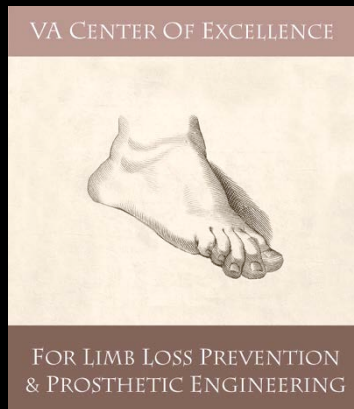




# Development of a biplane fluoroscope at the VA Puget Sound

William R. Ledoux, Joseph M. Iaquinto,  
Richard Tsai, Bruce Sangeorzan, Grant  
Marchelli, Matthew Kindig, Eric Thorhauer,  
Duane Storti, and David Haynor



RR&D Center of Excellence for Limb Loss  
Prevention and Prosthetic Engineering,  
VA Puget Sound

Departments of Mechanical Engineering,  
Radiology, Orthopaedics & Sports Medicine,  
University of Washington

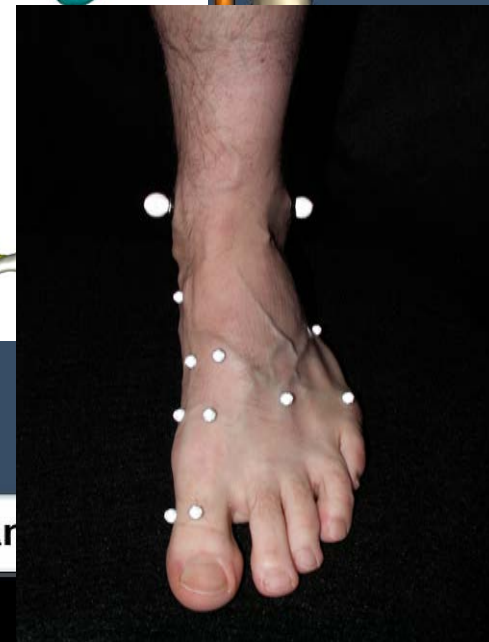
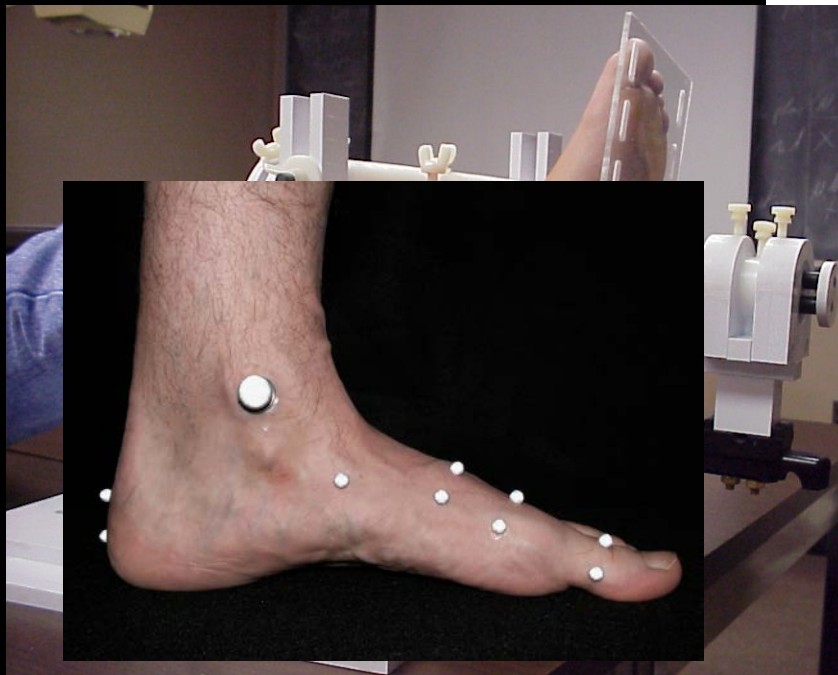




# Motivation for biplane fluoroscopy development

- CT
- MRI

Elshinbarka WE, et al., J Orthop Res, 24, 2006  
Engineering, 133, 2011





# Bone pins

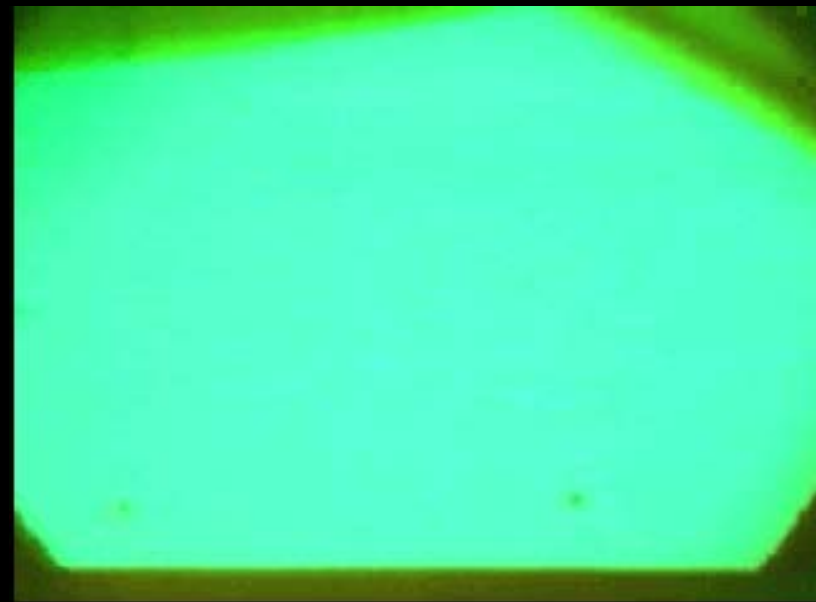
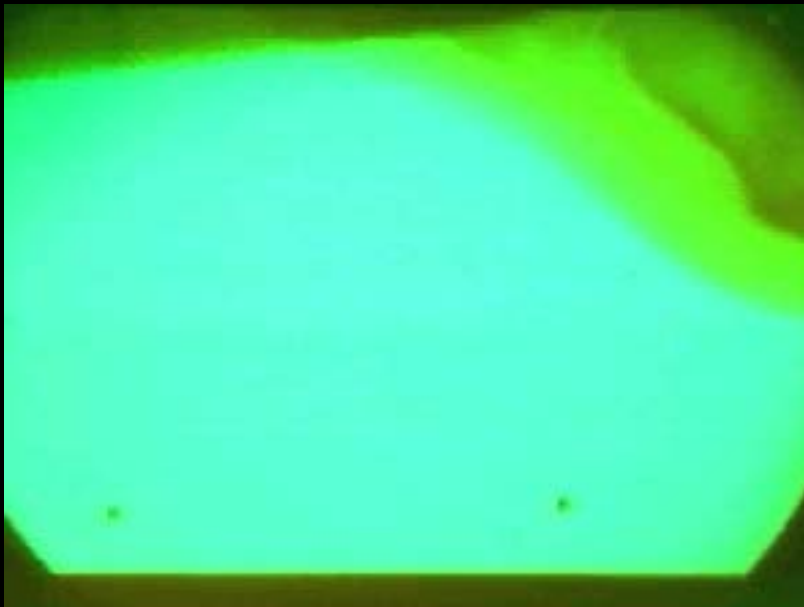


Arndt et al., 2007

Invasive; not used for routine clinical care



# Fluoroscopy systems



De Clercq et al., 1994

Single plane; exposure to radiation



# Fluoroscopy systems

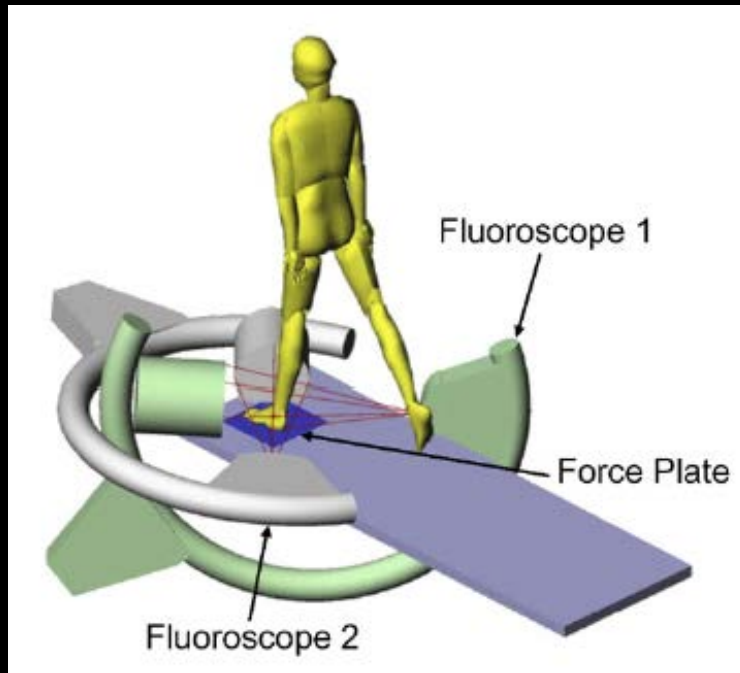


Yamaguchi et al., 2009

hindfoot only; exposure to radiation; 3D-2D



# Fluoroscopy systems



Li et al., 2008



Caputo et al., 2009

Portion of stance; exposure to radiation





# Biplane fluoroscopy

- Custom biplane room too expensive
  - Henry Ford Hospital, U Pittsburgh, Brown
- C-arms
  - Mass General Hospital, Duke
- Modify existing C-arms
  - Steadman-Philippon Research Institute
- Hardware:
  - Two Philips BV-Pulsera C-arms
- Software:
  - Customized



