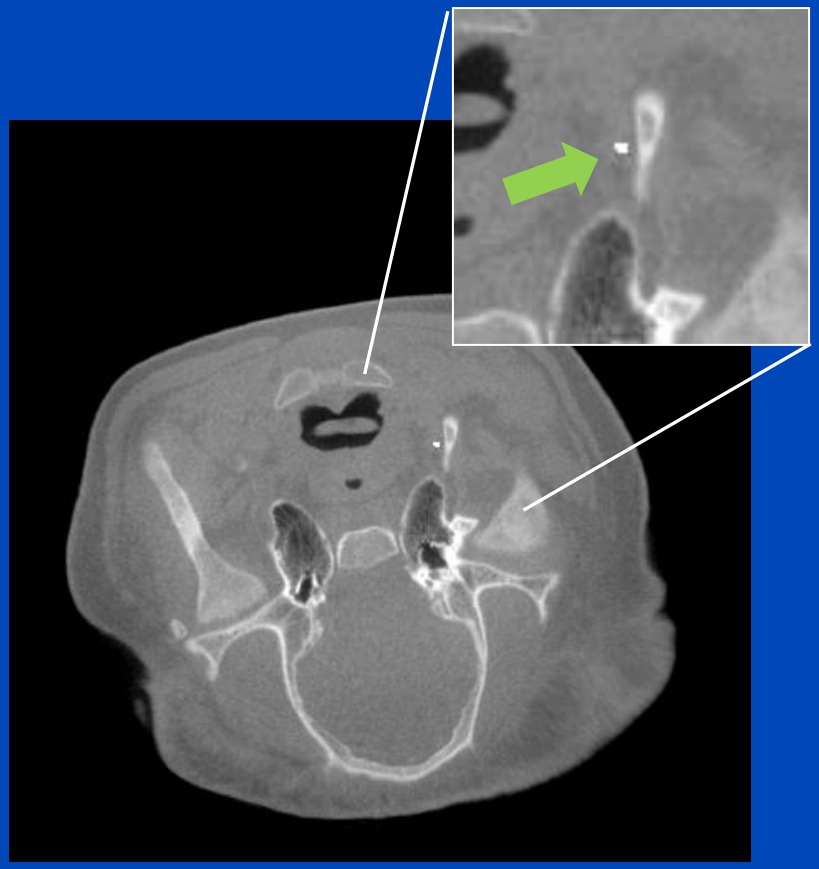
Static Prior vs. Running Prior II

PrIDICT using static prior

Wrong wire position

PrIDICT using running prior



Correct wire position

C = 0 HU, W = 1500 HU

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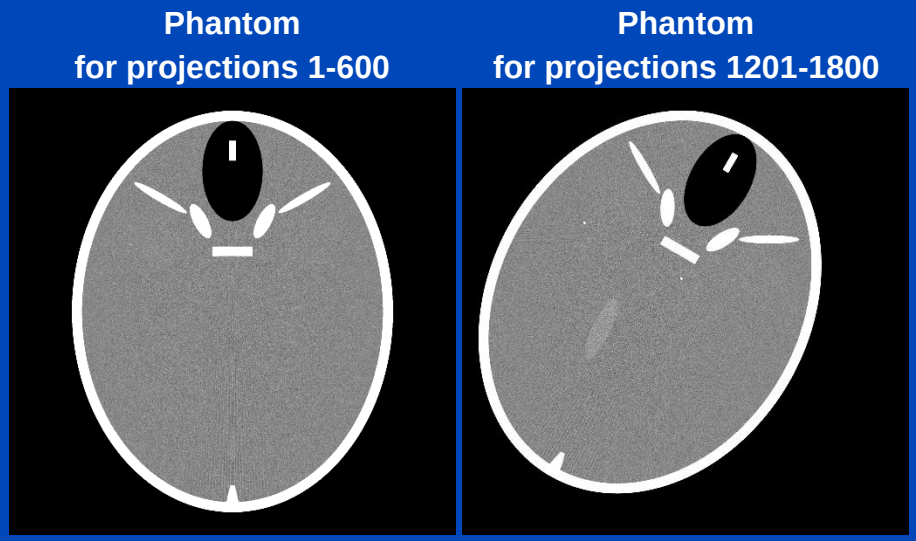
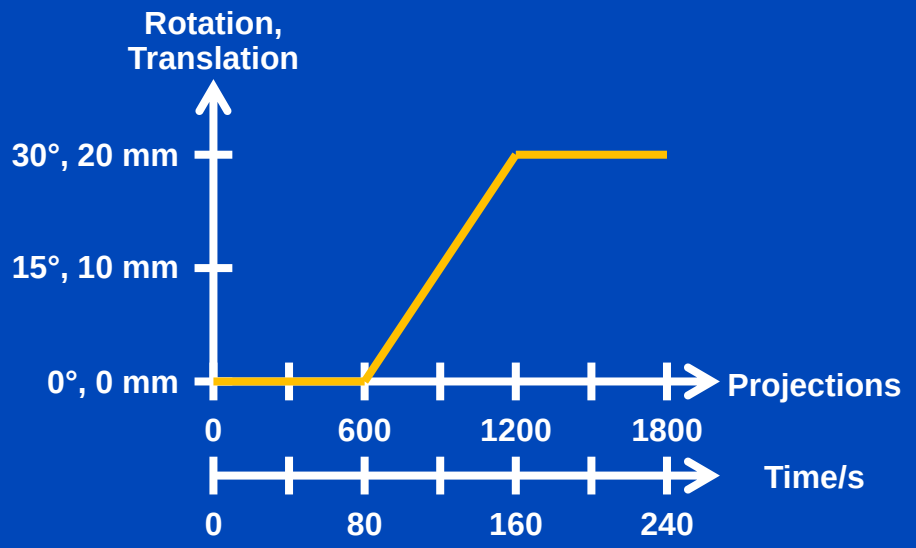
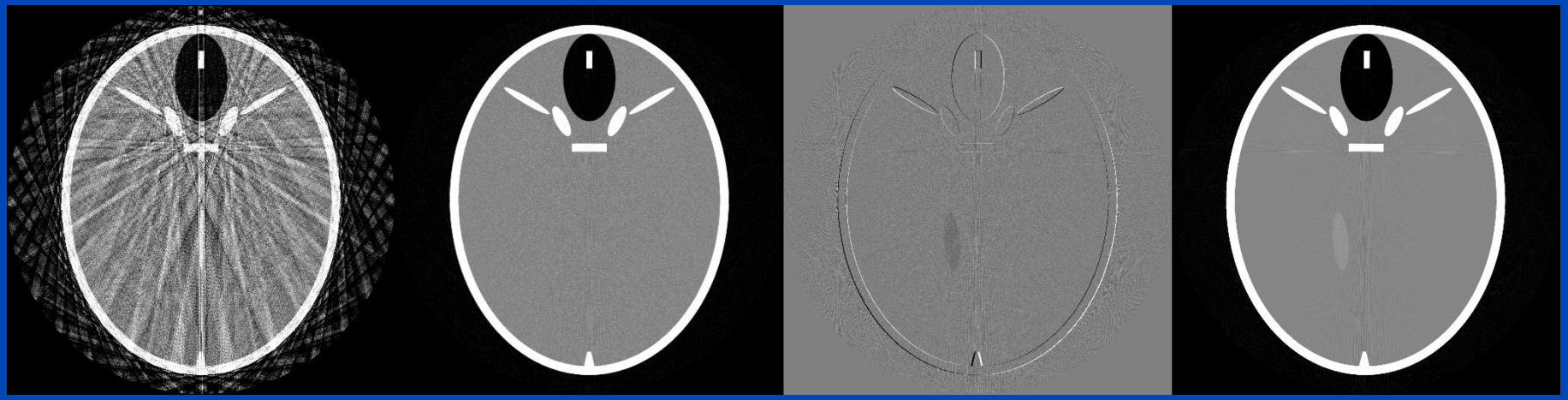
Simulation

- **3D cone-beam geometry:**
  - 1800 projections within 60 rotations
  - Same geometry as Volume CT
  - Head phantom with inserted ellipsoid (150 HU) after 600 projections
  - Poisson-distributed noise added to rawdata
- **Motion:**
  - Between projection 600 and 1200 the phantom is moved continuously.
  - Simulated guide wire is inserted from projection 600 to 1800.





Running Prior with Continuous Motion



- During motion phase the running prior is slightly behind the ground truth.
- Ellipsoid appears in the running prior.
- When motion stops running prior fits the ground truth.

