Perelman School of Medicine University of Pennsylvania

Penn Center for Musculoskeletal Disorders

PCMD MicroCT Imaging Core Learning Lunch Series

MicroCT Imaging to Uncover the Internal Structural Responses of Specimens Under Mechanical Loading

March 4th, 2021

PCMD MicroCT Imaging Core

(Management team: X. Sherry Liu, Yilu Zhou, Rebecca Chung)

Invited speakers:

Dr. Sarah E. Gullbrand (Dept. Orthopaedic Surgery, UPenn)

Dr. Jing Du (Dept. Mechanical Engineering, Penn State University)

PENN Center for Musculoskeletal Disorders

McKay Orthopaedic Research Lab University of Pennsylvania

Penn Center for Musculoskeletal Disorders (P30-AR069619)

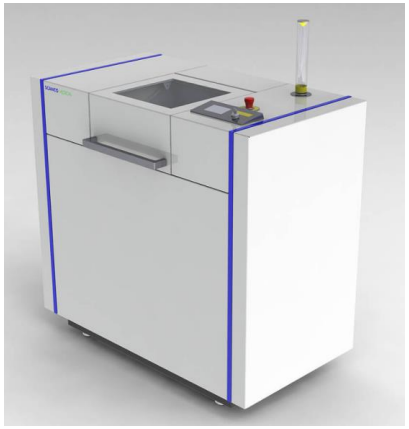
Outlines

- Brief introduction of our core facility
- Recent progress of our video tutorials, automated services
- MicroCT imaging setup for specimens under mechanical loading
- MicroCT project highlights from Dr. Sarah E. Gullbrand (Dept. Orthopaedic Surgery, UPenn)
- MicroCT project highlights from Dr. Jing Du (Dept. Mechanical Engineering, Penn State University)

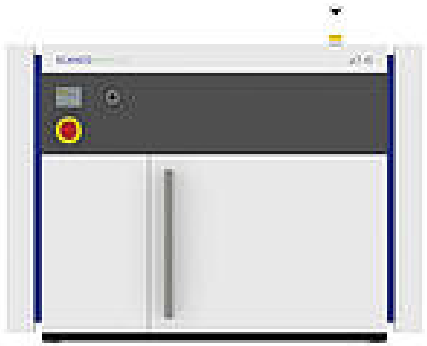
Available Scanners in our Core

- Specimen µCT
  - µCT 35
  - µCT 50
  - µCT 45 ***new!***

- *In Vivo* µCT
  - vivaCT 40
  - vivaCT 75
  - vivaCT 80 ***new!***



- Clinical µCT
  - XtremeCT II



µCT Imaging Core Resources

	Model	Location	Scan Size (ØxL;mm)	Voxel Size (µm)	Applications
1	µCT 35	Stemmler Hall	37.9 x 120	3.5-72	High resolution *ex vivo* scans
2	µCT 45	Stemmler Hall	50 x 120	3.0-100	High resolution *ex vivo* scans
3	vivaCT 40	Stemmler Hall	38.9 x 145	10.5-76	High resolution *in vivo* scans for small animals
4	vivaCT 80	Stemmler Hall	80 x 145	10.4-76	High resolution *in vivo* scans for small animals
5	µCT 50	PVAMC/TMRC	50 x 120	0.5-100	Ultra high resolution (sub-micron) *ex vivo* scans
6	vivaCT 75	PVAMC/TMRC	79.9 x 145	21-150	*In vivo* scans for small animals; *ex vivo* scans for large specimens
7	XtremeCT II	CTRC	140 x 200	60-82	Clinical scans for peripheral skeleton

Video Tutorials & Instruction Documents

https://www.med.upenn.edu/pcmd/mctimagingcore/user-tutorials.html

Video Tutorials:

Our YouTube channel: https://www.youtube.com/channel/UCzznR9Fdv-3kjEX7miwsioA/

µCT scan setup:

