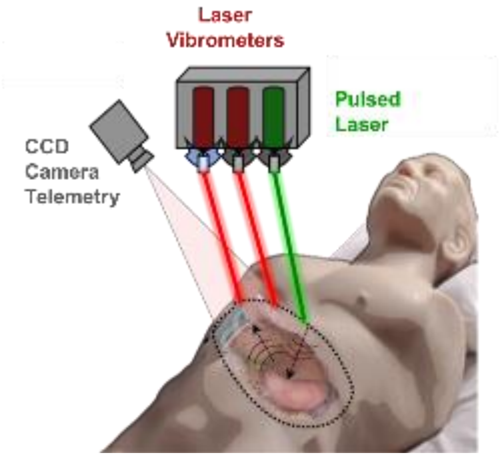
Noncontact Laser Ultrasound (NCLUS)

Medical Imaging Device and System

Anthony Samir MD MPH and Robert Haupt MS



Anthony Samir – Disclosures (Past 24 Months)

Consulting
- AutonomUS Medical Technologies, Inc. †
- Cryosa, Inc.
- Novo Nordisk
- Omnizare, Inc. †
- Quantonation
- Resolve Stroke S.A. †
- Thinksono †
- Vortex Medical †

Advisory / Scientific Boards
- Rhino Federated Computing †
- Ochre Bio †
- Resolve Stroke †
- Thinksono †
- Vortex Medical †
- Foundation for the NIH †
- American Institute of Ultrasound in Medicine

Research Support
- Canon †
- Echosens †
- General Electric †
- Philips †
- Siemens †
- Supersonic Imagine
- Terason
- United Imaging †

Research Funding
- DOW †
- National Institutes of Health †
- Foundation for the NIH (FNIH) †
- Fujifilm
- General Electric HealthCare †
- United Imaging †

Equity
- AutonomUS Medical Technologies, Inc. †
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- Ochre Bio, Inc. †
- Quantix Bio LLC †
- Rhino Federated Computing, Inc. †
- Thinksono Limited †
- Vortex Imaging †

All relationships shown were active within the past 24 months. † *= ongoing relationship.*

NCLUS Development Team

Robert Haupt	*PI/PM – MIT Lincoln Laboratory*
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Rajan Gurjar PhD	*System Architect – MIT Lincoln Laboratory*
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Trevor Mitcham PhD	*Ultrasound Image Reconstruction - MIT Lincoln Laboratory*
Teddy Pierce MD	*Clinical Translation – MGB CURT*
Marko Jakovljevic PhD	*Ultrasound Visualization – MGB CURT,*
Ion Candel PhD	*Translational Engineering – MGB CURT*