# Biplane fluoroscopy







# Biplane fluoroscopy



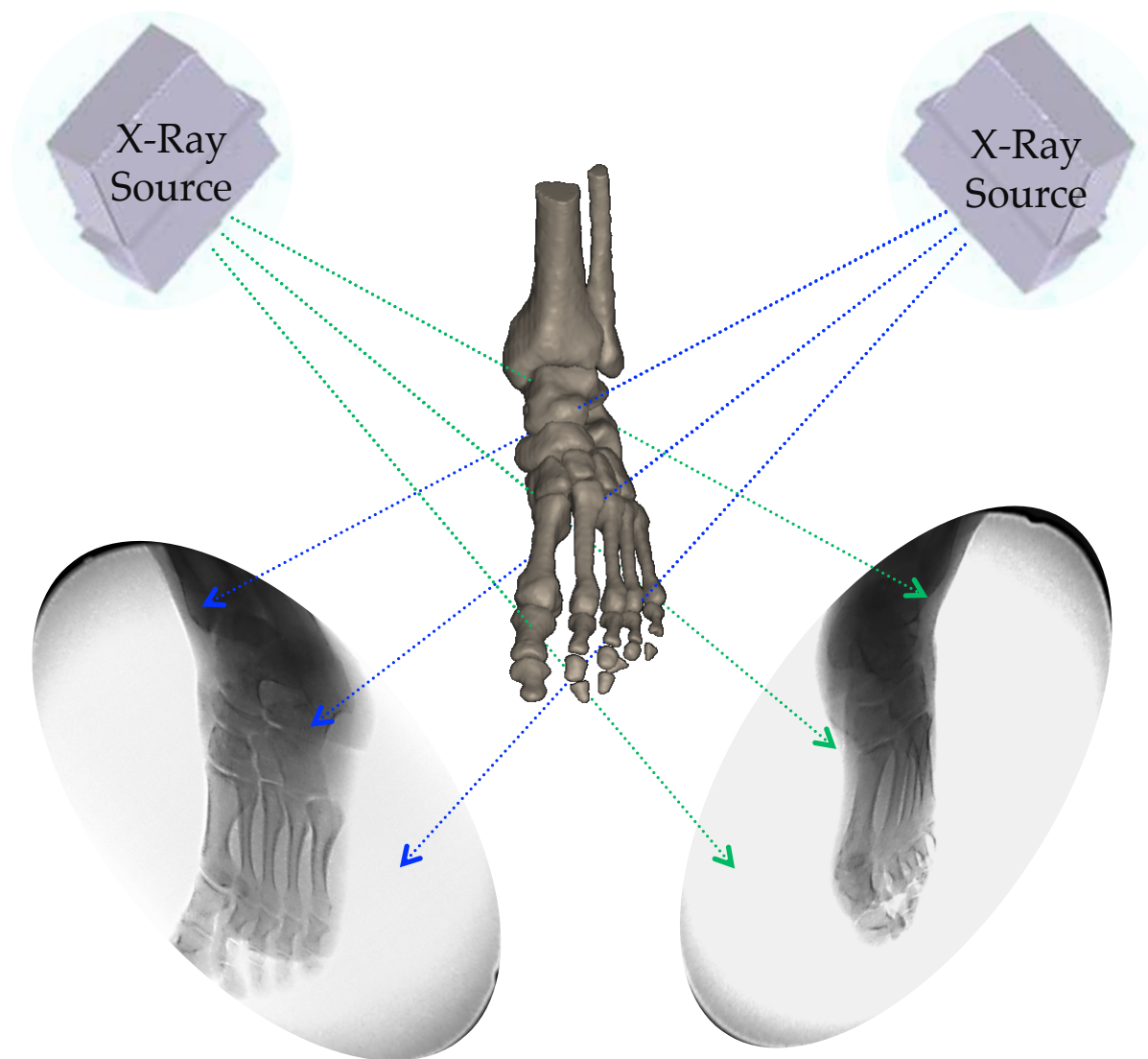


# Biplane fluoroscopy





# Biplane fluoroscopy







# Foot phantom



[www.phantomlab.com](http://www.phantomlab.com)

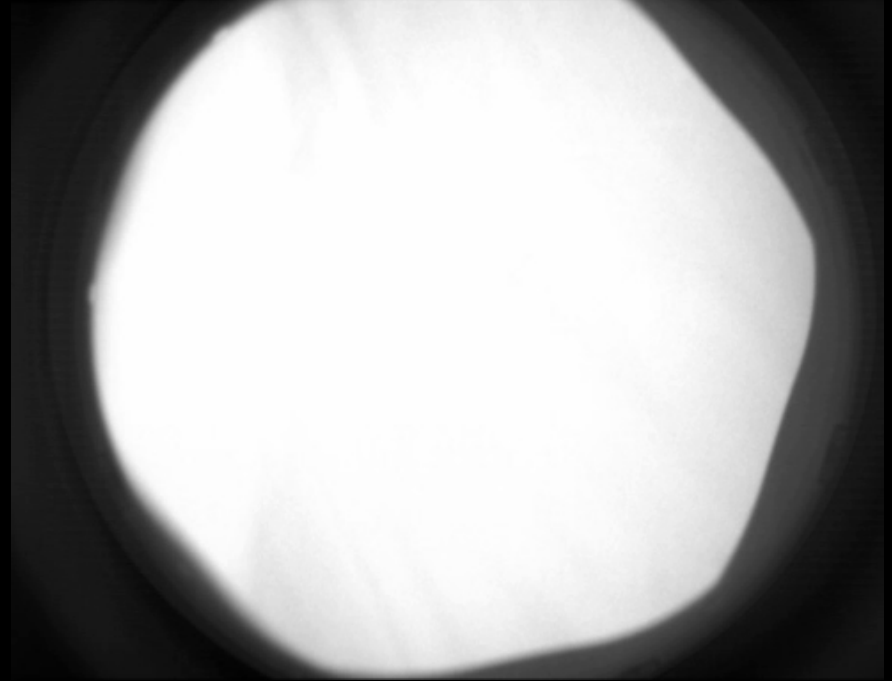
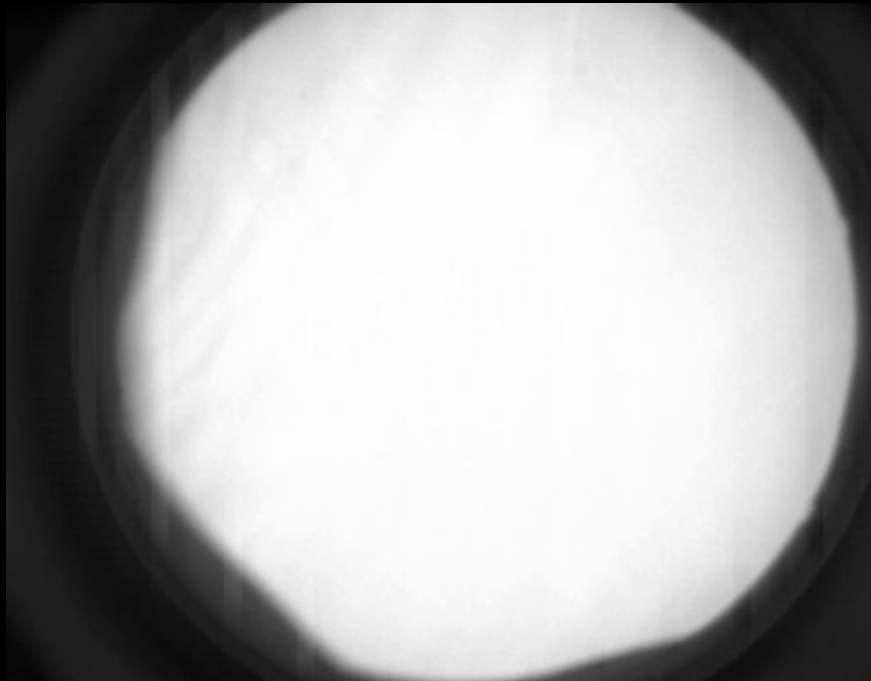