1. How to set up a scan on µCT35 (PDF download) (Video download)
   https://www.youtube.com/watch?v=QUtoQqIYJ8o
2. Demo: How to set up a scan on µCT45 (Recommended: Carousel version)
   (PDF download) (Video download)
   Note: To use this Carousel version, please remove the sample holder on the rotation stage.
   https://www.youtube.com/watch?v=fzIfffR5XyE
3. Demo: How to set up a scan on µCT45 (Non-carousel version) (PDF download) (Video download)
   Note: To use this Non-carousel version, please remove all sample holders on the carousel.
   https://www.youtube.com/watch?v=JEoLn1i9EjE
4. How to set up an ex vivo scan on VivaCT40 (PDF download) (Video download)
   https://www.youtube.com/watch?v=sxvTV4bvosw
5. How to set up an ex vivo scan on VivaCT80 (PDF download) (Video download)
   https://www.youtube.com/watch?v=HdQYWwjulXM

µCT viewing & analysis:

1. How to use "microCT Analysis" computers (PDF download) (Video download)
   https://www.youtube.com/watch?v=qHHcB6KJJe4
2. Tutorial for cropping, exporting, and requesting microCT images (PDF download) (Video download)
   https://www.youtube.com/watch?v=umRF6ODcQqQ
3. Tutorial for 3D display of microCT images (PDF download) (Video download)
   https://www.youtube.com/watch?v=YdQSo41rgR8
4. Tutorial for cortical bone analysis (mouse tibia midshaft) (PDF download) (Video download)
   https://www.youtube.com/watch?v=B4OE9X8Bkwg

Automated Service: File Request

https://www.med.upenn.edu/orl/uct/assets/user-content/secure/User_file_request%20(v2020.01).xlsx

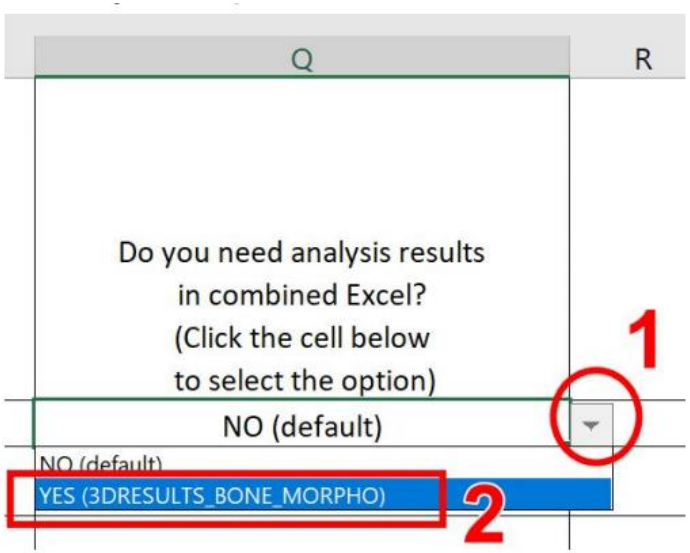
- File request: 7/24 automated service sharing MicroCT data files to users
  - Completed 320 requests from 35 users last year

- Auto compiling microCT results into Excel sheet (NEW!)

Your Gmail: meniscus@gmail.com

MicroCT35			Vivact40			Vivact80		
Sample#	Measure#	File_Types	Sample#	Measure#	File_Types	Sample#	Measure#	File_Types
7234	17817	DICOM						
7234	17816	DICOM						
7234	17815	DICOM						
7234	17814	DICOM						
7234	17813	DICOM						
7234	17812	DICOM						
7233	17811	DICOM						
7233	17810	DICOM						
7233	17809	DICOM						
7204	17726	DICOM						
7204	17725	DICOM						
7204	17724	DICOM						

Example (1)

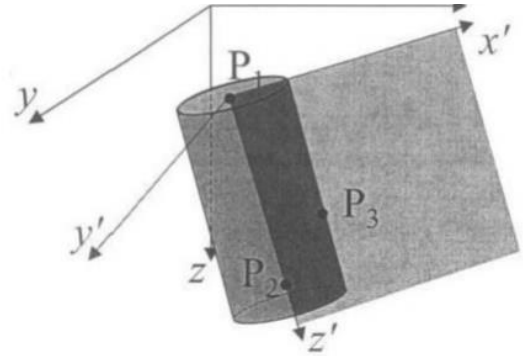


Automated Service: Sample Realignment

https://www.med.upenn.edu/orl/uct/assets/user-content/secure/Sample_Realignment_request(v2020.01).xlsx

- Sample realignment/reorientation request: 7/24 automated service help users to do sample realignment
  - Completed 40 requests from 10 users in 2020

