Adaptive Imaging – Syncing with Patients for Safer and Smarter 3D Imaging

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Disclosure and Disclaimer

- The concept and information presented in this paper are based on research and is not commercially available. Due to regulatory reasons its future availability cannot be guaranteed.

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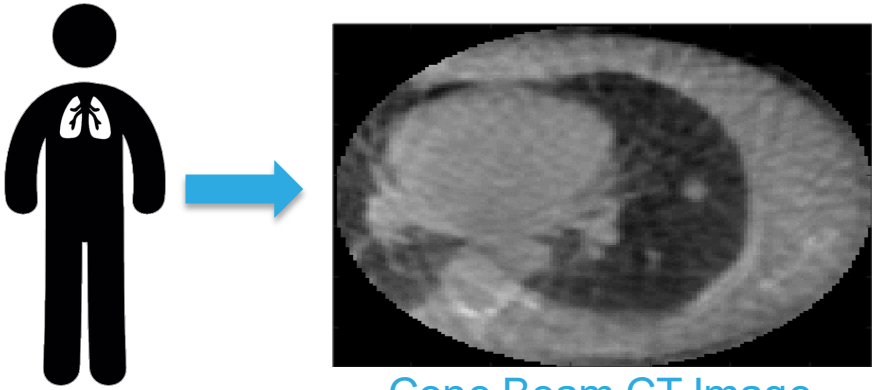
Patient Connected Imaging

Motivation for Patient Connected Imaging

The Problem: Patient movement can severely affect image quality.



Cone Beam CT Image

- Streaking is caused by physiological changes: heartbeat, breath, coughing, involuntary movement.
- Currently there is no feedback from motion signal to imaging hardware

Our Approach

Prospectively gate from patient's physiological signals

Adapt the image acquisition in real time

Control the gantry velocity and projection time interval

Completely customizable, personal and motion mitigated imaging

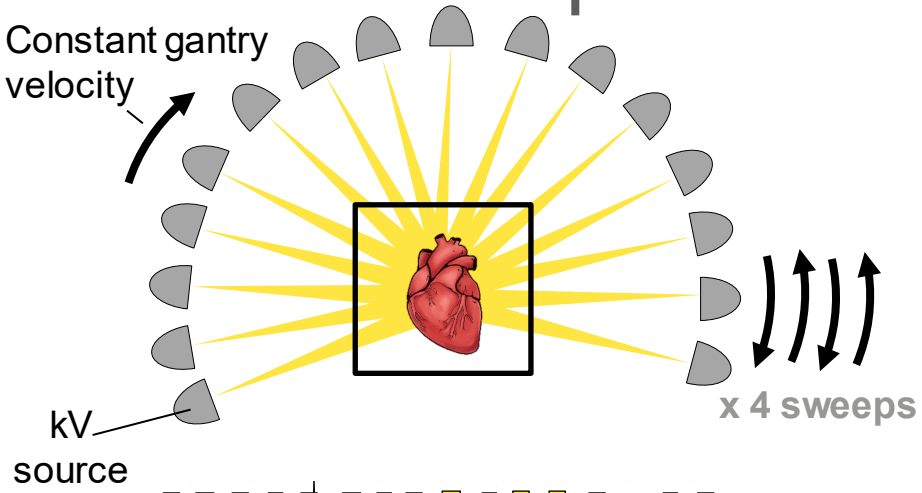
Interventional cardiac imaging with ACROBEAT (Adaptive CaRdiac cOne BEAm computed Tomography)

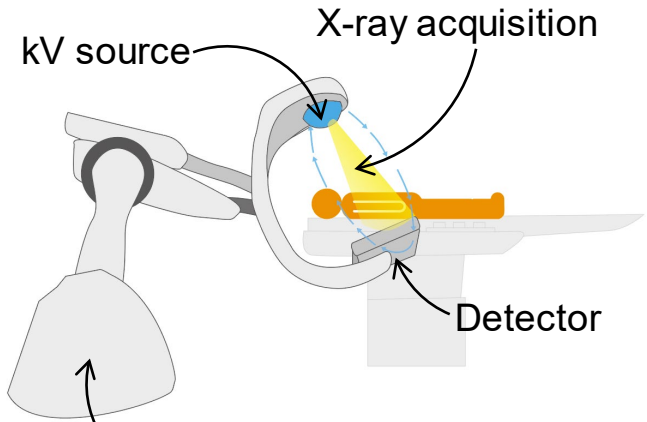
Introduction

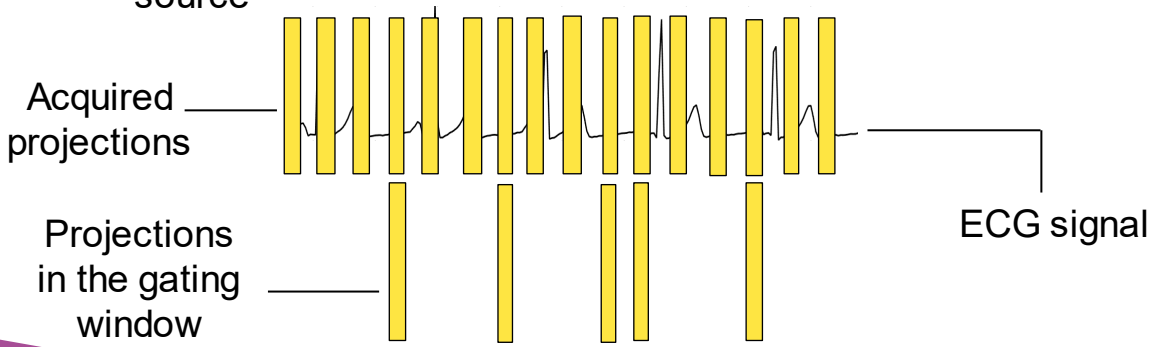
- **Cone Beam Computed Tomography (CBCT)**
  - Compact size and mobility
  - Established integration within operating theatres
  - Current cardiac imaging protocols have high imaging dose and low image quality
  - Adaptive imaging that simultaneously reduces imaging dose and improves image quality

The Hybrid Theatre at the University of Sydney

Conventional: Constant gantry velocity and projection acquisition rate. Retrospective ECG gating.