Core of Radiology - Metrics for Internal Injury Imaging

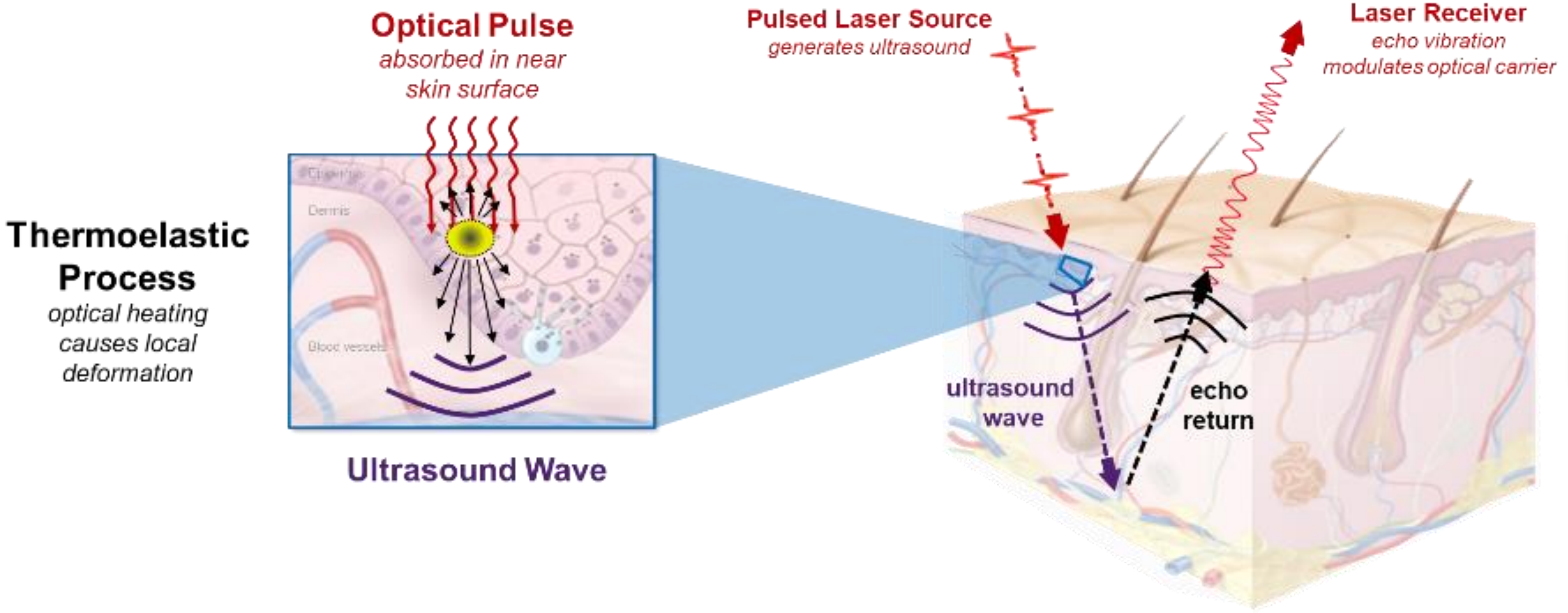
		Portable	Cost	System Complexity	Soft Tissue Imagery	Bone Imagery	Image Registration	Automated Acquisition
X-ray								
CT Scan								
Magnetic Resonance (MRI)								
Ultrasound								

Vision: **Combine each system's advantages into an *ideal* portable, *field-forward* imaging system**

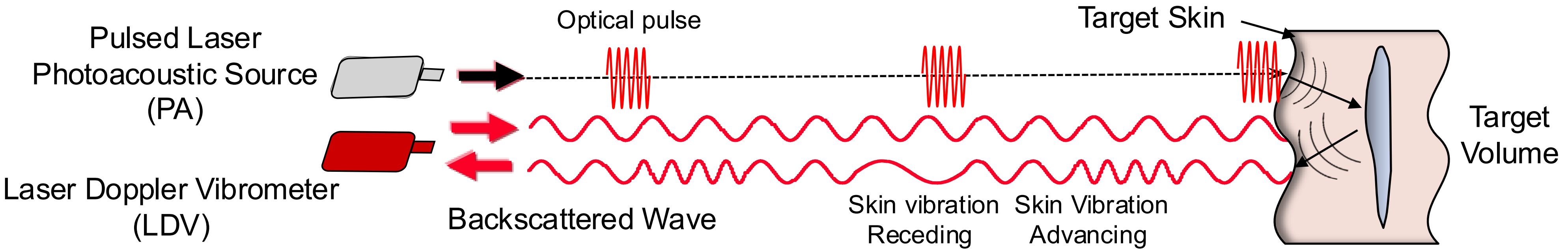
Outline

- Introduction & Motivation
- Noncontact Laser Ultrasound (NCLUS)
  - Phenomenology & Advantages
  - Clinically Relevant Imaging System
  - Human Subject Testing in Clinical Setting
  - Device Translation