1. Enter your email here:	yiluzhou1987@gmail.com (1)				
2. Select machine	3. Select alignment options: (3)	4. Select import options (4)			
(2) Vivact80	3 Point Alignment (AlignZ)	Import with old sample name	Use COMMA btw each number, e.g.: 100,100,100		
Sample#	**Measure#**	**New Sample#**	**P1**	**P2**	**P3**
(5) 298	1057	299	193,181,0	185,58,0	289,99,0

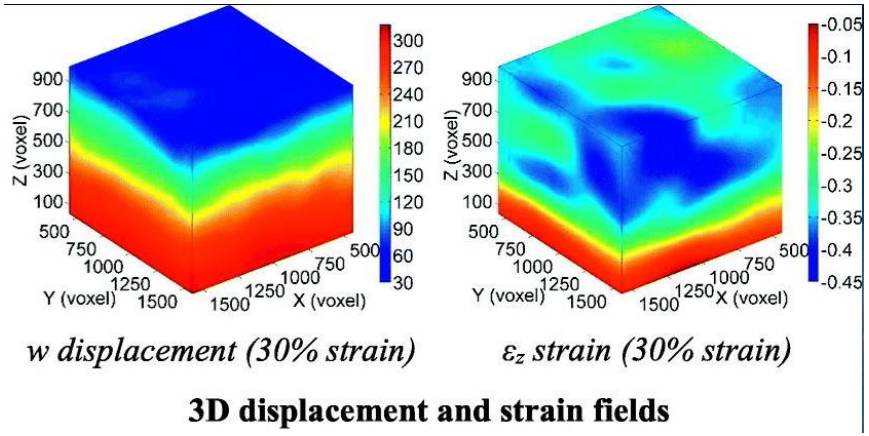


P1: the coordinates of the new origin
P2: the coordinates of a point on the new Z-axis
P3: the coordinates of a point in the new XZ-plane

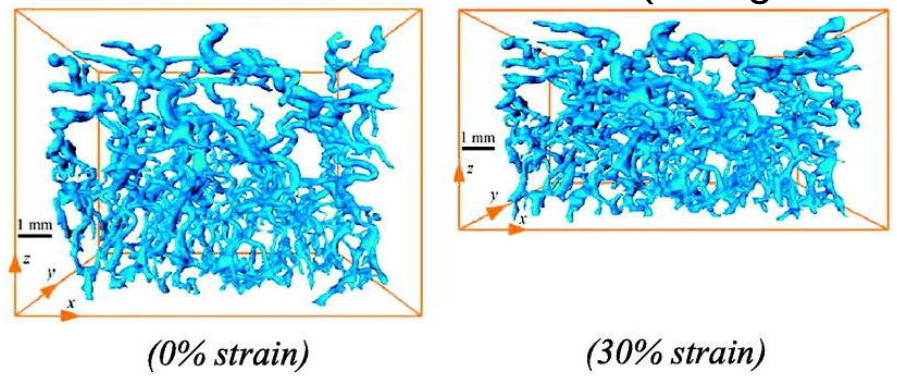
Why need 3D Strain Measurement?

- Essential tool to study the structure-function relationships
- To track the movement of microstructural features throughout the specimen in response to an applied load (Bay+ 2001)
- To understand the mechanical demands to which biological material such as bone is subjected *in situ* (Liu+ 2007)
- To explore the failure mechanism of biological material at a sub-micrometer resolution

(Wang+ 2018)