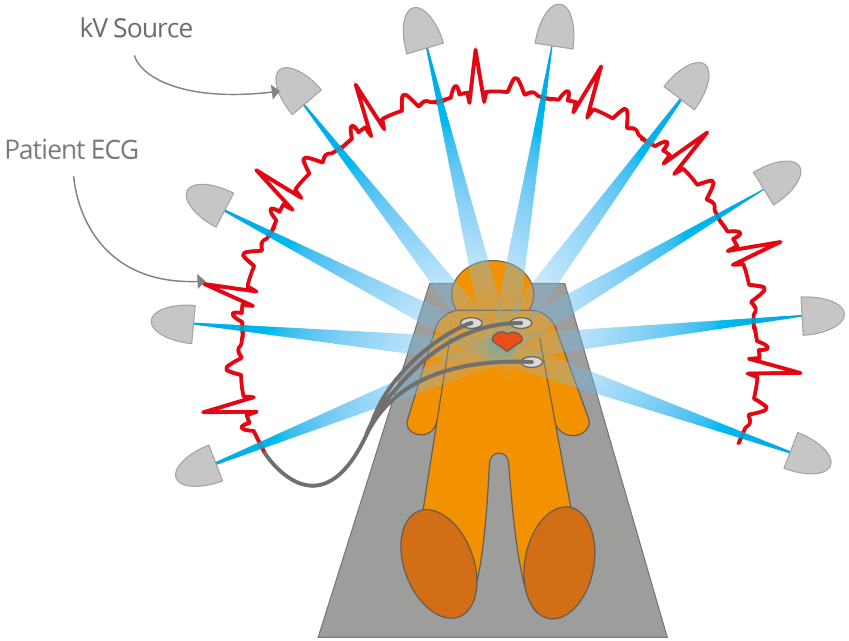






Siemens ARTIS pheno robotic C-arm Cone Beam CT system

ACROBEAT: Adaptive CaRdiac cOne BEAm computed Tomography



The patient's ECG signal is used to adapt the gantry velocity and projection time interval in real time

ACROBEAT: Adaptive CaRdiac cOne BEAm computed Tomography

Main aims:

1. Ensure projections are only acquired within the defined acquisition window

2. Improve the angular separation between projections

Advantages:

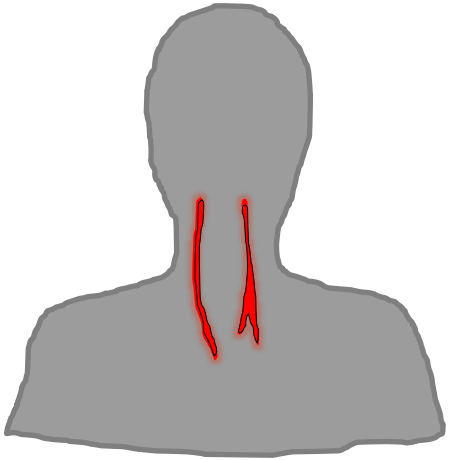
1. Completely customizable (location of acquisition window within cardiac cycle).

2. Control over 2 additional degrees of freedom: gantry velocity and projection time interval.

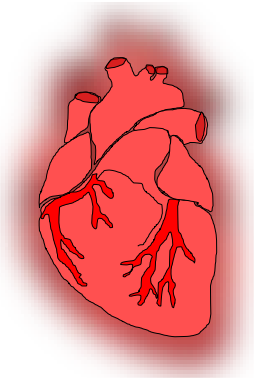
3. Single sweep of the gantry.