# Dynamic data collection





# Biplane fluoroscopy







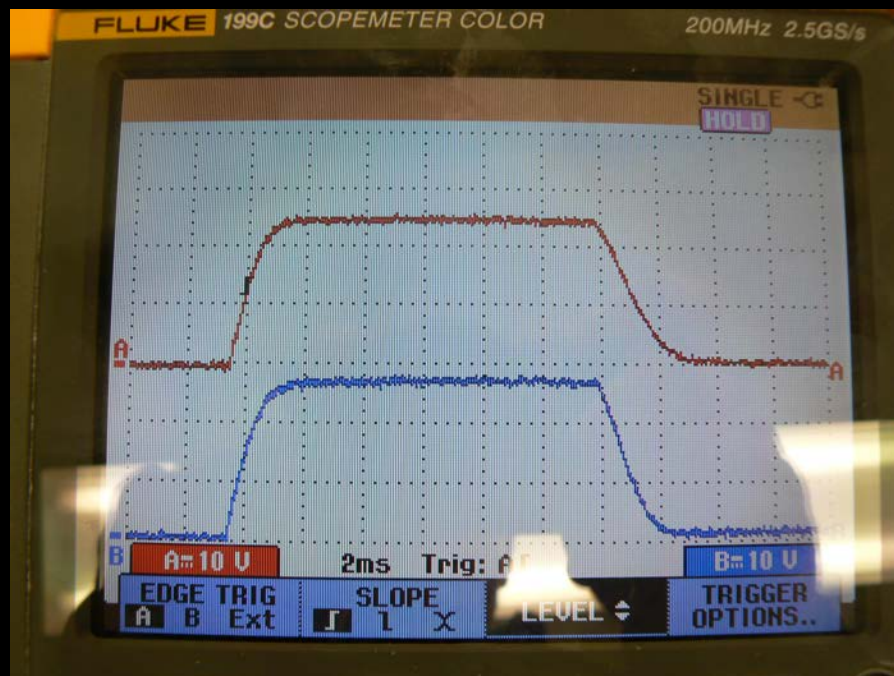
# Philips BV Pulsera C-Arms

- Typical hospital C-arm
- 30 pulses / s or continuous



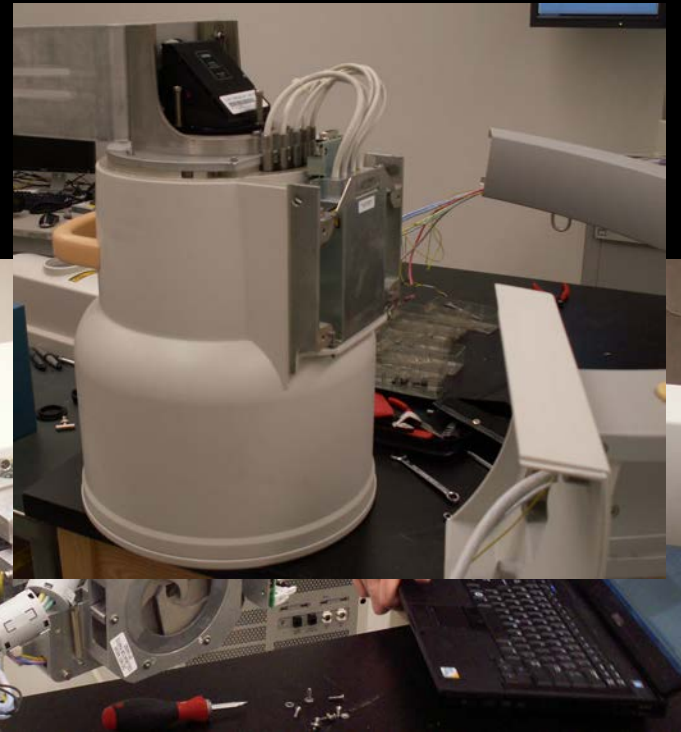
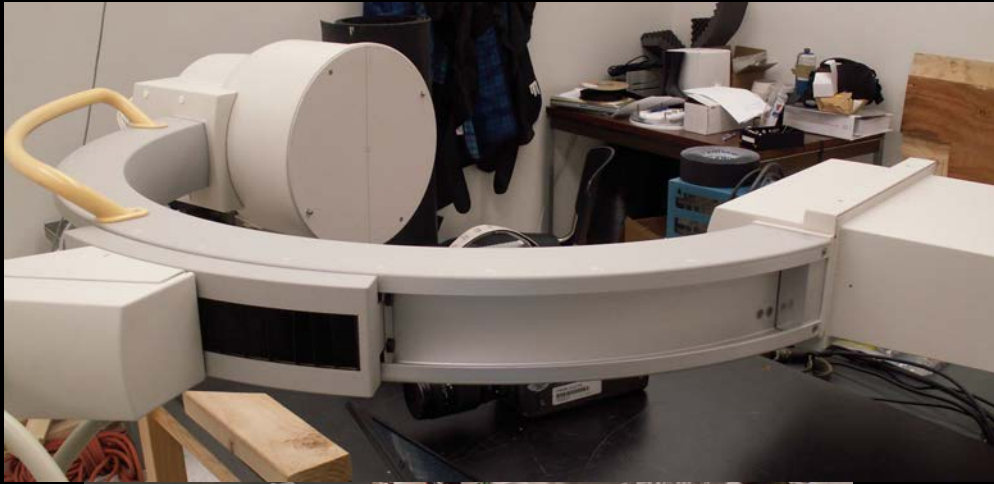


# Synchronizing systems





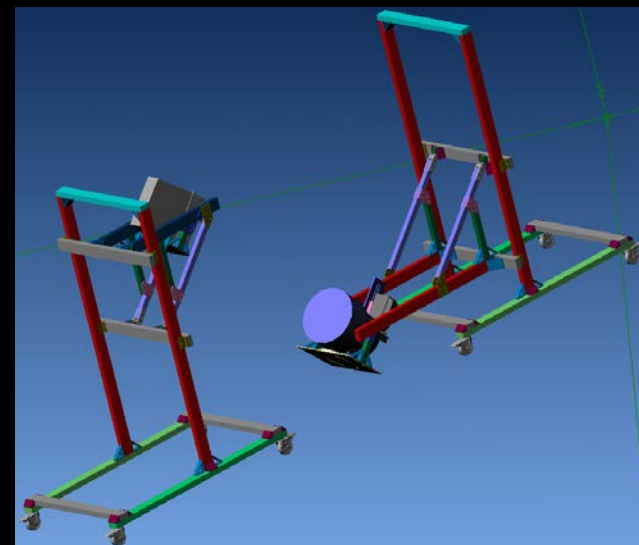
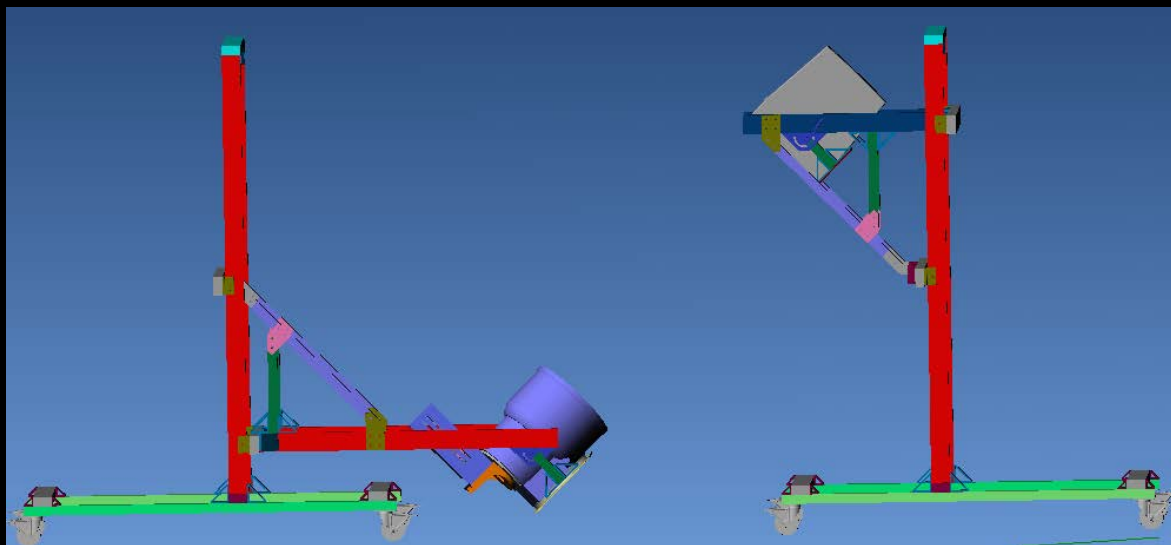
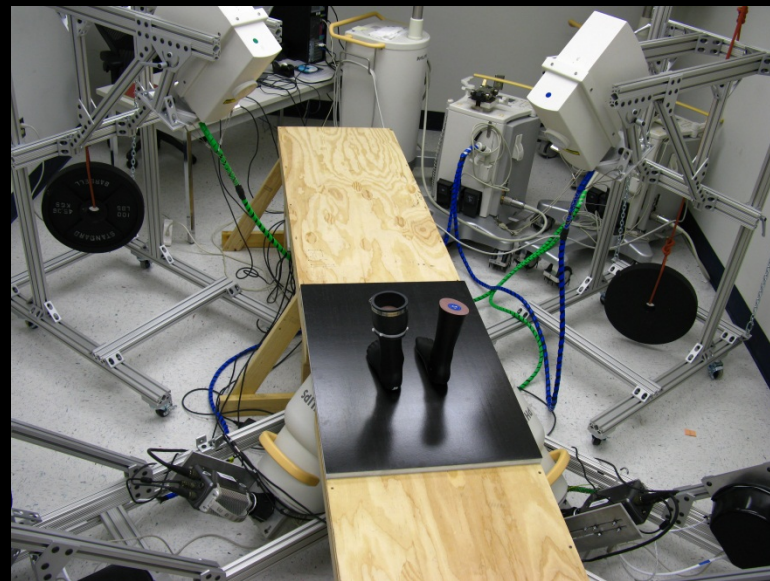
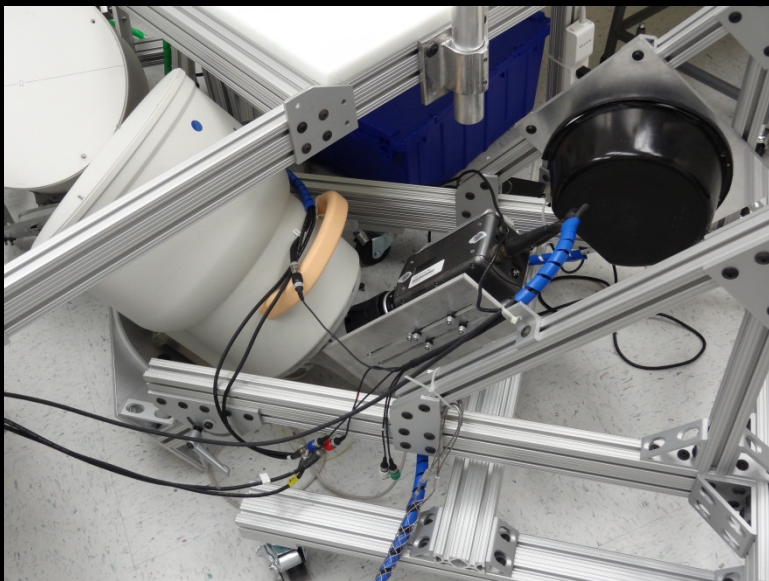
# Disassembling C-arms