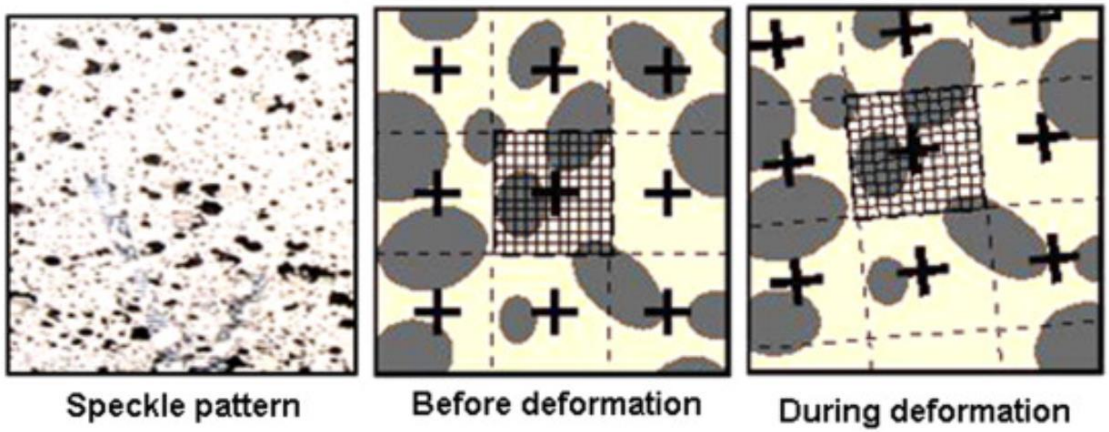
3D displacement and strain fields

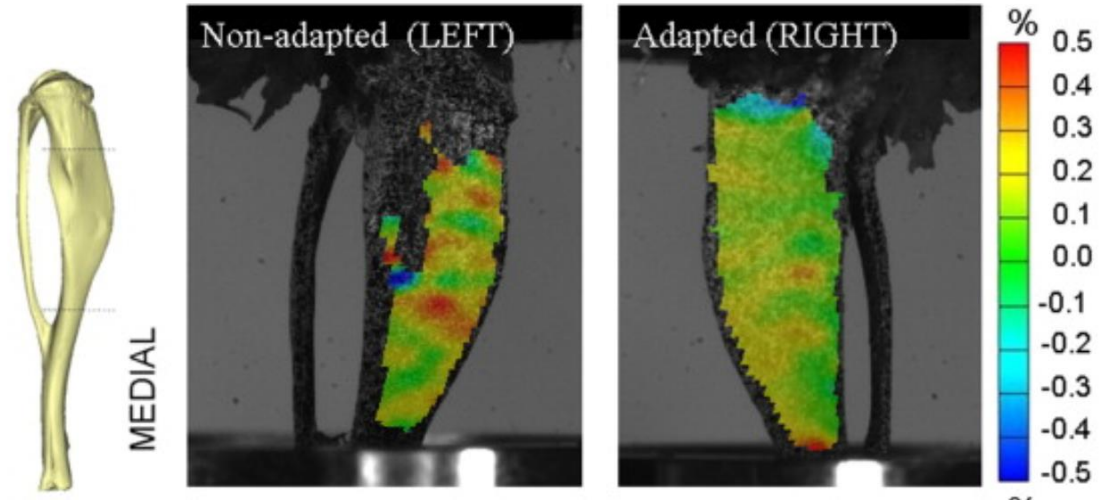


Bundles morphology

How to measure 3D strain?

Digital Image Correlation (2D images)