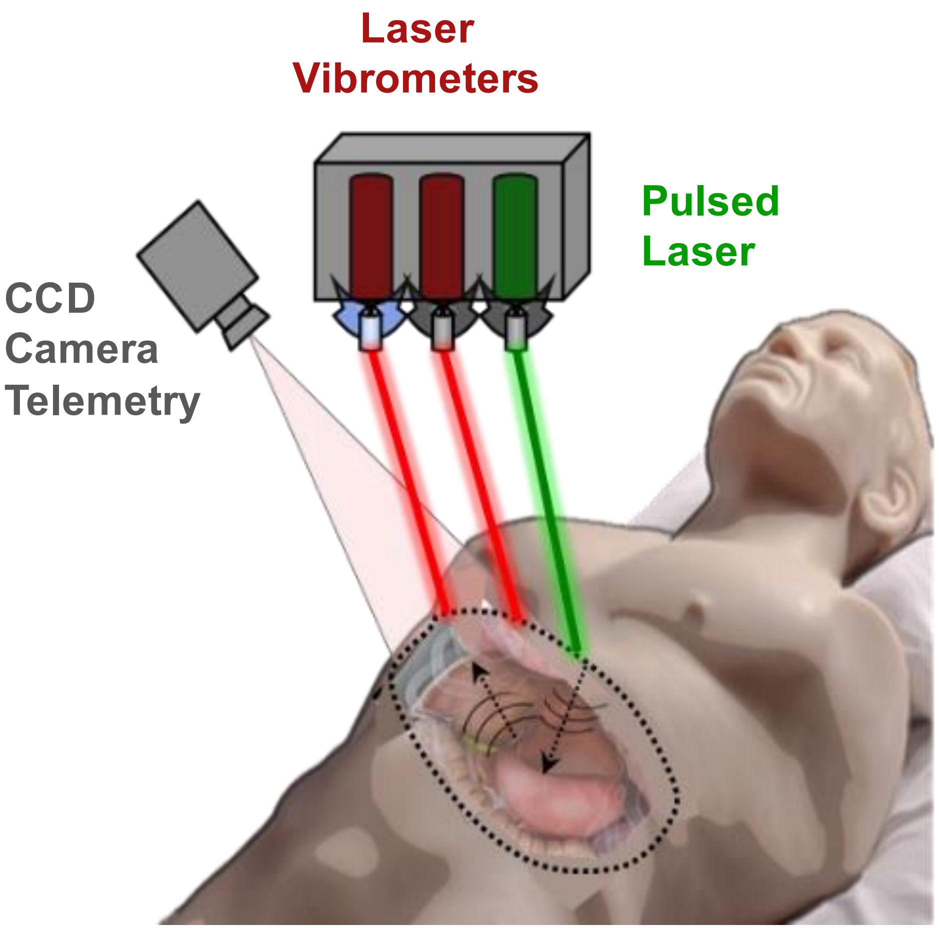
NCLUS Phenomenology and Measurement



Any exposed tissue surfaces can become viable ultrasound sources and detectors



NCLUS System Concept & Advantages



- **Mitigate Operator Variability**
  - Data acquisition and laser movement are fully automated eliminating the need for a sonographer
- **Provide Image Registration**
  - accurate and repeatable transmit and receive positioning allows image data to be represented as low-variability spatially localized anatomic “slices,” as with CT and MRI
- **Scanning System Provides Great Versatility**
  - versatile excitation and receive positioning eliminates a fixed transducer geometry, allowing the creation of a near-unlimited range of acquisition array shapes and sizes from a single system
  - programmability allows automated and registered large field of view imaging while enabling the ability to track localized tissue feature changes over time

Potential New Applications in Ultrasound using Lasers

Minimal Interference Ultrasound

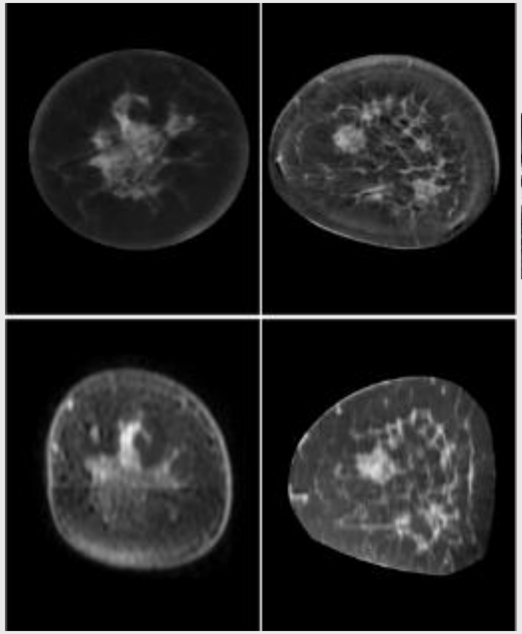
Surgical Assessment

- Open Body Imaging
- Surgical Guidance and Feedback
- Significant Standoff with use of mirrors for laser positioning