C = 0 HU, W = 2000 HU

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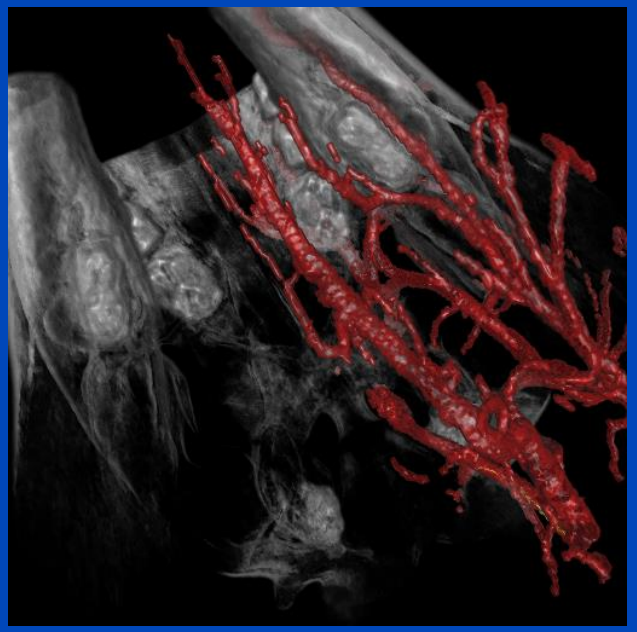
Benefit of Running Prior

- Advantages of the running prior compared to the static prior:
  - Less artifacts in the update volumes resulting from motion between prior scan and intervention scan
  - Higher reliability because interventional material is displayed at correct position
- No additional dose needed for continuously updating the prior.