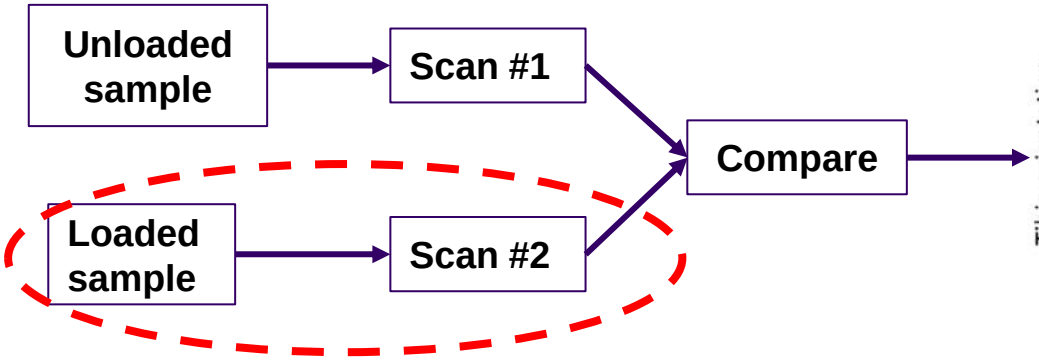


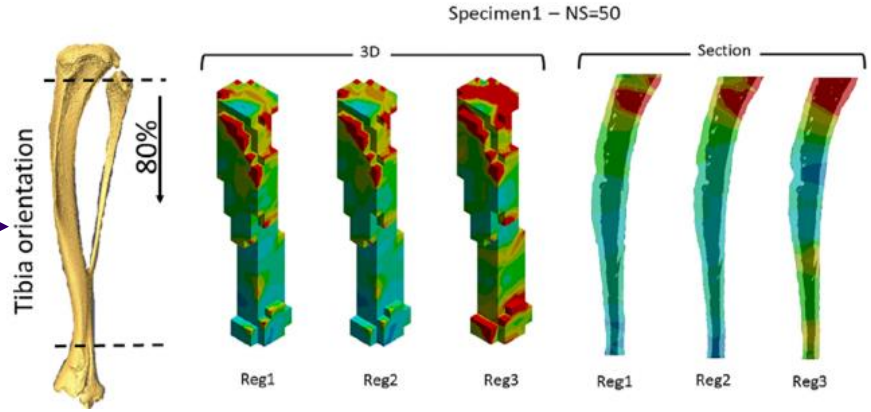
(Gillard+ 2013)

- DIC traces the deformation on the specimens surface.

Digital Volume Correlation (3D images)

- DVC: Extension of DIC, using 3D images
- Measuring strains throughout the interior of a specimen
- Powerful non-intrusive technique to identify interior material deformation, defects, discontinuities
- The idea is simple, just to compare the volume images of samples in unloaded and **loaded states**

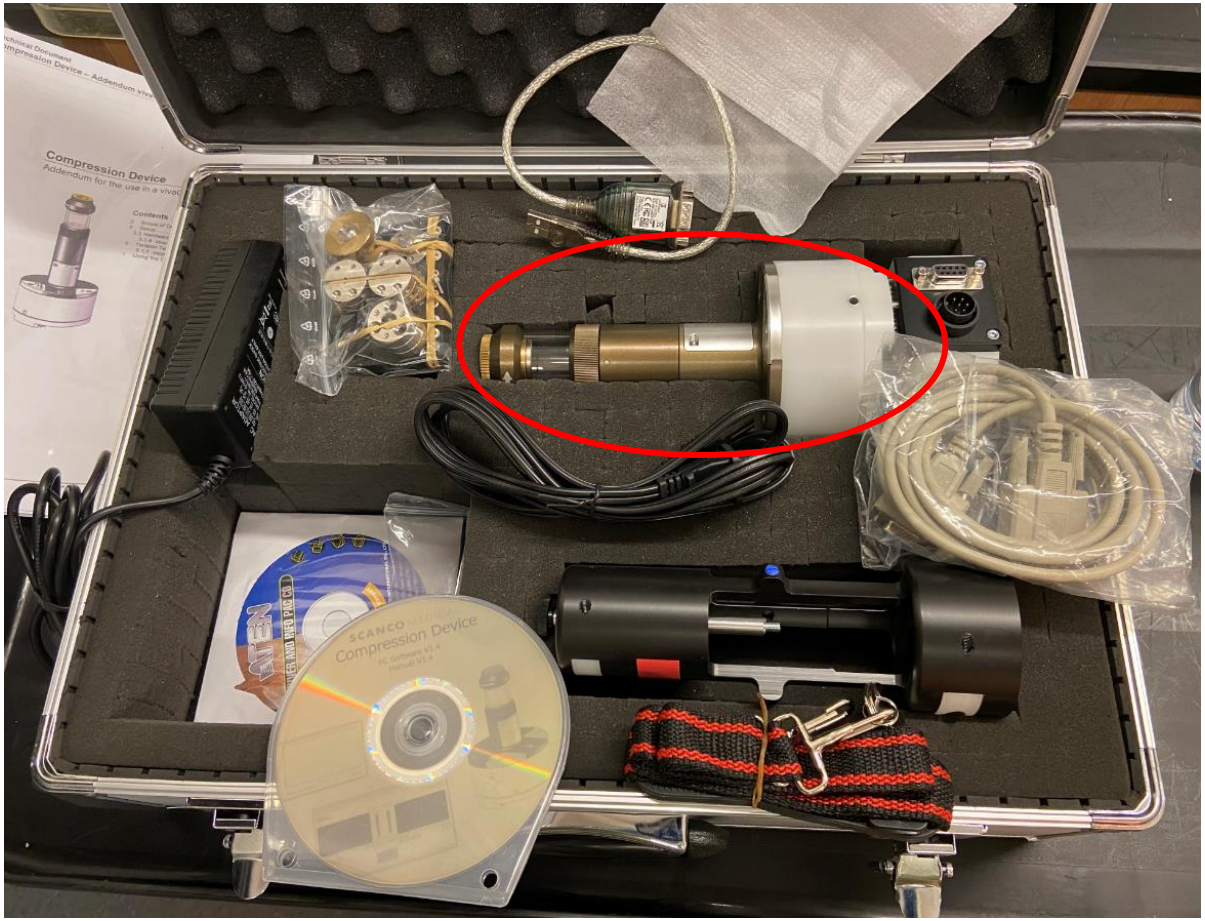




How to scan loaded sample?