Adaptive Imaging Scenarios

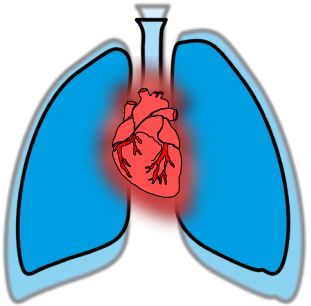
Cardiac Pulsing: artery imaging



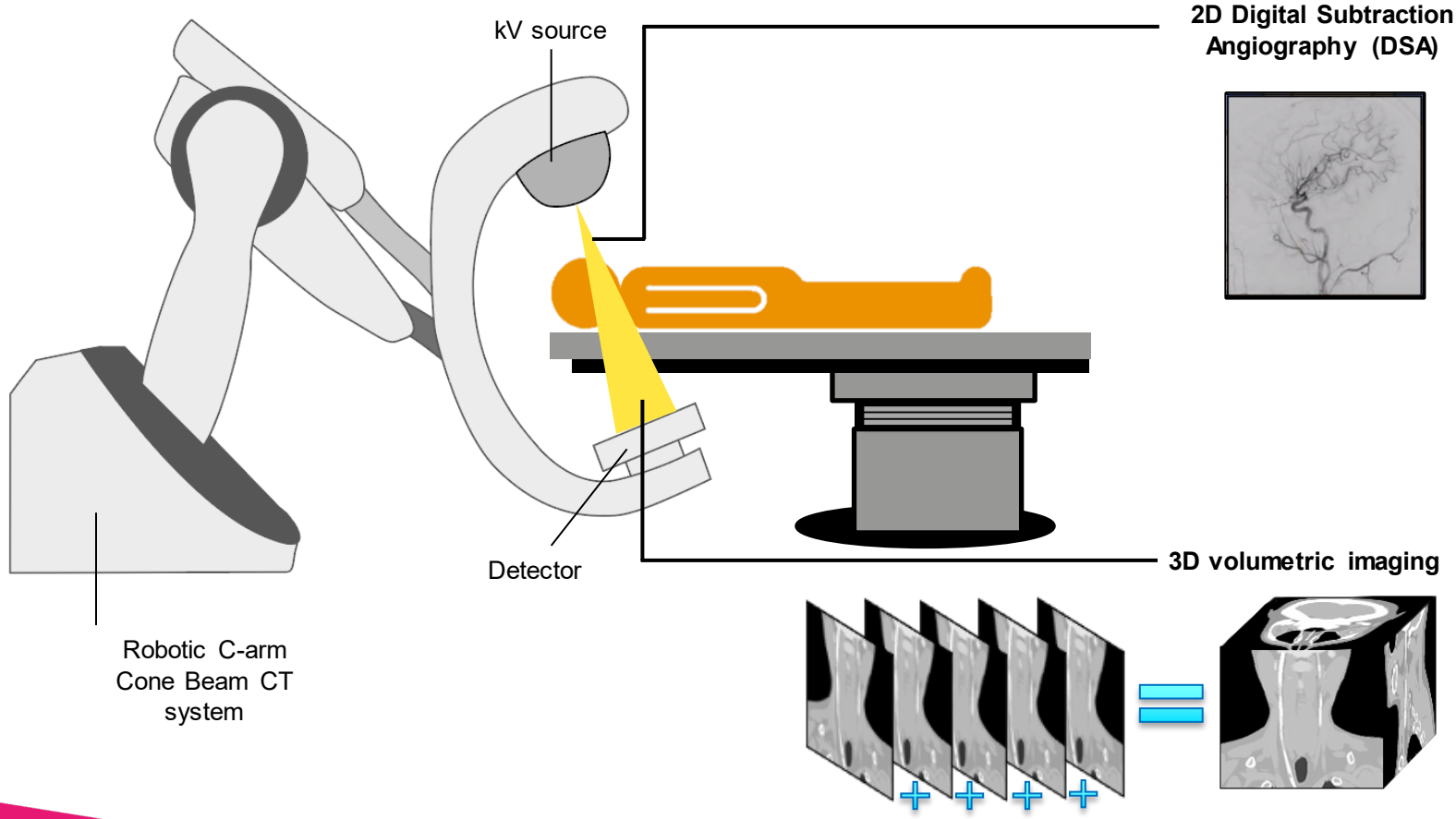
Cardiac motion: heart imaging



Cardiac and respiratory motion: heart imaging



Artery Imaging



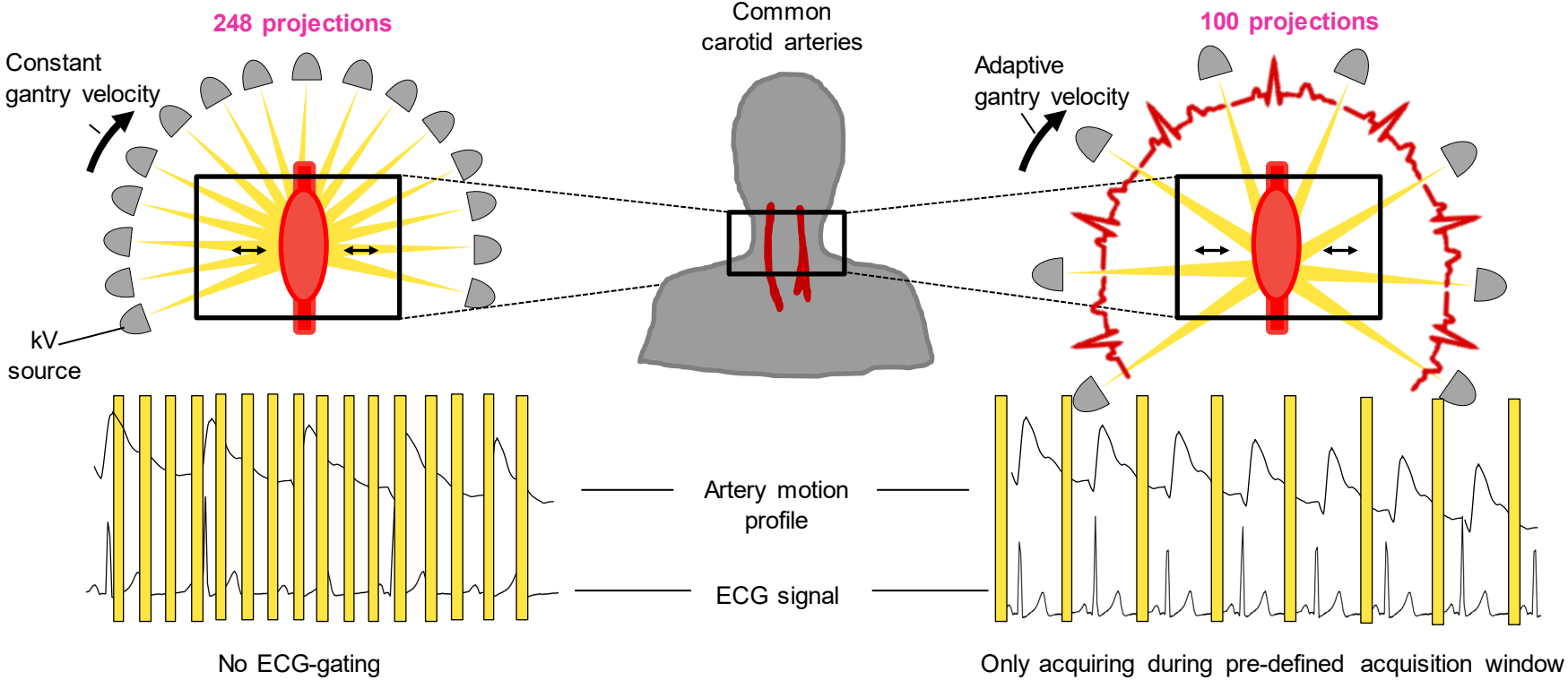
Acquisition Protocols

Conventional: Constant gantry velocity and projection acquisition rate

248 projections

Adaptive CaRdiac cOne BEAm computed Tomography (ACROBEAT)[1,2]

100 projections



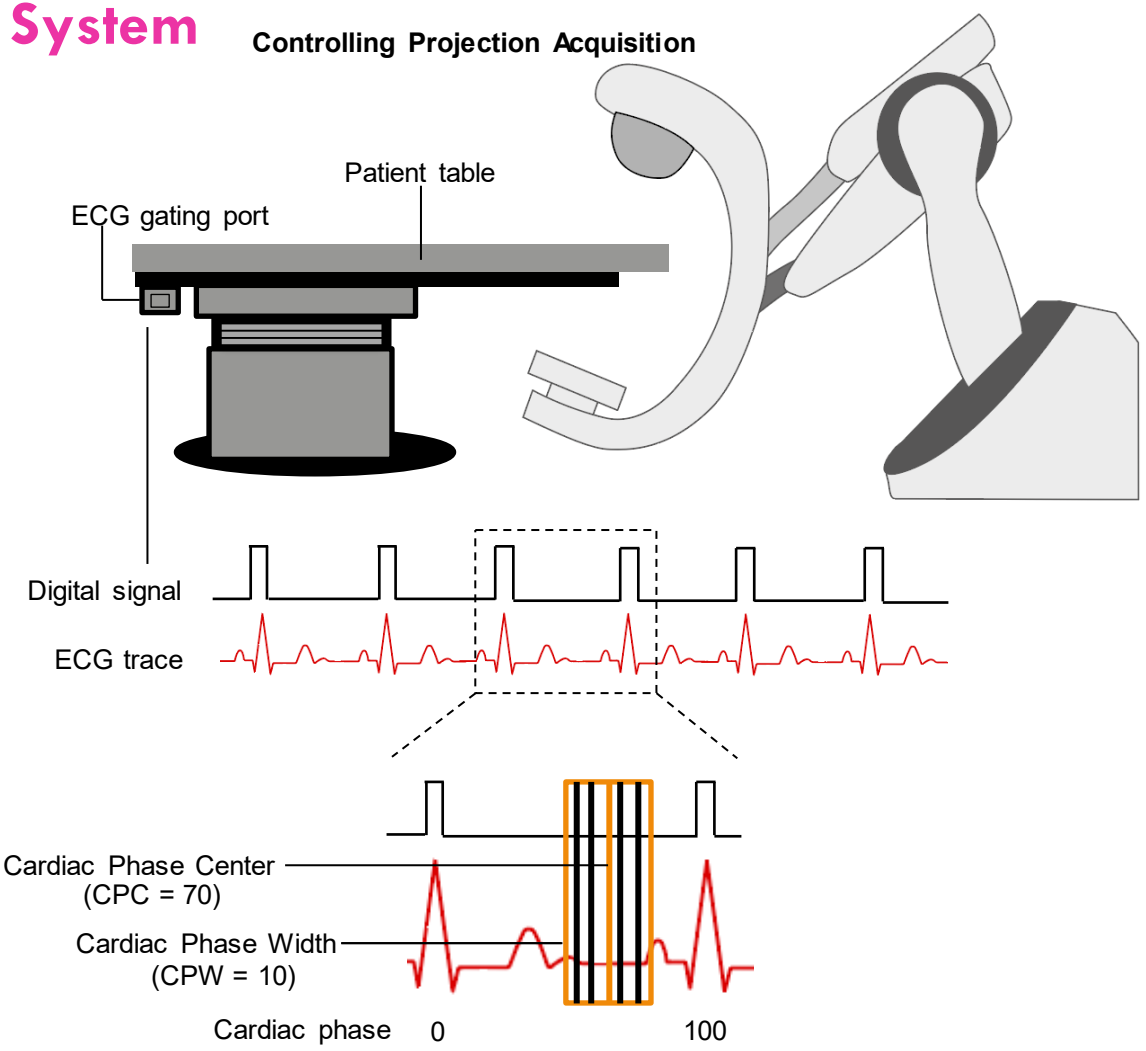
1. **T. Reynolds et al.** *Towards patient connected imaging with ACROBEAT: Adaptive CaRdiac cOne BEAmcomputed Tomography*. **Phys. Med. Biol. 2019.**
2. **T. Reynolds et al.** *Dual cardiac and respiratory gated thoracic imaging via adaptive gantry velocity and projection rate modulation on a linear accelerator: a proof-of-concept simulation study*. **Med. Phys. 2019**