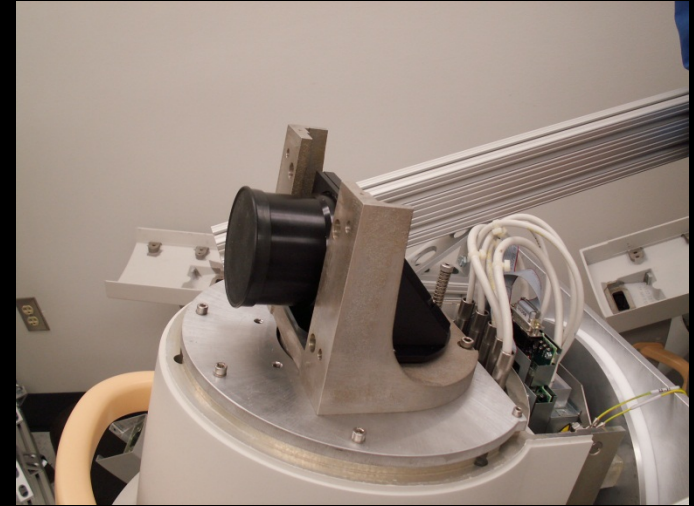
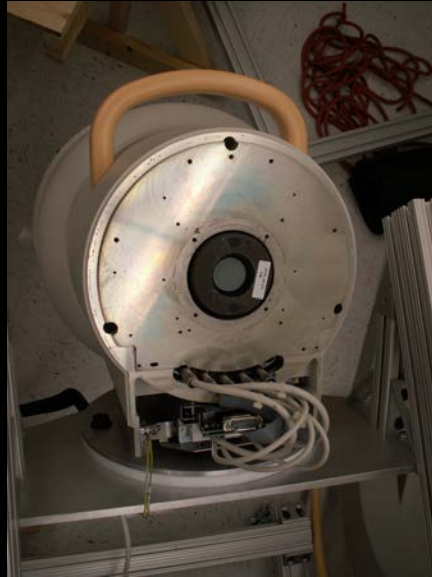
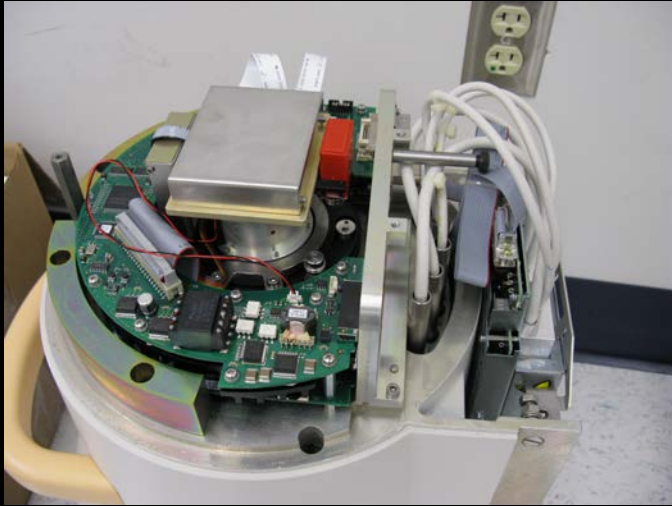


# Custom mounting devices





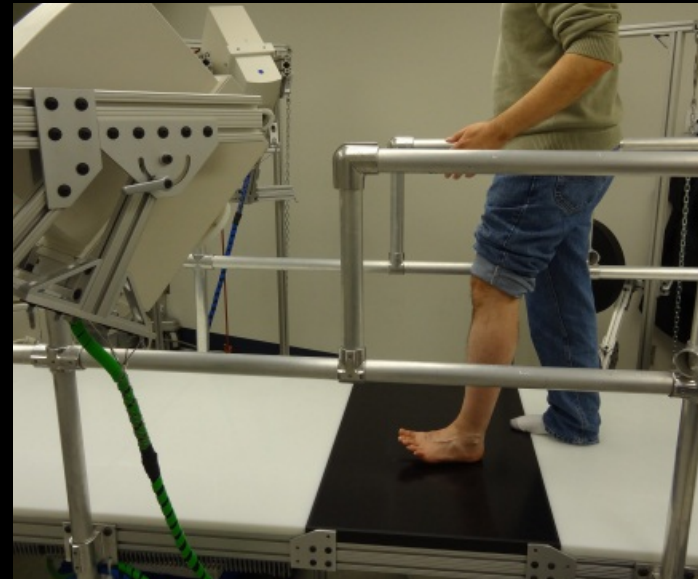
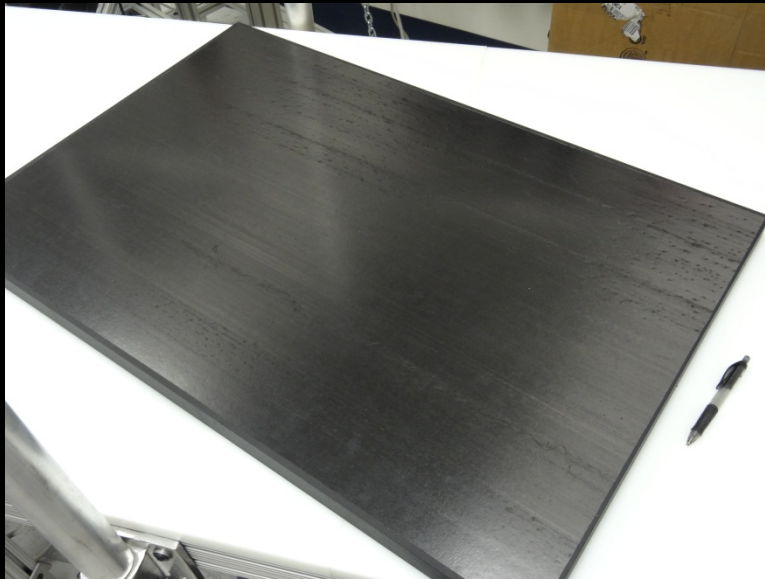
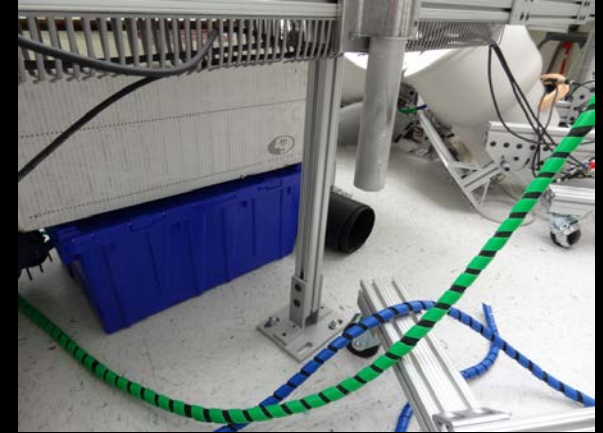
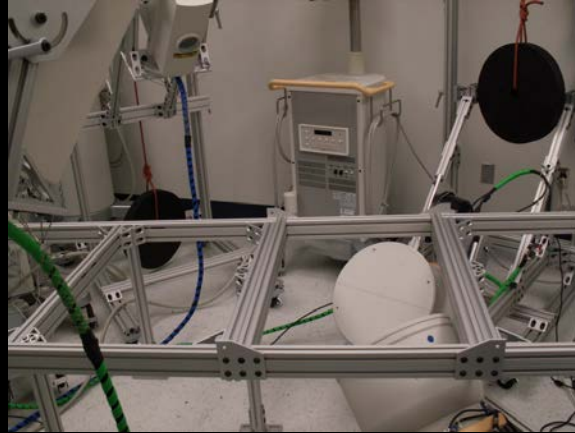
# Replacing cameras