(Giorgi+, 2018)

Mechanical Device for µCT Scanner



The whole set of mechanical device from Scanco

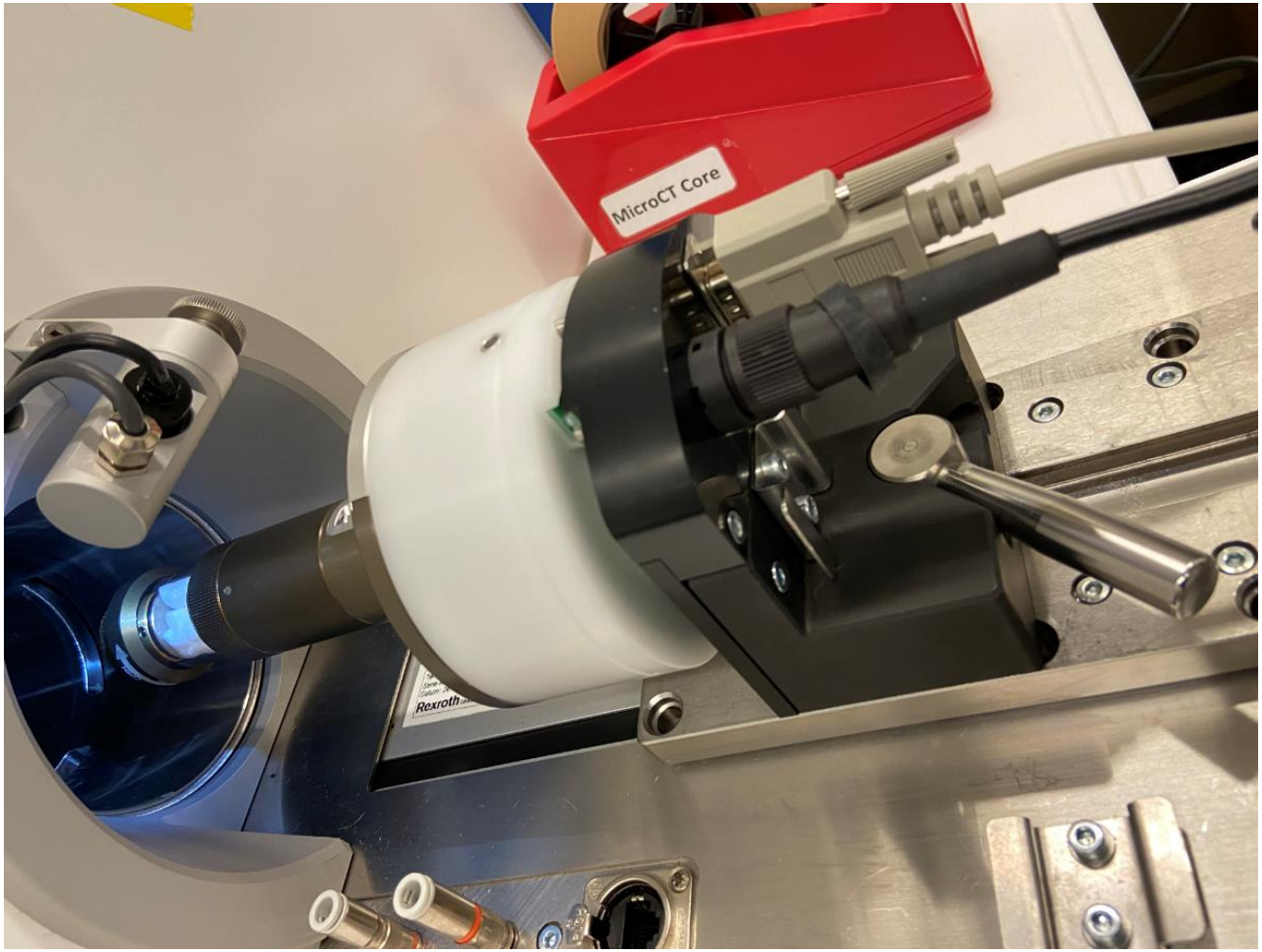
Mouse Tibia under Compression

- Mouse tibia was loaded in the imaging chamber
- μCT scan on mechanical loaded mouse tibia