Unique Imaging System

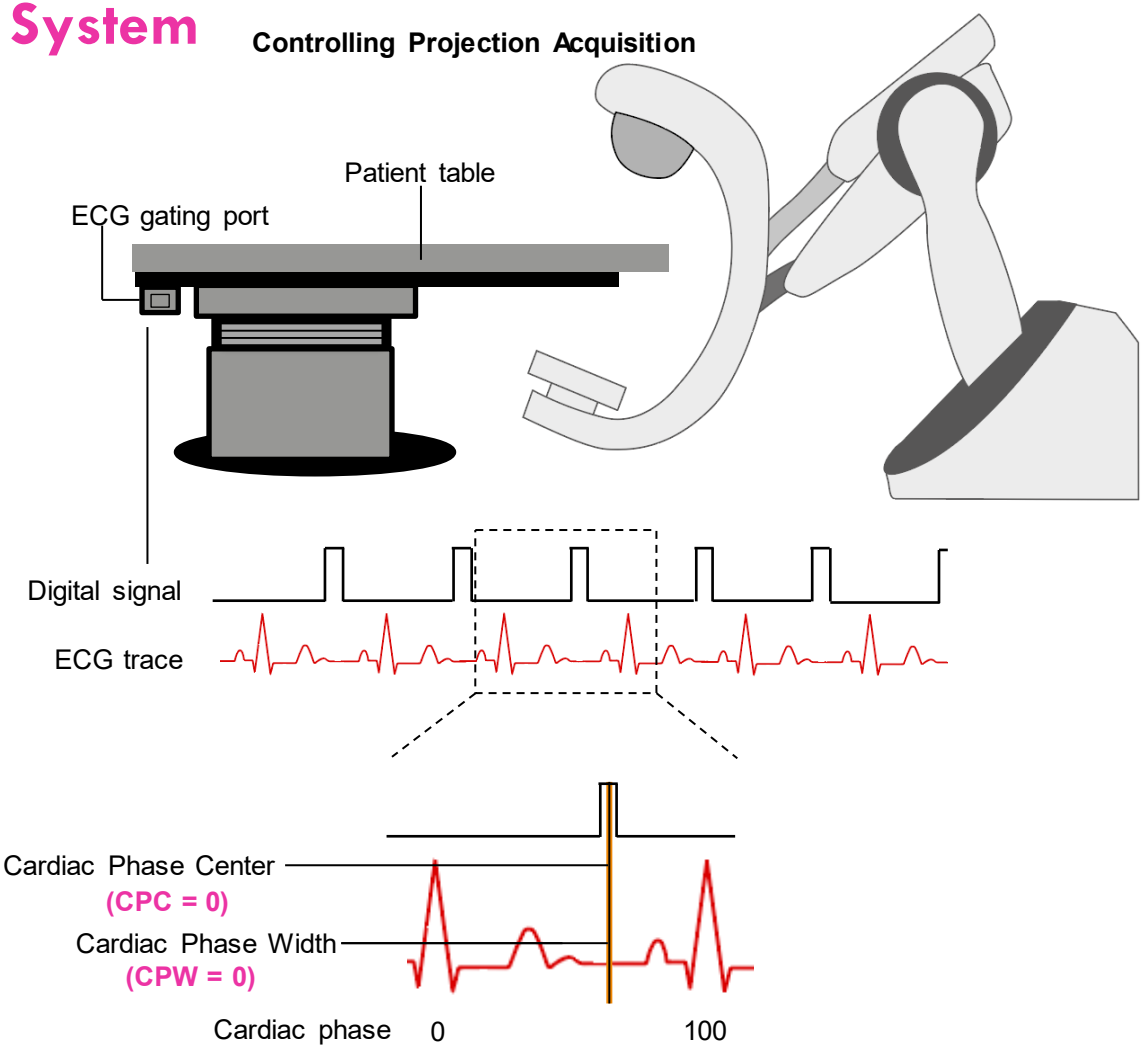
Regulating Gantry Velocity

- Siemens provided access to their **Test Automation Control System (TACS)**, enabling real-time control of the position of the C-arm.
- The TACS allows control of the **Pilot Module** via a C# DLL
- For safety reason, the gantry rotation speed is limited to 20 degrees/s **(normal operational speed is 90 degrees/s)**