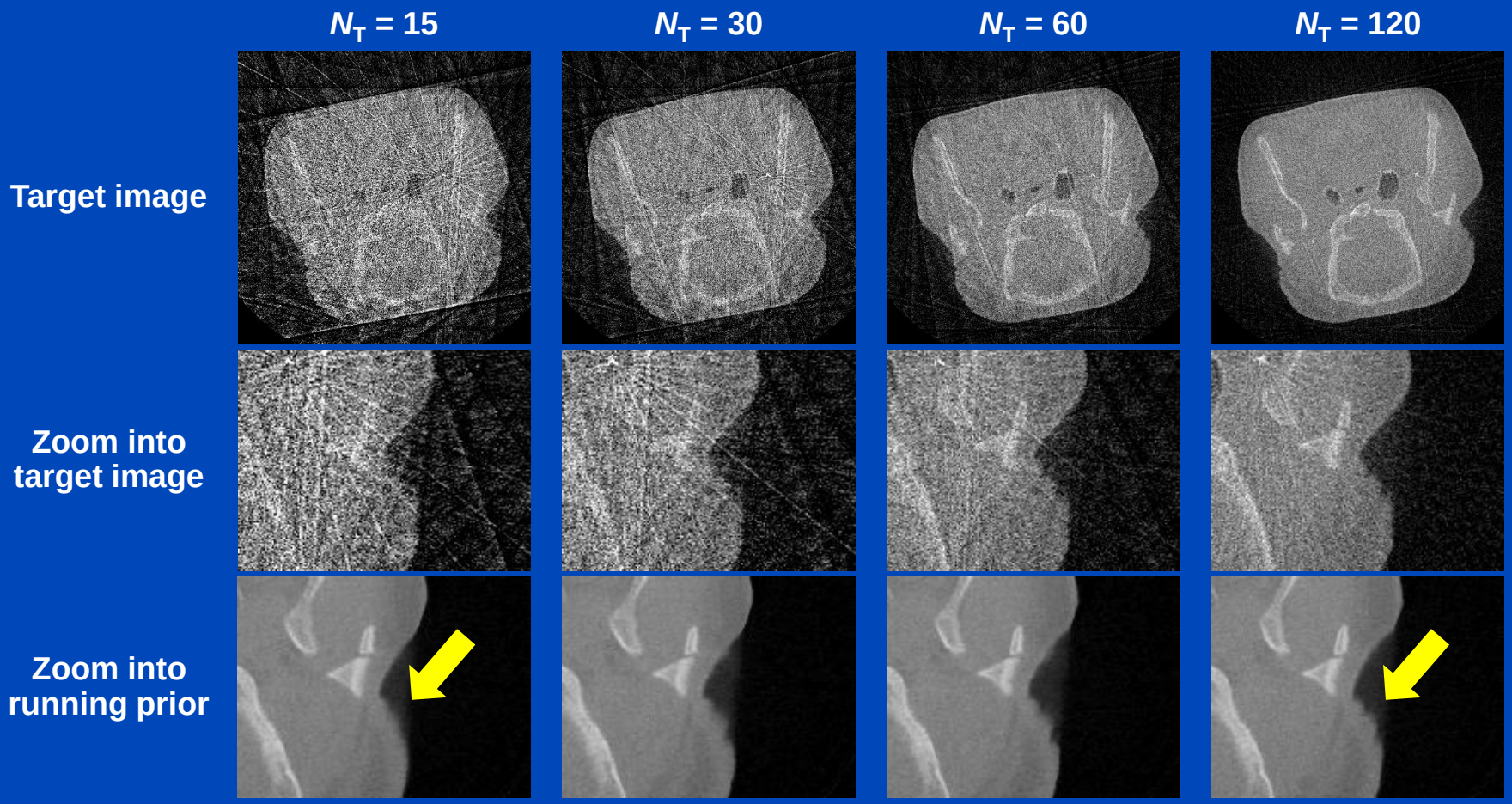


- 4D intervention guidance at dose level comparable to projective fluoroscopy may become possible also with patient motion by using the running prior technique.

Investigations on Number of projections N_T used for reconstruction of target image

- **Investigated parameters:**
  - N_T = 15 (half rotation, same number as for calculation of interventional material)
  - N_T = 30 (one full rotation)
  - N_T = 60 (two rotations)
  - N_T = 120 (four rotations)

Measurements – Accuracy I



- Image quality should be high enough to guarantee good/accurate registration results.

C = 0 HU, W = 2000 HU

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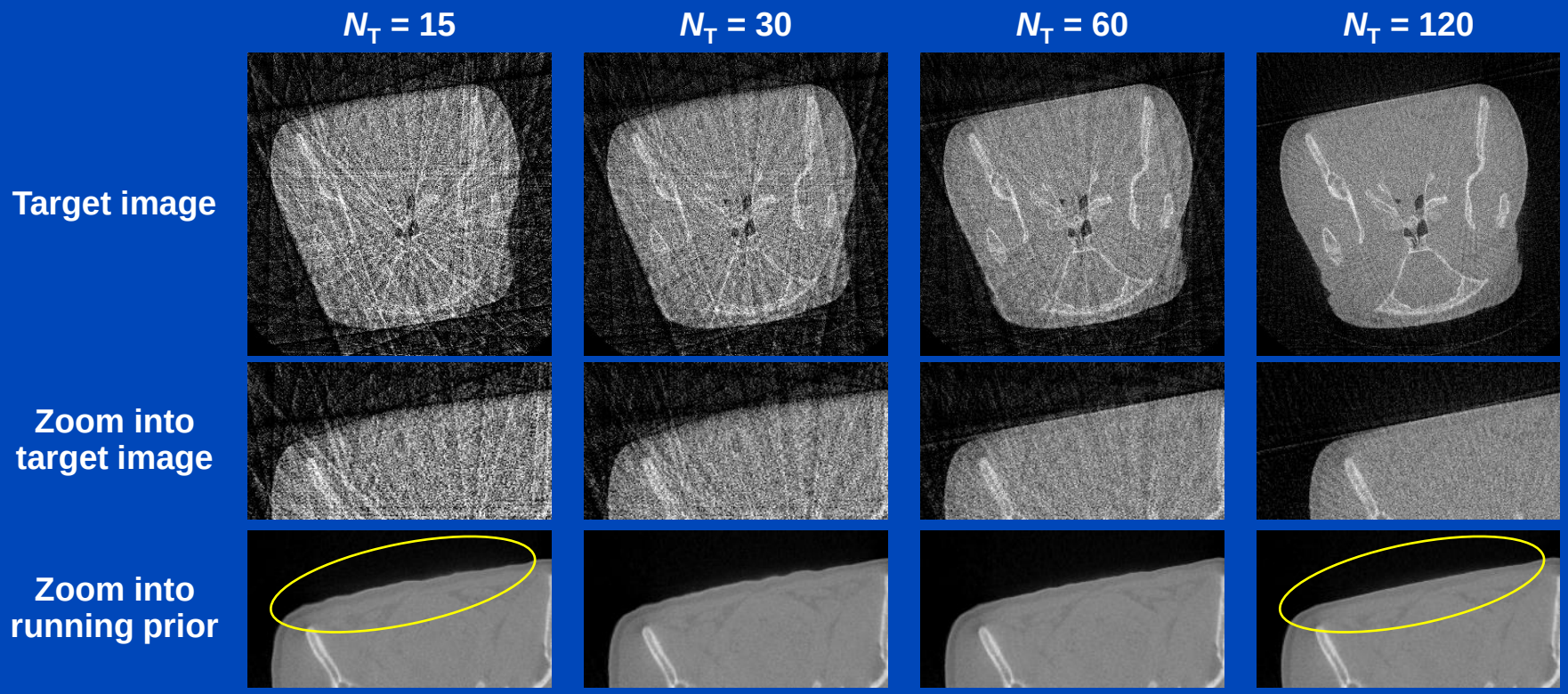
Measurements – Accuracy II