Compression Force

Mouse Tibia under Compression

- Load the mechanical device into µCT Scanner (VivaCT 80 or µCT 45)



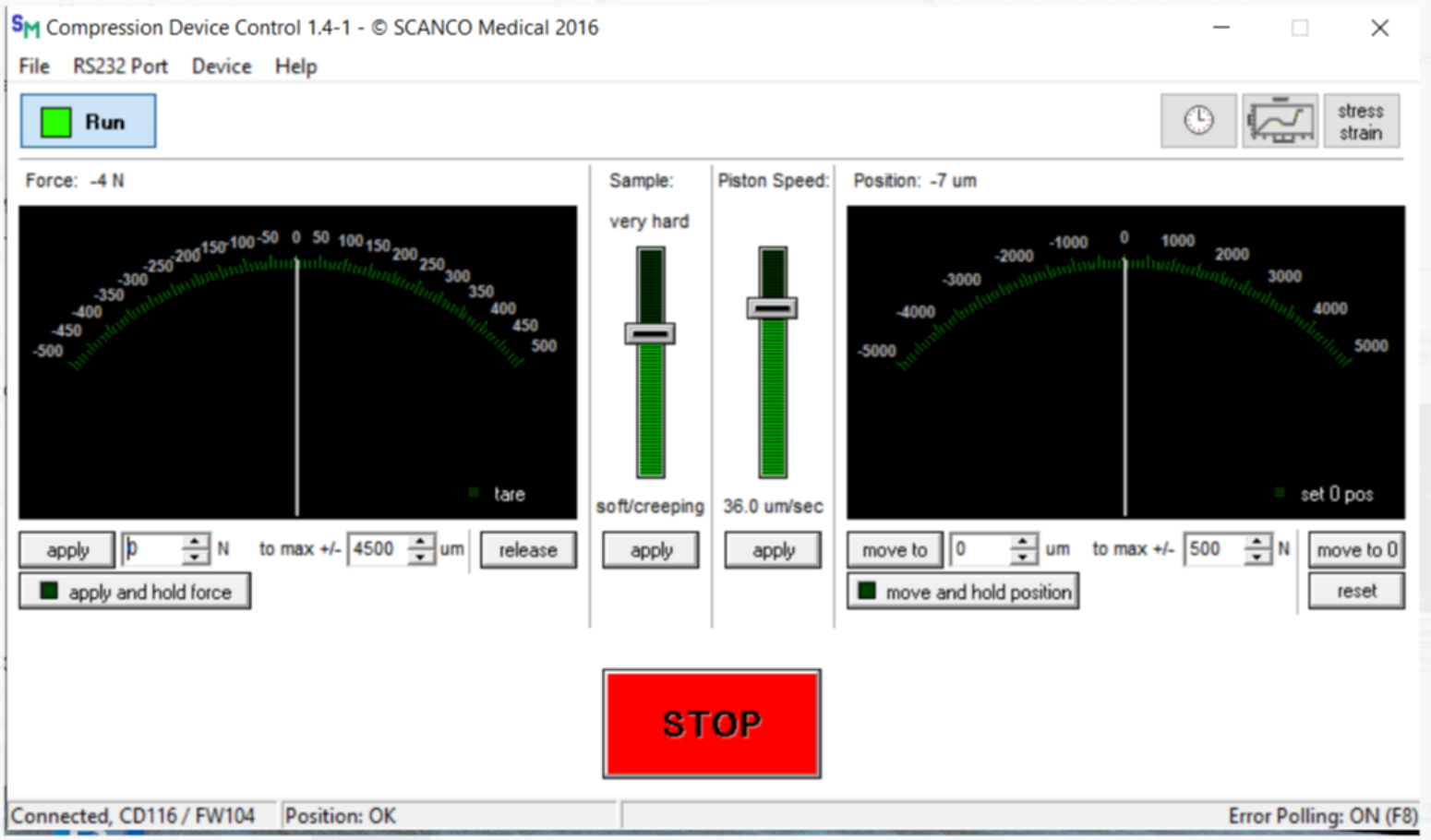
Sample under Tension

- Tensile testing could also be set up on this mechanical device

Tensile testing setup helper

Controller Software

- Scanco software:
  - Motor displacement control
  - Force curve record from the load cell.