# Final floor





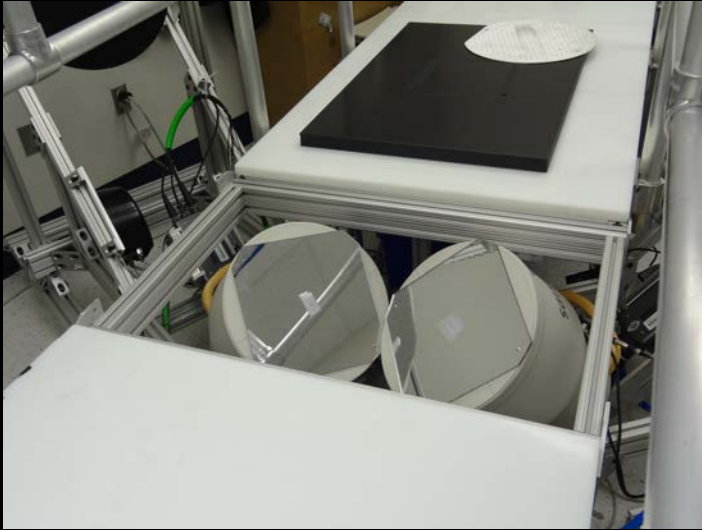


# Light sabers?





# Laser alignment





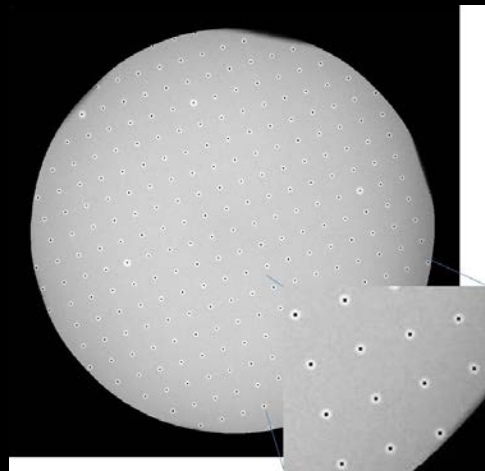
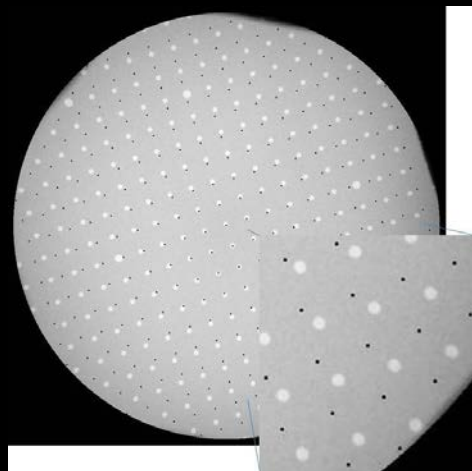
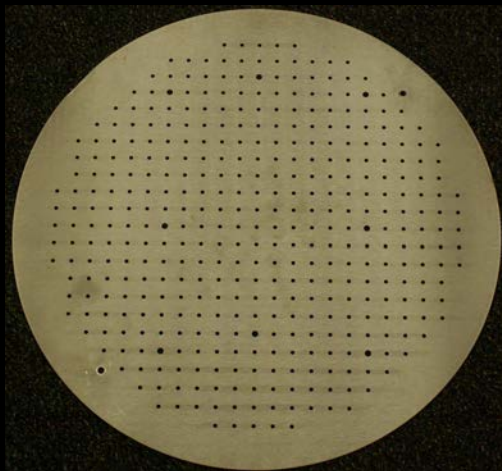
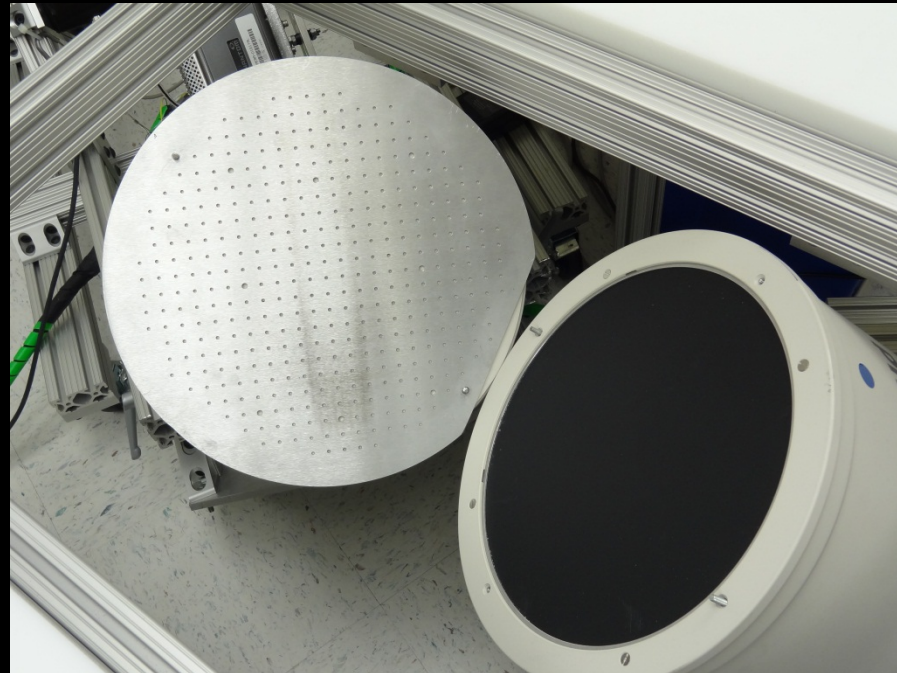
# Customized software

- Matlab, C/C++, CUDA
- Phase I: distortion and bias correction, 3D calibration
- Phase II: generation of digital reconstructed radiographs (DRRs)
- Phase III: implementation of similarity measures and comparison methods
- Phase IV: speed and memory optimization