Ultrasound Voxel Image Registration for Surgical Assistance

Tomographic Breast Imaging

Transition Univ Rochester Water Tank Immersion System to Free Air with NCLUS



U Rochester Ultrasound

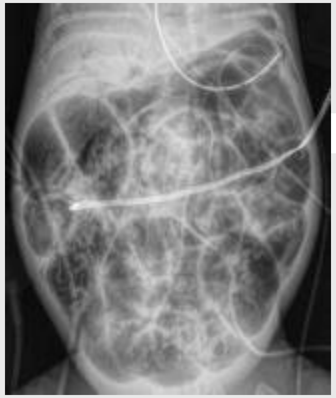
MRI Comparison

Immersion Free Systems

Neonatal Imaging

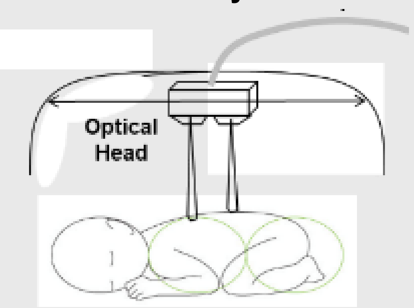
Neonatal NCLUS Imaging Incubator Lid Concept

Neonatal necrotizing enterocolitis (NEC)
Infant Bowel inflammation, necrosis, and perforation



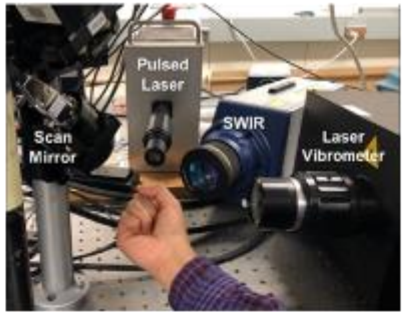
X-ray image of neonate abdomen and bowel region

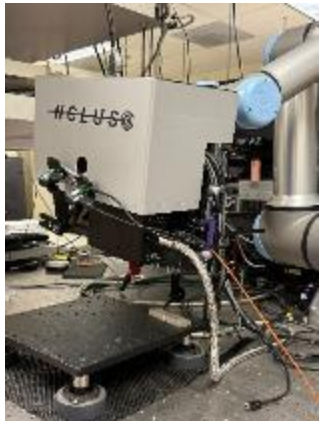
Incubator Lid NCLUS System

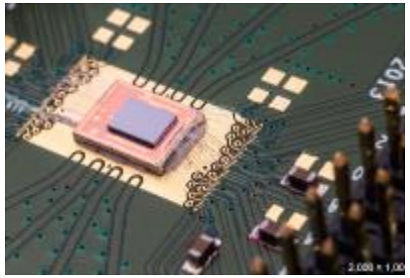


Standoff US Frequent Imaging without touching fragile tissue and while reducing health risk to infant