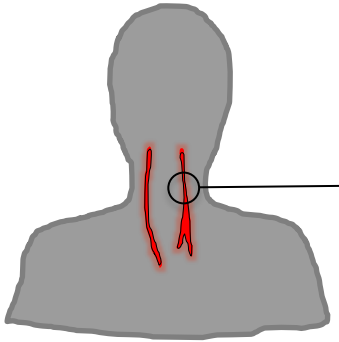
Unique Imaging System



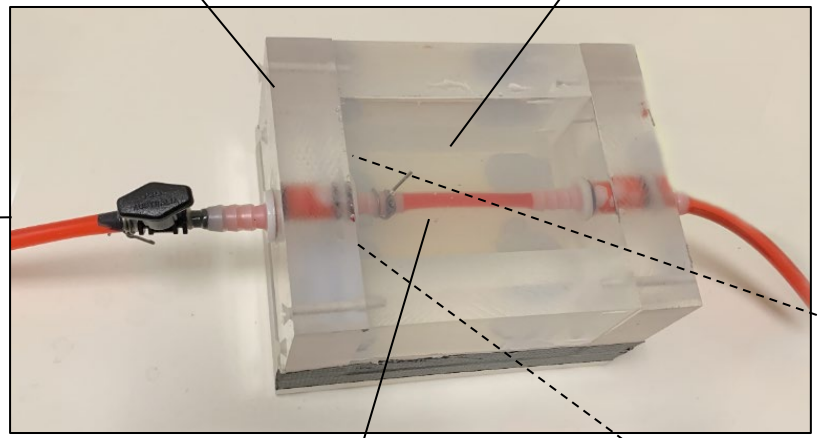
Unique Imaging System

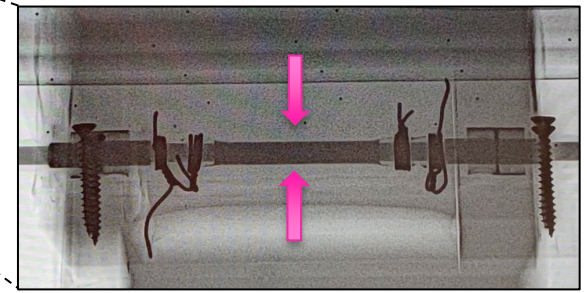


Carotid Artery Imaging

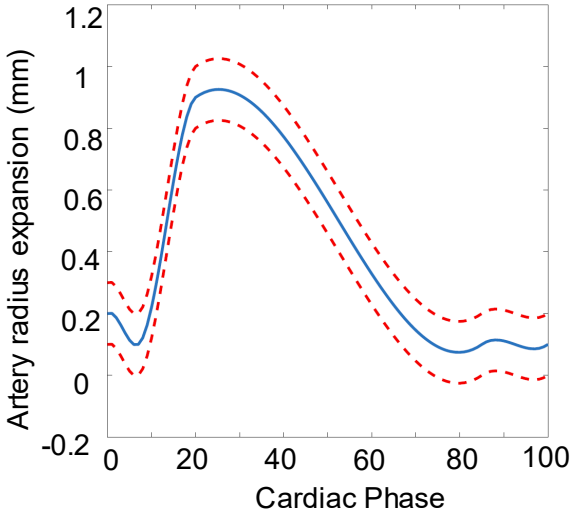


Phantom



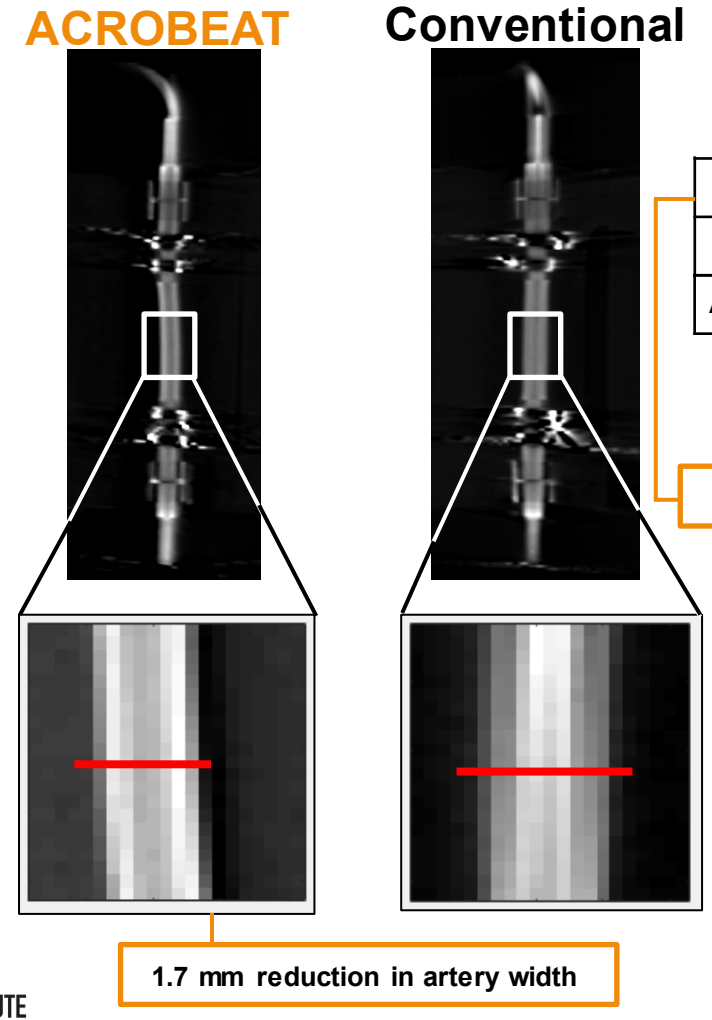


2D fluoroscopic images



Full details: T. Reynolds, O. Dillon, J. Prinable, B. Whelan, P.J. Keall, and R. T. O'Brien (2020), **Toward improved 3D carotid artery imaging with Adaptive CaRdiac cOne BEAm computed Tomography (ACROBEAT)**. Med. Phys., 47: 5749-5760

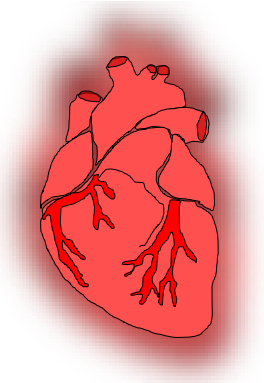
Results



	56 bpm trace	
	ACROBEAT	Conventional
# of projections	100	248
Scan time (s)	103.2	4
Artery width (mm)	8.7	10.4