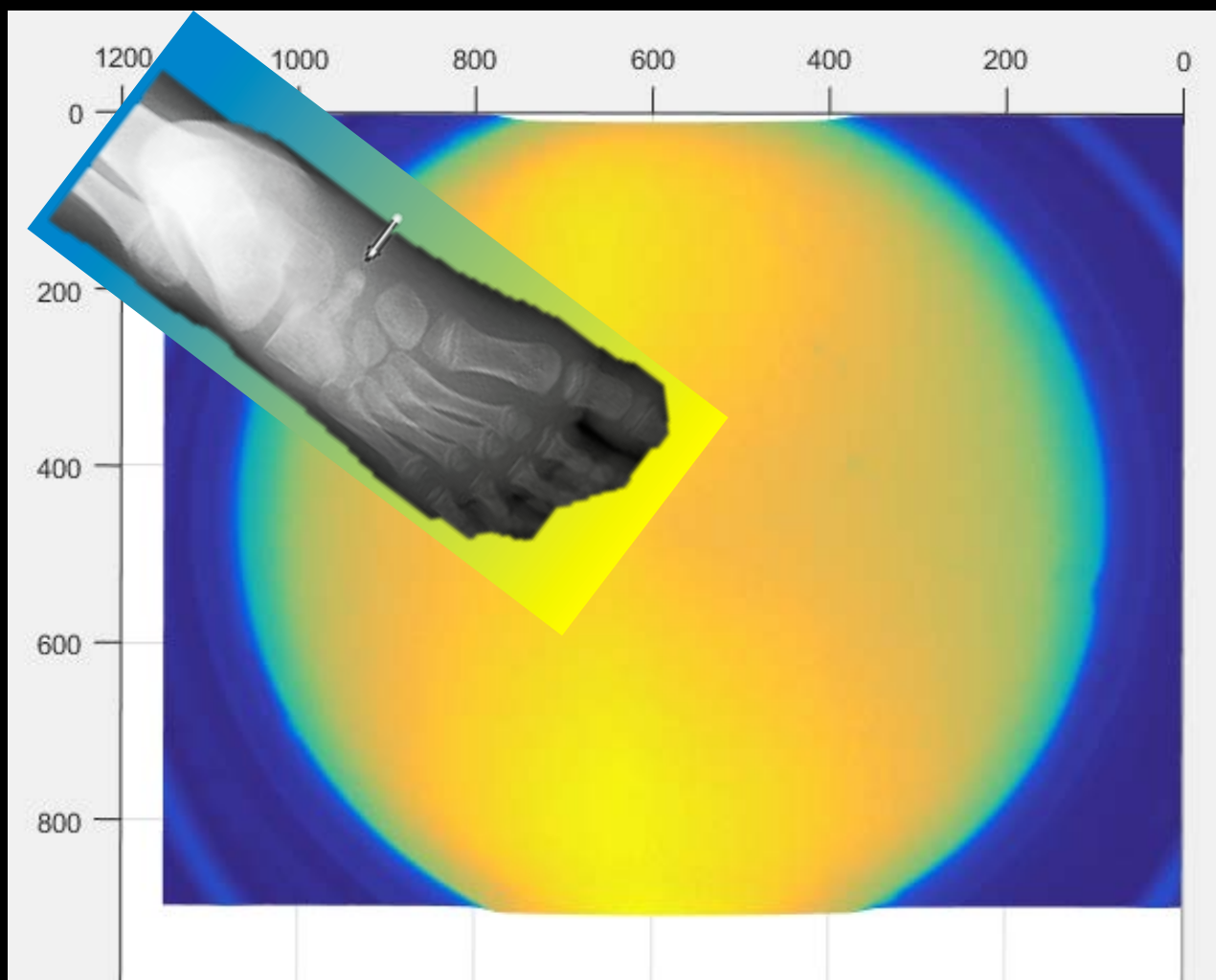


# Distortion correction



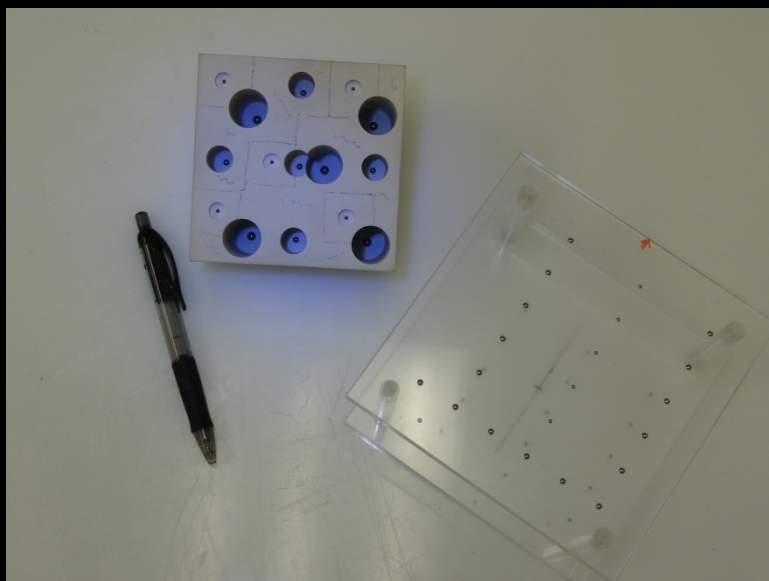


# Flat-field correction





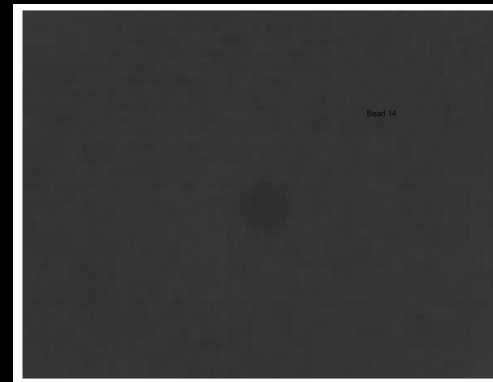
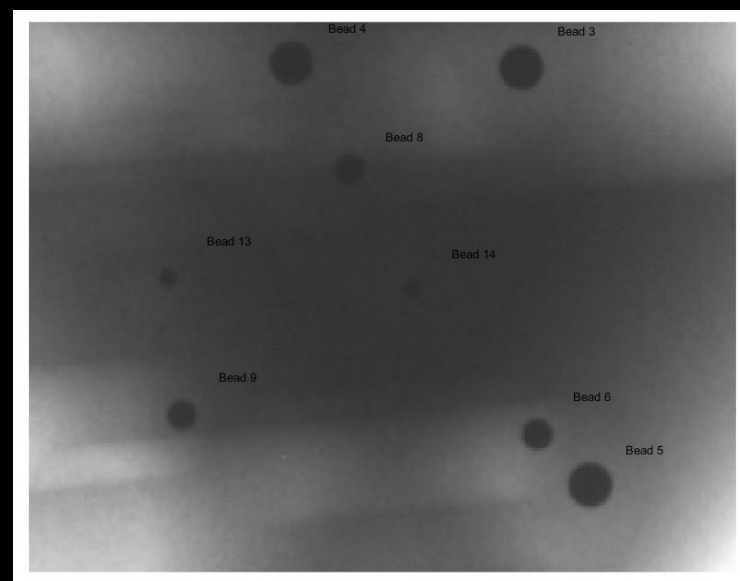
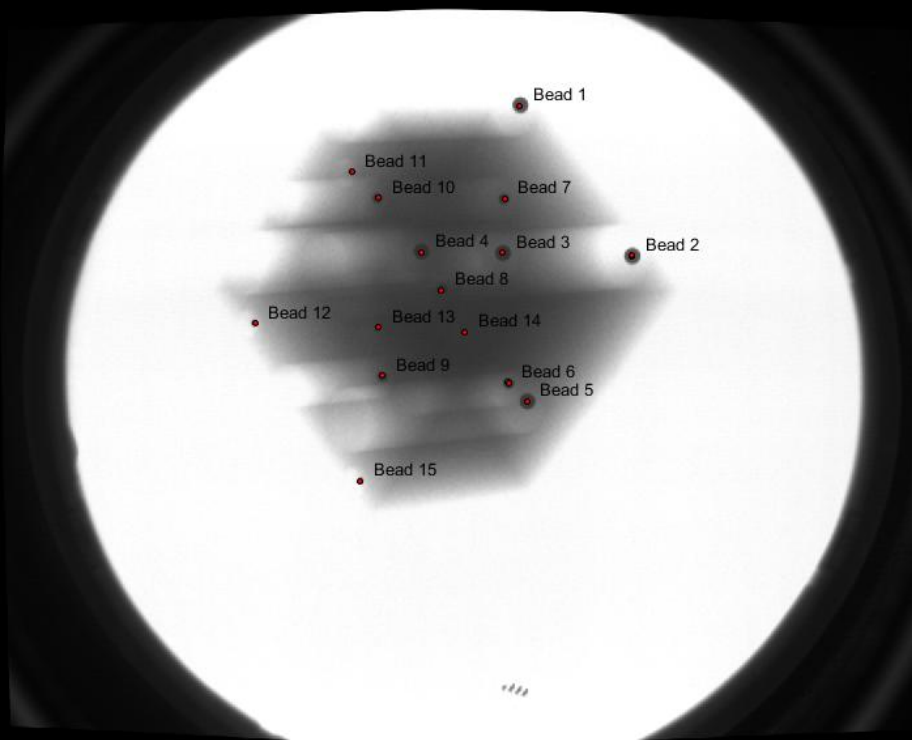
# 3D Calibration







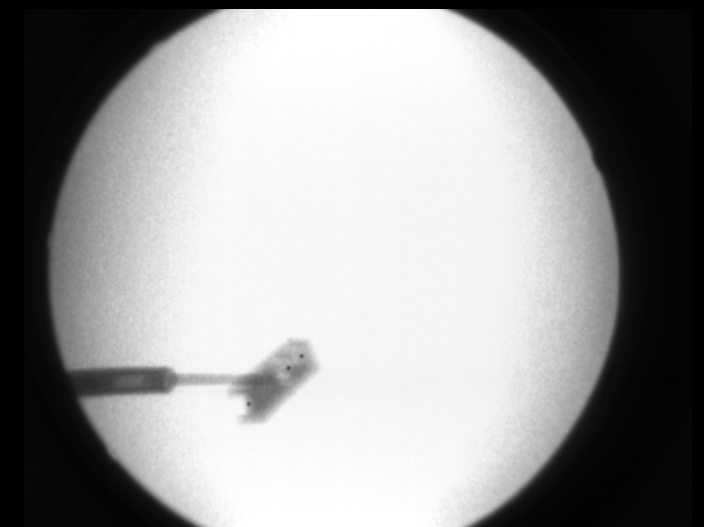
# 3D calibration revised





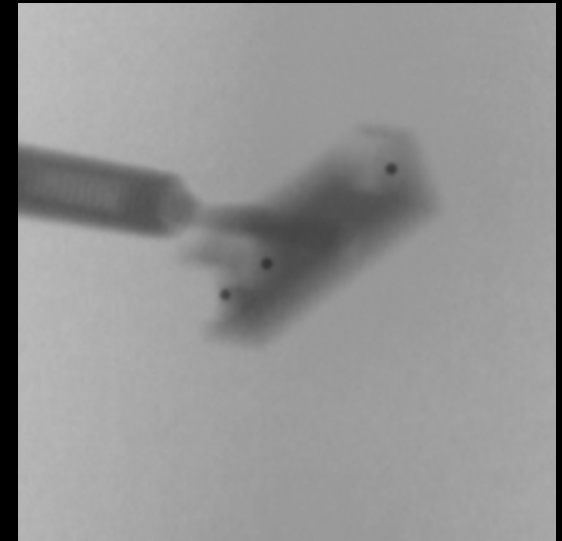
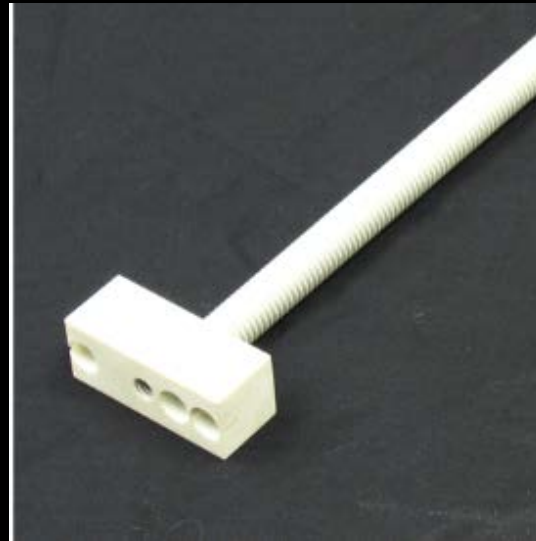
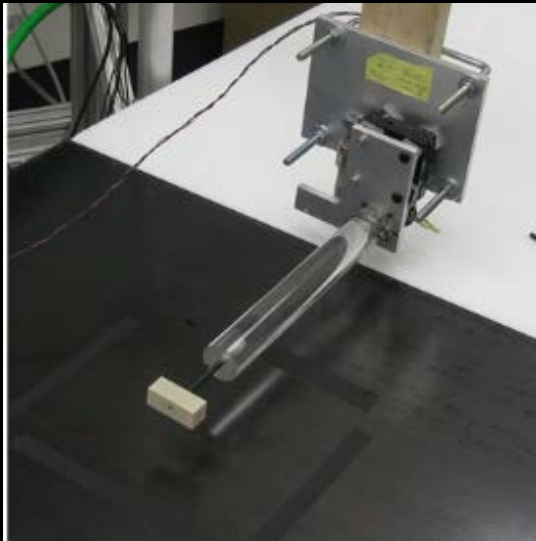
# Validation: Bead-based