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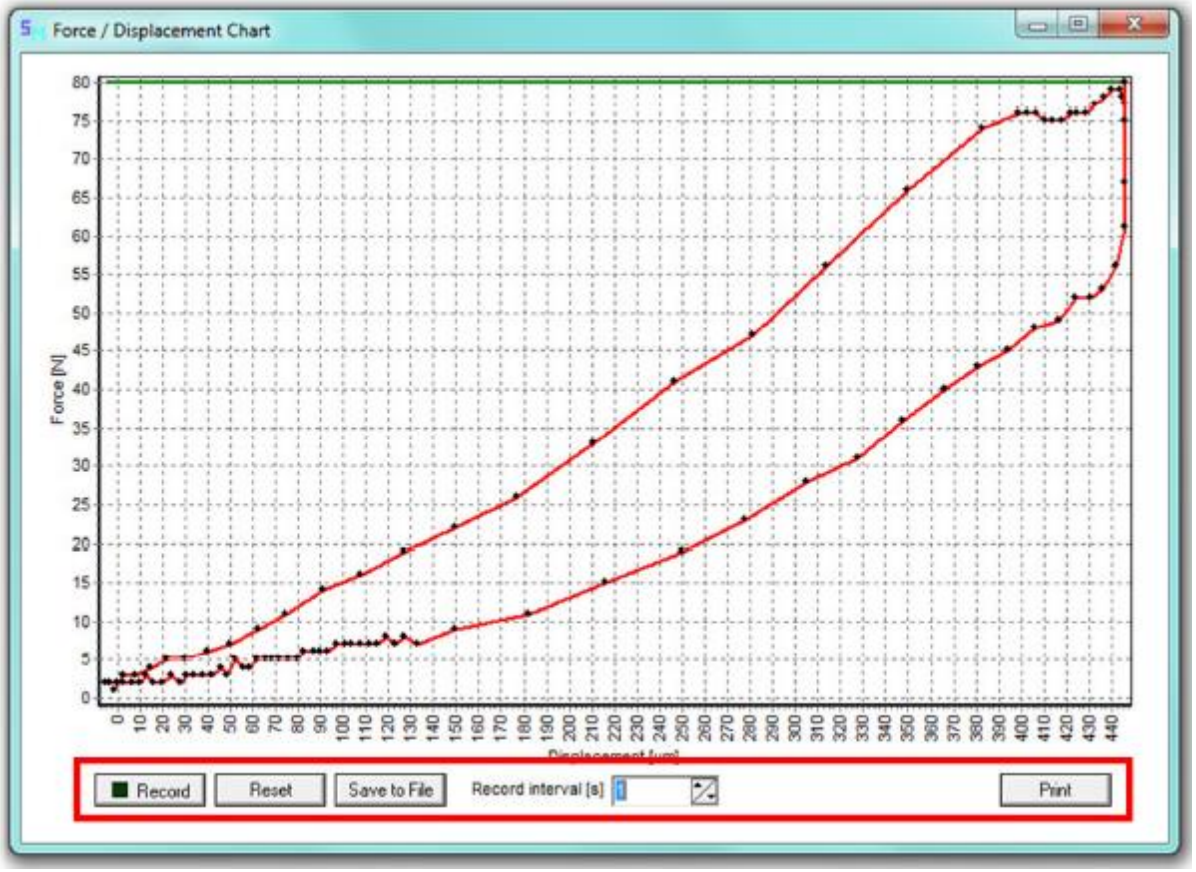

Force vs. Displacement curve

Technical Specifications

- Sample:
  - Max Sample Diameter: 24 mm
  - Max Sample Length: 55 mm (unfit for large animal tissue)
- Force:
  - Max Force at Compression: 500N
  - Max Force at Tension: 500N
  - Force Accuracy: ±5N (insensitive for mouse tibia)
- Displacement:
  - Max Displacement: ±4.5mm
  - Displacement Accuracy: ±0.02mm