- Streak artifacts in the target image lead to a wobbling body outline.

C = 0 HU, W = 2000 HU

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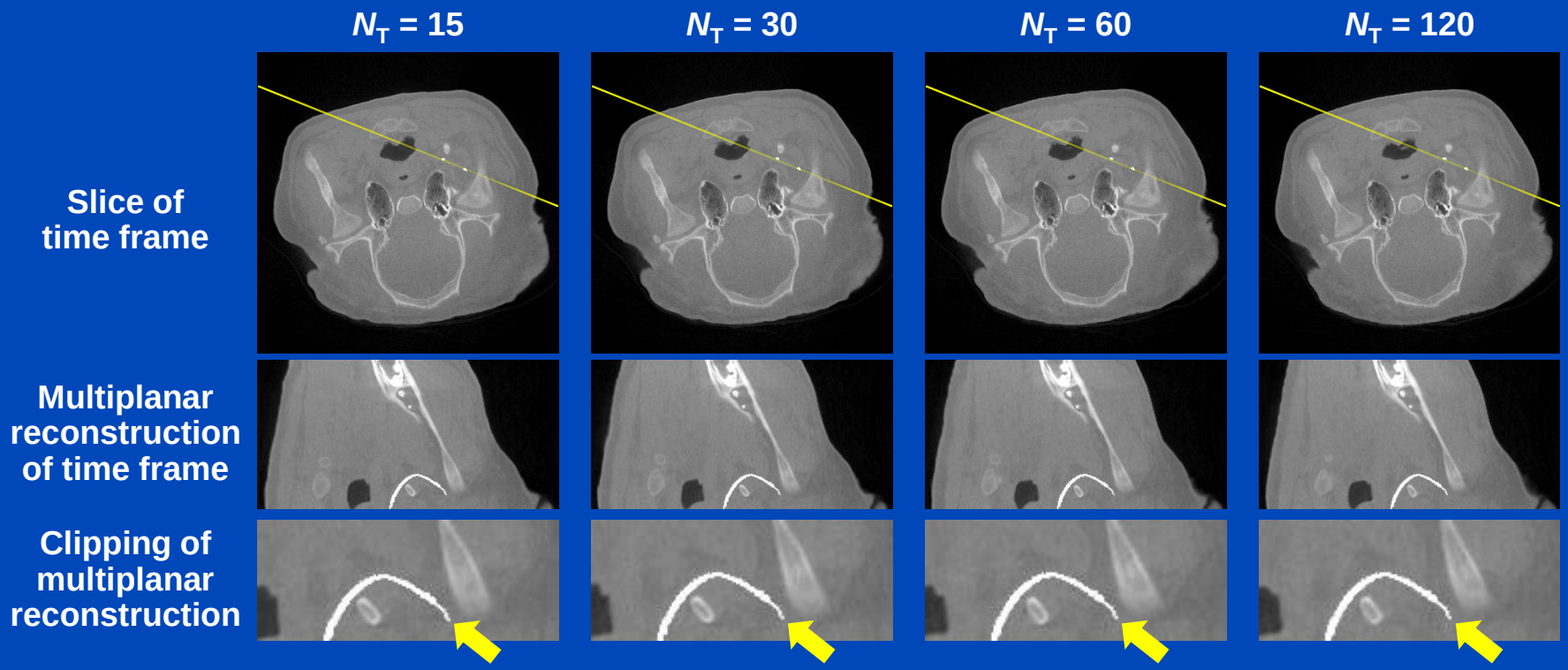
Measurements – Intervention Guidance



- Interventional material is displayed at the correct position for all investigated parameters N_T.
- Slightly inaccurate registration results (artifacts like wobbling) do not significantly affect intervention guidance.