- Machined block or “wand”
  - 1.6mm tantalum beads
  - measured within 7 microns
- Wand translated and rotated via a 1 micron precision stepper-motor (static testing)
- Wand manually waved though FOV at  $\sim 0.5\text{m/s}$  (dynamic testing)





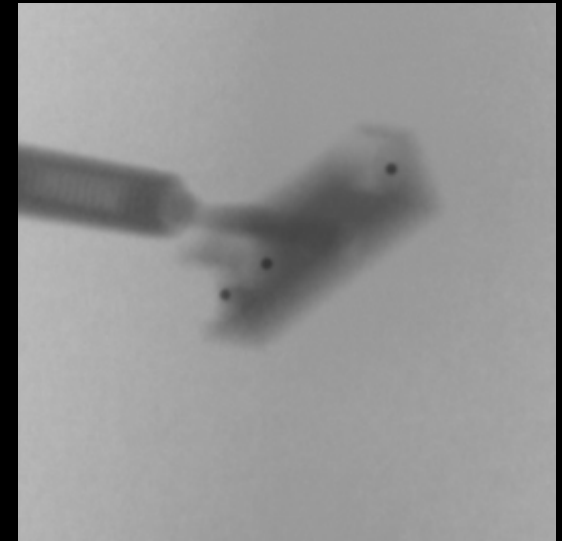
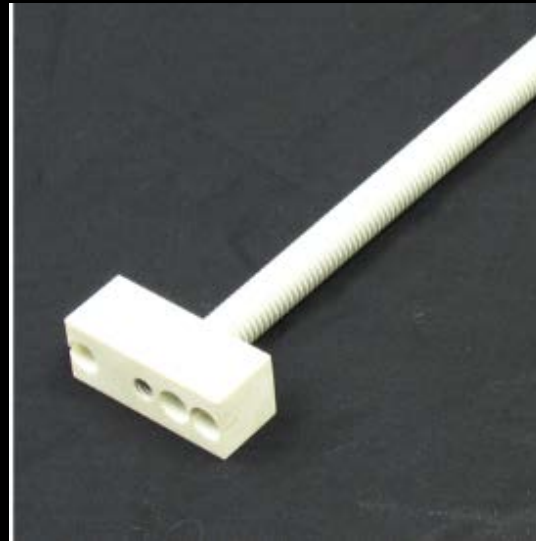
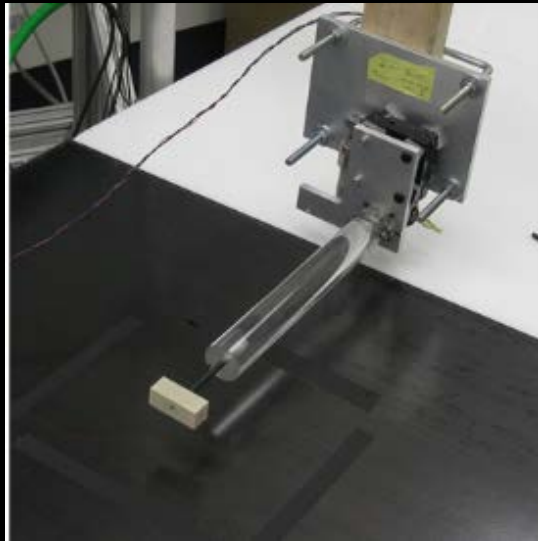
# Validation: Bead-based, Static



- Average translational accuracy = 0.0811 mm
- Average translational precision =  $\pm 0.0103$  mm
- Average rotational accuracy =  $0.1541^\circ$
- Average rotation precision =  $\pm 0.1382^\circ$



# Validation: Bead-based, Dynamic

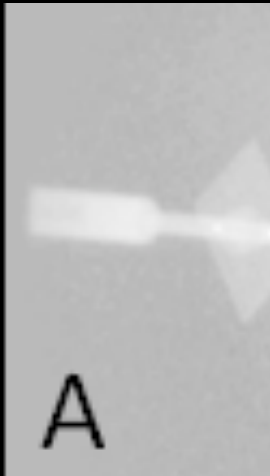


- Average accuracy = 0.1260 mm
- Average precision =  $\pm 0.1218$  mm



# Validation: Bone-based

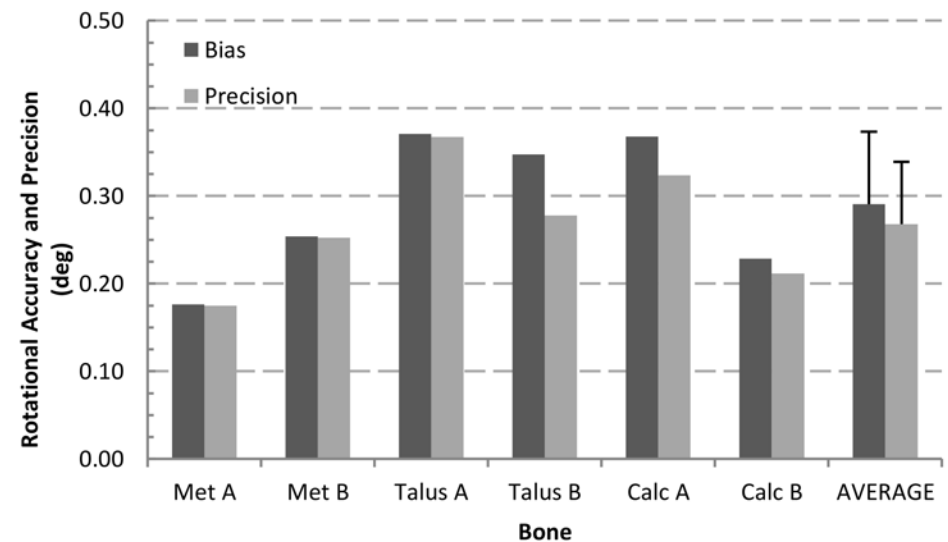
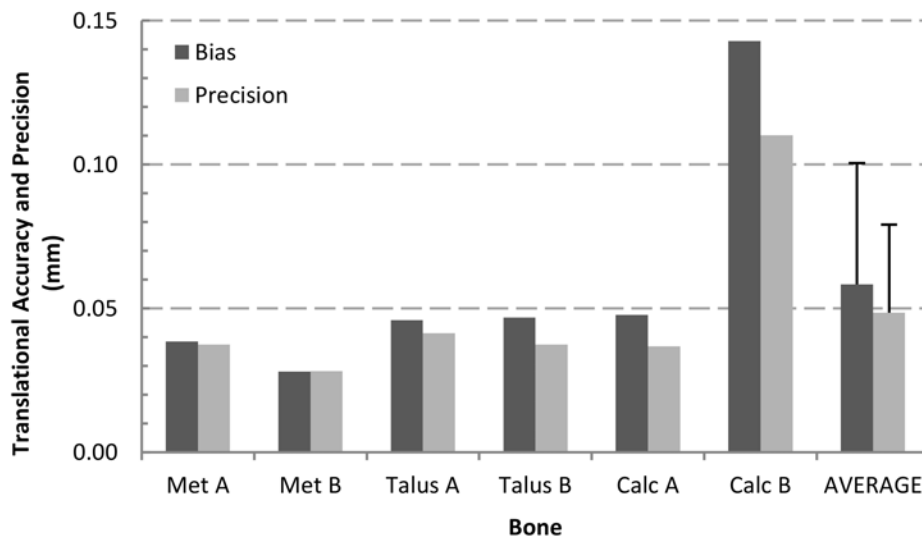
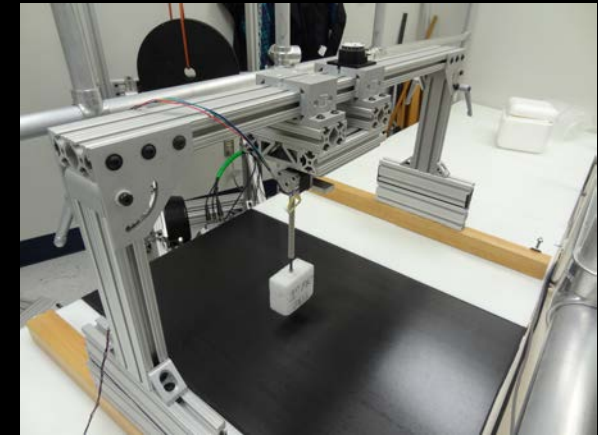
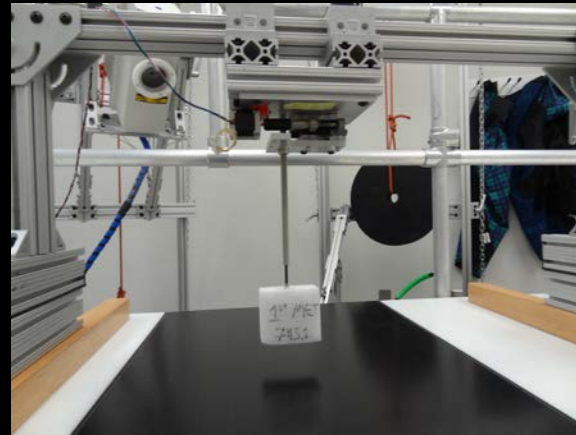
- Bones in foam block
  - 1.6mm tantalum beads
- Block translated and rotated via a 1 micron precision
- Block moved at  $\sim 1$  m/s