Heart Imaging

Cardiac motion: heart imaging

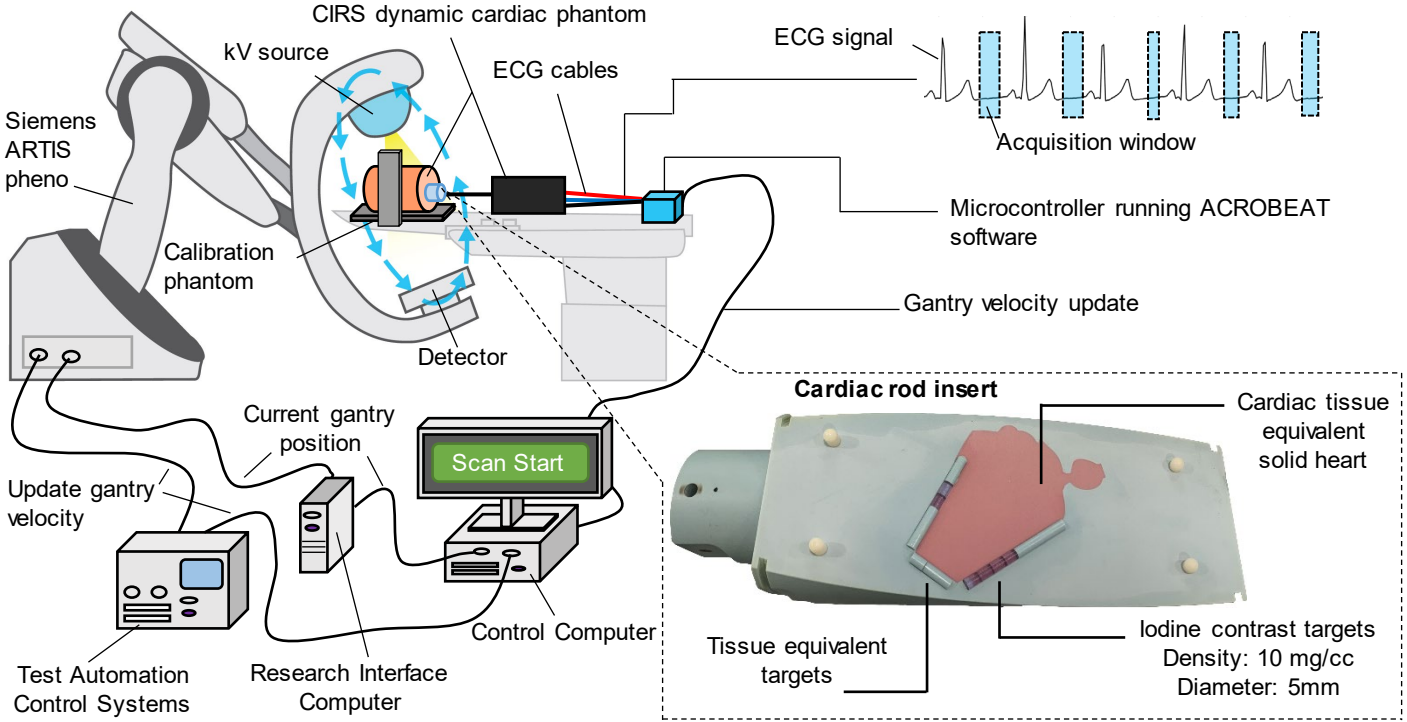


Changes to the experimental setup:

- Projection acquisition
- Phantom
- Number of ECG traces

Full details: T. Reynolds, O. Dillon, J. Prinable, B. Whelan, P.J. Keall, and R. T. O'Brien (2021), **Adaptive CaRdiac cOne BEAm computed Tomography (ACROBEAT): Developing the next generation of cardiac cone beam CT imaging.** Med. Phys. (early view online)