C = 0 HU, W = 2000 HU

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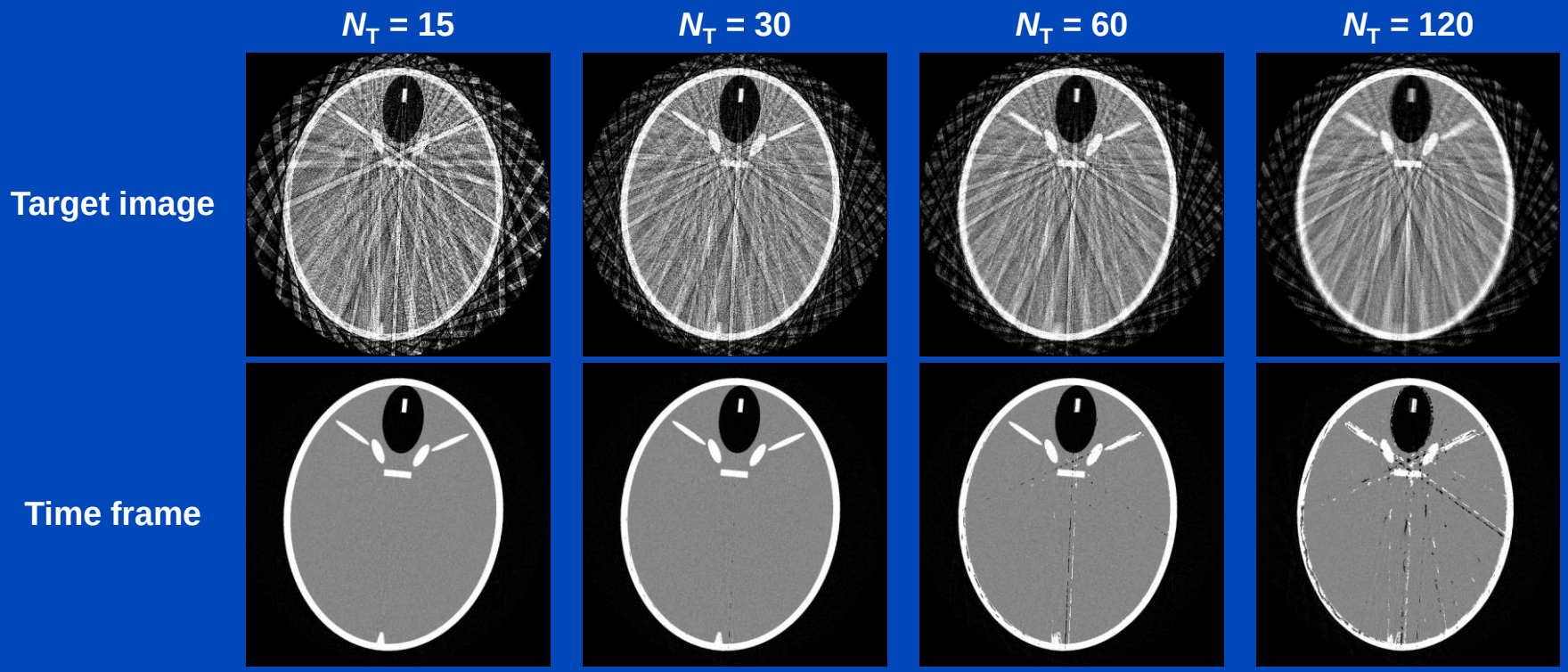
Simulation – Temporal Delay



- To focus on the effect of motion within the target image (not on artifacts) we applied only a rigid registration in this case.
- To correct for motion the target image has to be “very“ up to date (means less projections).
- If information in target image is partially outdated, the running prior does not fit optimally to the current situation. => Artifacts when applying the PrIDICT algorithm

C = 0 HU, W = 2000 HU

Conclusion

- Quality of running prior strongly depends on the image quality of the target image
- Trade-off between
  - Many projections: good image quality of target image such that registration result not affected by artifacts
  - Few projections: target image without motion (depends on the magnitude of motion)
- Minimum $N_T = 15$ provides satisfying results for intervention guidance but image quality may be slightly deteriorated by our current registration approach (e.g. wobbling).
- $N_T = 60$ provides good image quality as well as acceptable motion within the target image in our cases.

Thank You!

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

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