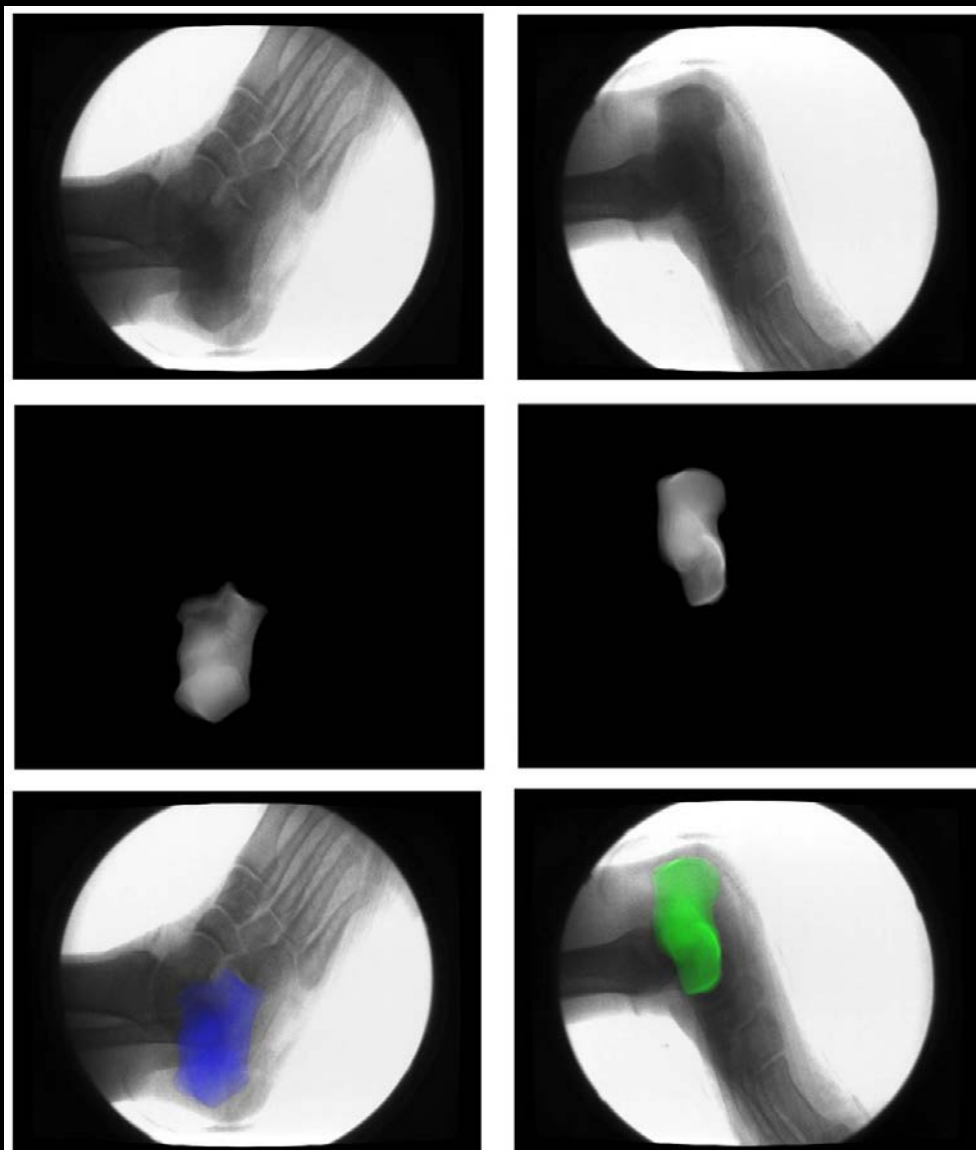
# Validation: Bone-based, Static







# Sample DRR





# GUI: unoptimized

Figure 1

File

Import Positioning Optimization Bead Tracking

Current Pose

	Angle (deg)	Translation (mm)
X	82.14	39.25
Y	2.54	117.56
Z	153.19	124.44

Undo Last Pose

Mouse Drag Mode

Translate/Rotate

Select Active Bone

Bone 4 (Calcaneus)

☐ Show Active Bone Surfaces

Select View

Bone View

Optimization Range

Current Frame Only (1)

Start Optimization

NCC Values

Blue Intensity	0.314
Blue Gradient-H	0.096
Blue Gradient-V	0.291
Green Intensity	0.344
Green Gradient-H	0.169
Green Gradient-V	0.243
Weighted	0.243

Frame Number 1 ☐ Keyframe

Previous Keyframe Next Keyframe

1 160

GUI Ready

☒ Display DRR ☒ Display Fluoro



# GUI: optimized

Figure 1

File

Import Positioning Optimization Read Tracking

Current Pose

	Angle (deg)	Translation (mm)
X	91.94	14.61
Y	5.26	111.24
Z	141.82	135.64

Undo Last Pose

Mouse Drag Mode

Translate/Rotate

Select Active Bone

Bone 4 (Calcaneus)

☐ Show Active Bone Surfaces

Select View

Blue Fluoro

Optimization Range

Current Frame Only

Start Optimization

NCC Values

Blue Intensity	0.950
Blue Gradient-H	0.849
Blue Gradient-V	0.838
Green Intensity	0.943
Green Gradient-H	0.834
Green Gradient-V	0.808
Weighted	0.870

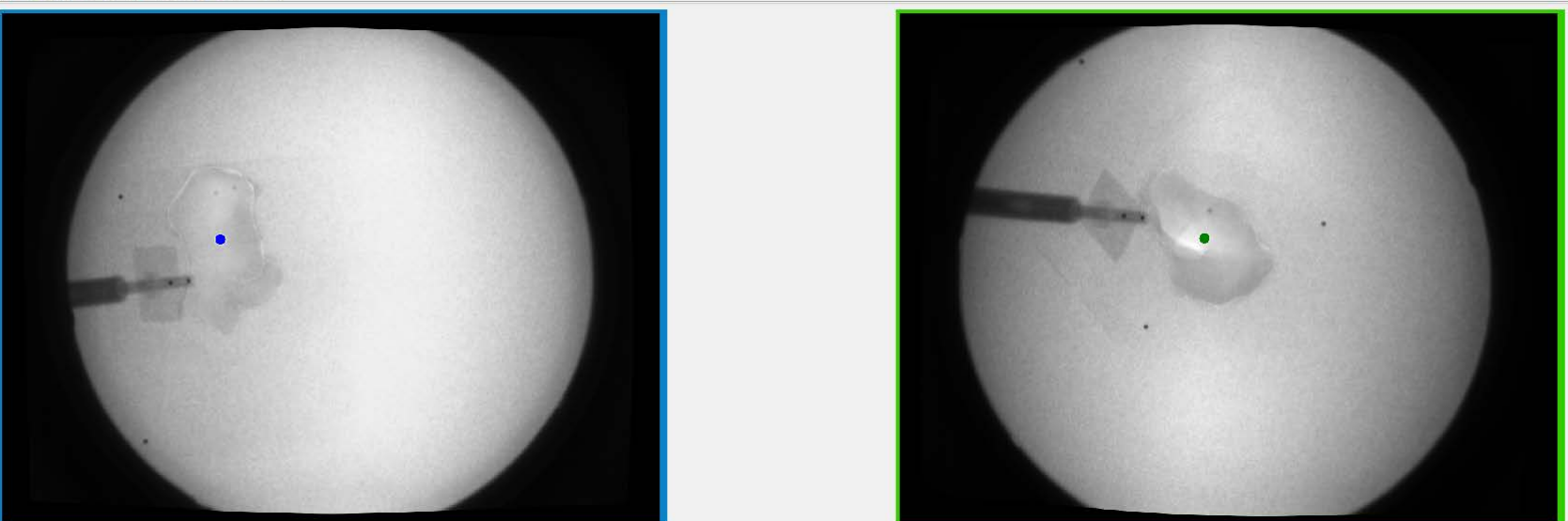
Frame Number 1 ☐ Keyframe

Previous Keyframe Next Keyframe

1 160

GUI Ready

☒ Display DRR ☒ Display Fluoro





# Sample videos