Experimental setup

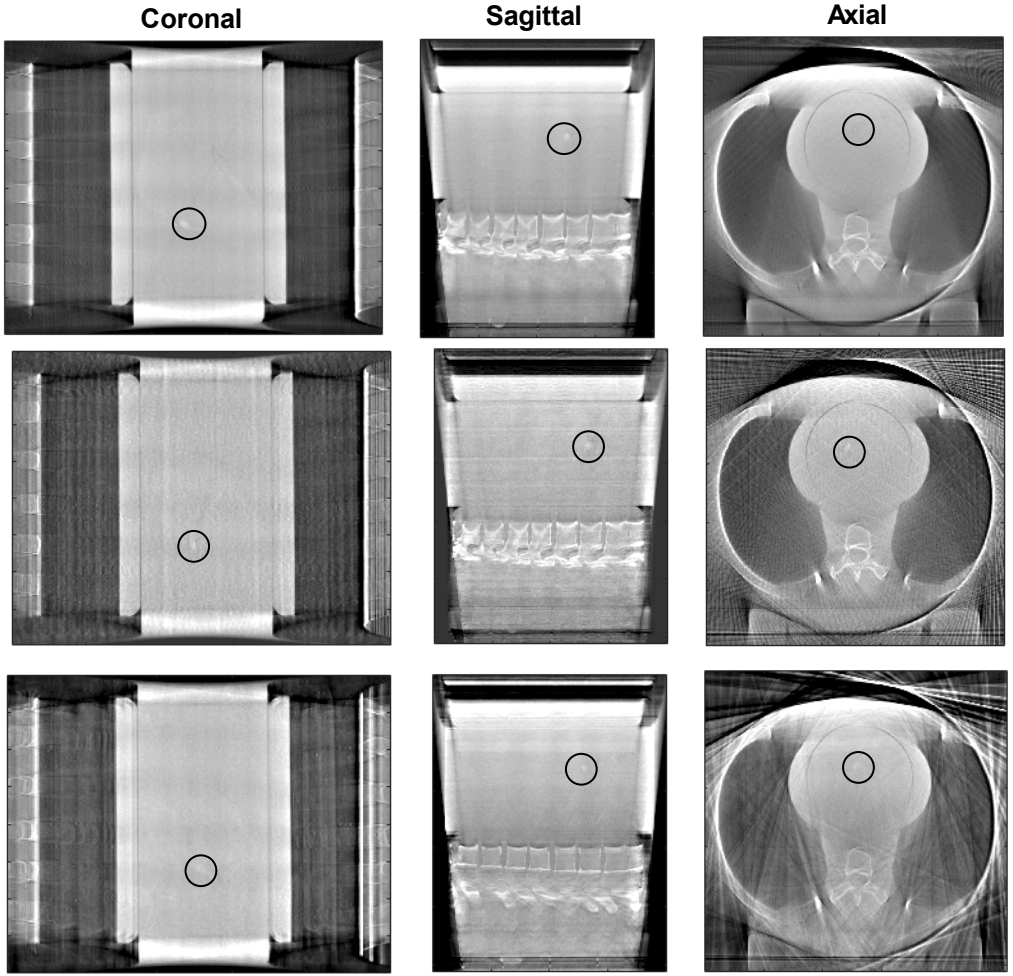


Results

Ground Truth
248 projections

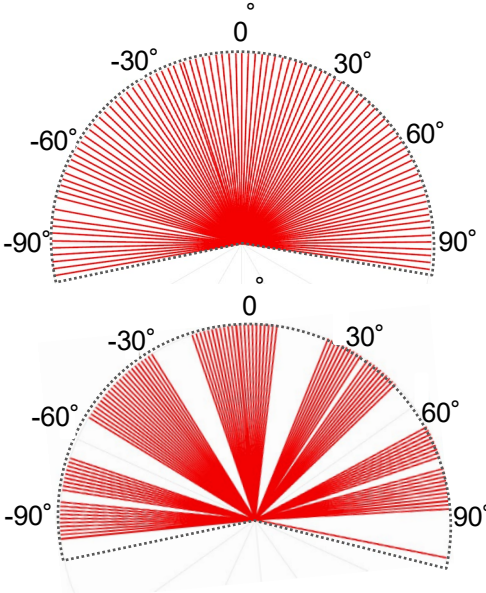
ACROBEAT
100 projections

Conventional
992 projections



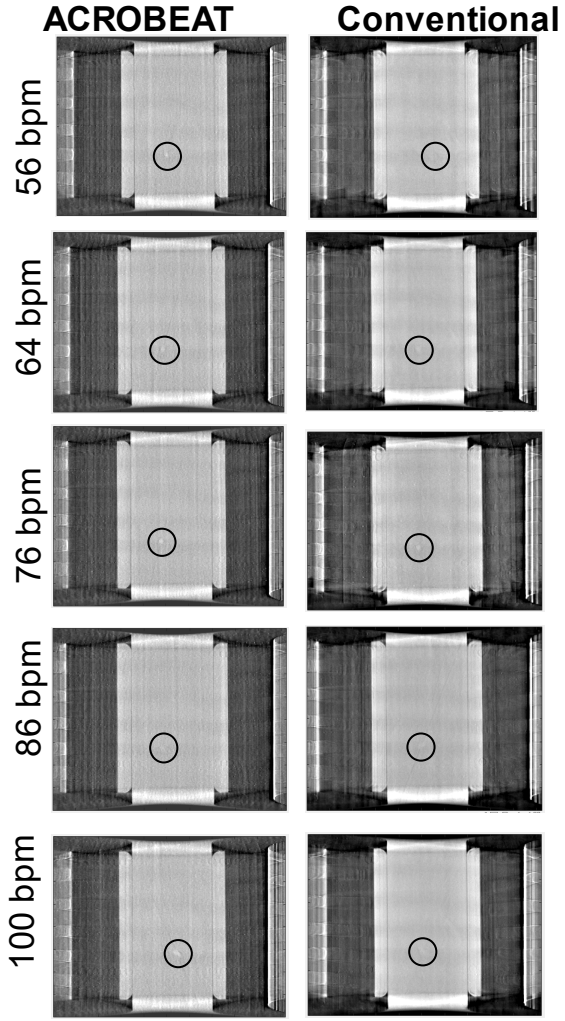
Projection location

Mean angular separation: 2.12°
Angular sep. variance: 0.07°

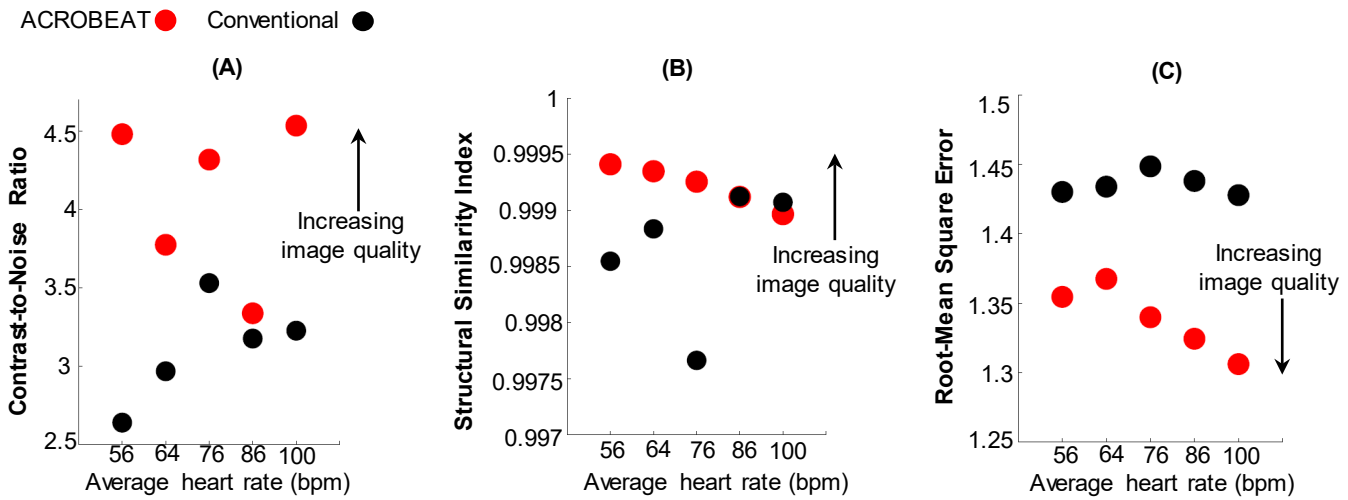


Mean angular separation: 1.39°
Angular sep. variance: 5.01°

Results



Results

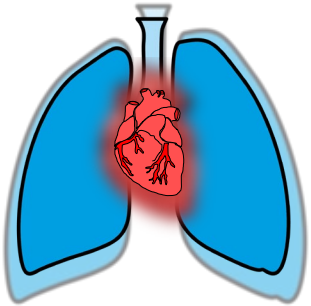

ACROBEAT
Conventional
(A)
Contrast-to-Noise Ratio
4.5
4
3.5
3
2.5
Increasing image quality
56 64 76 86 100
Average heart rate (bpm)
(B)
Structural Similarity Index
1
0.9995
0.999
0.9985
0.998
0.9975
0.997
Increasing image quality
56 64 76 86 100
Average heart rate (bpm)
(C)
Root-Mean Square Error
1.5
1.45
1.4
1.35
1.3
1.25
Increasing image quality
56 64 76 86 100
Average heart rate (bpm)

Results

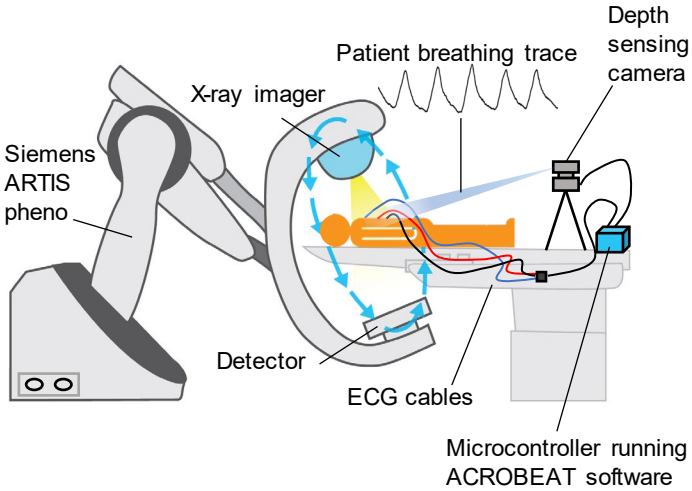
Total scan time (s)	
ACROBEAT	Conventional
103.1	26.6
94.0	25.7
79.9	25.7
74.9	25.8
61.5	25.9

Heart Imaging

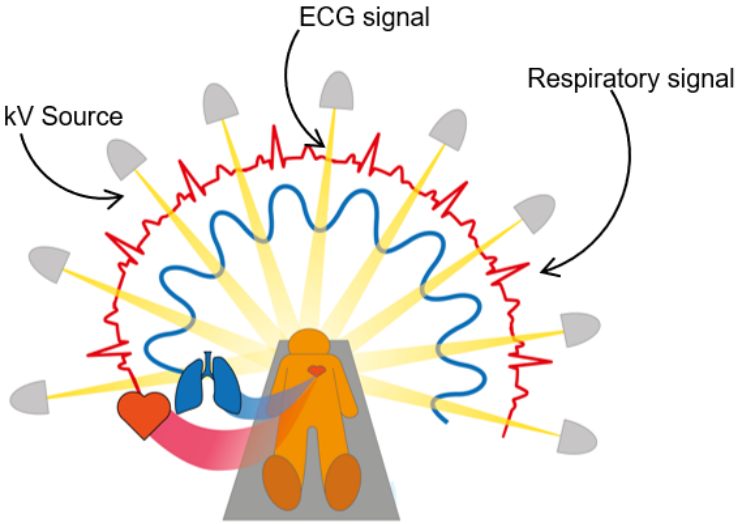
Cardiac and respiratory motion: heart imaging



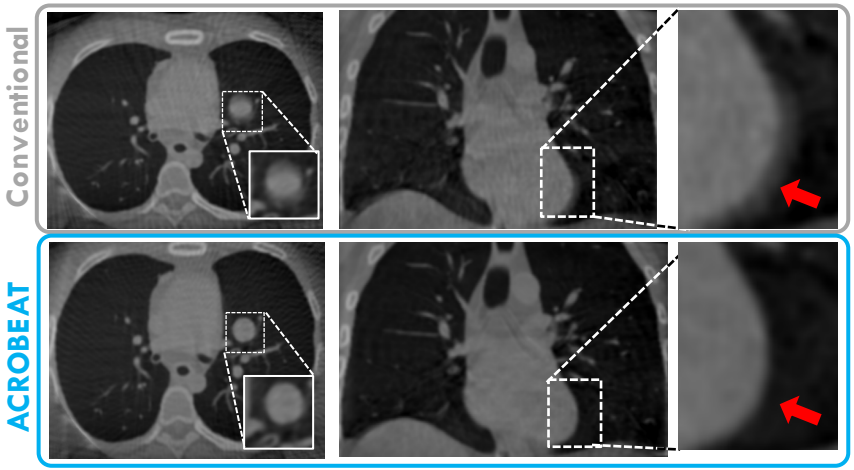
Changes to the experimental setup:



Dual respiratory and cardiac imaging



KEY SIMULATION RESULTS:



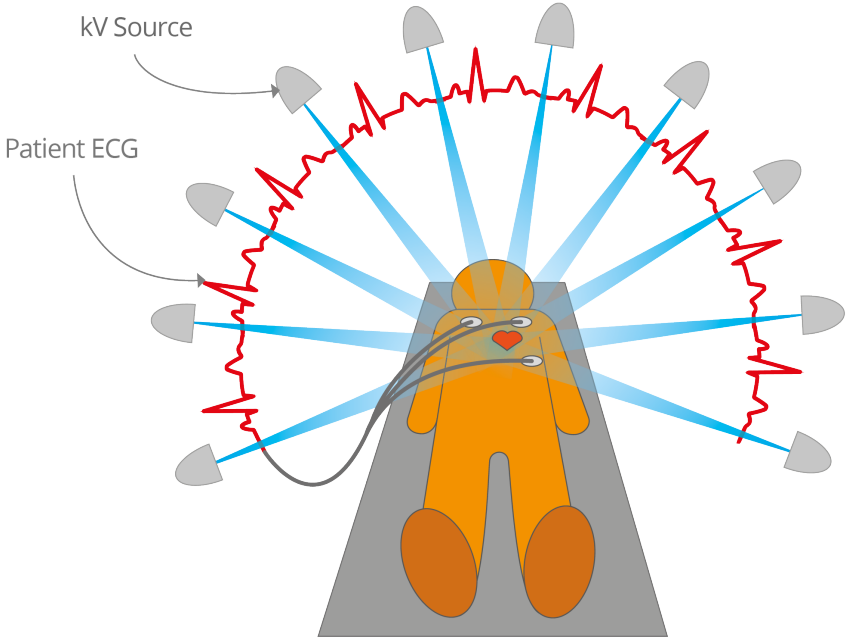
Reduction in imaging dose:
93%

Reduction in scan time:
17%

Flexible imaging:
- Cardiac gated
- Respiratory gated
- Full 5D

Possible applications:
- Radiotherapy
- Cardiac radio-ablation
- Interventional procedures

Motion Compensation Reconstruction



The patient's ECG signal is used to adapt the gantry velocity and projection time interval in real time

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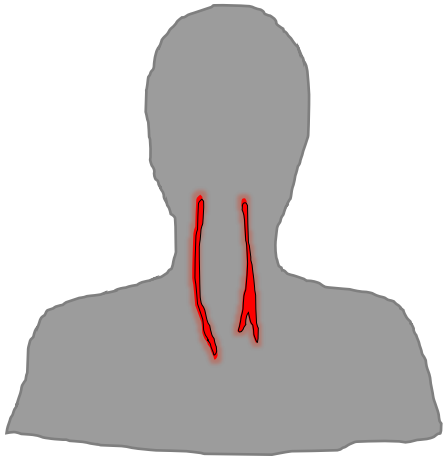
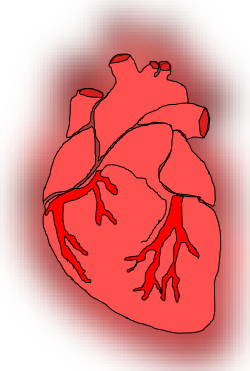
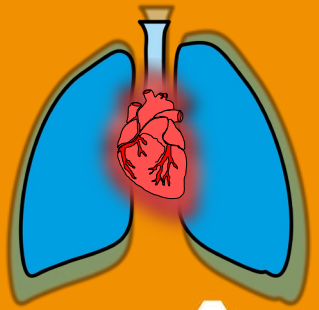
Cardiac Pulsing: artery imaging



Cardiac motion: heart imaging



Cardiac and respiratory motion: heart imaging



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