NCLUS System Evolution

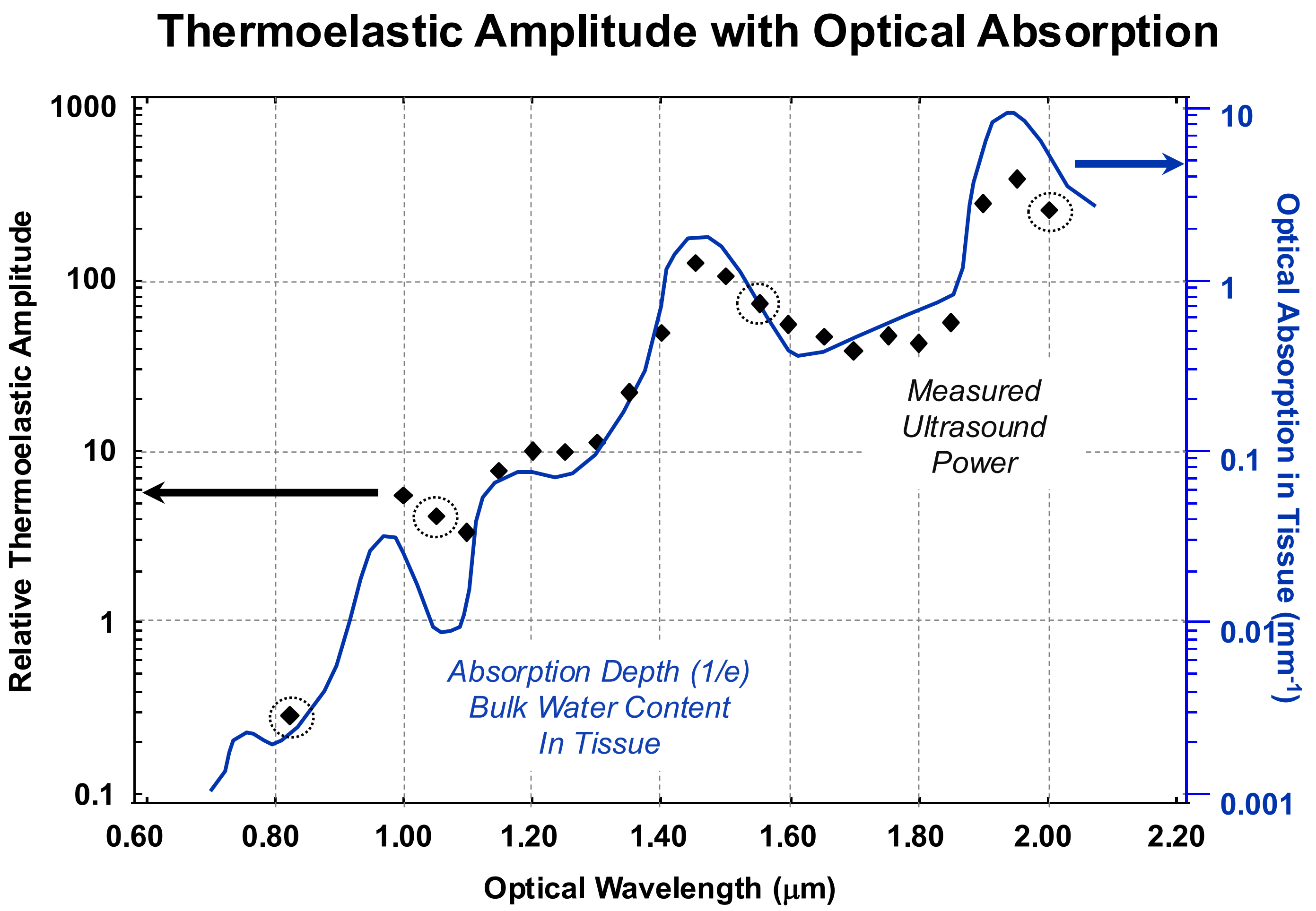


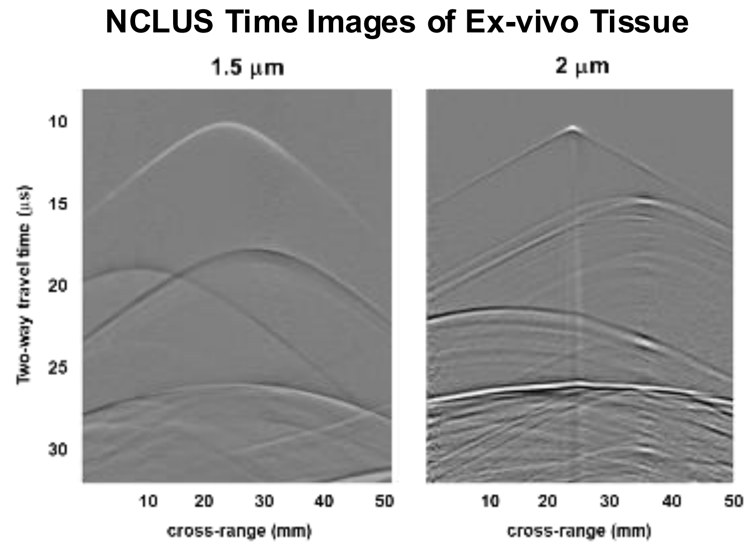


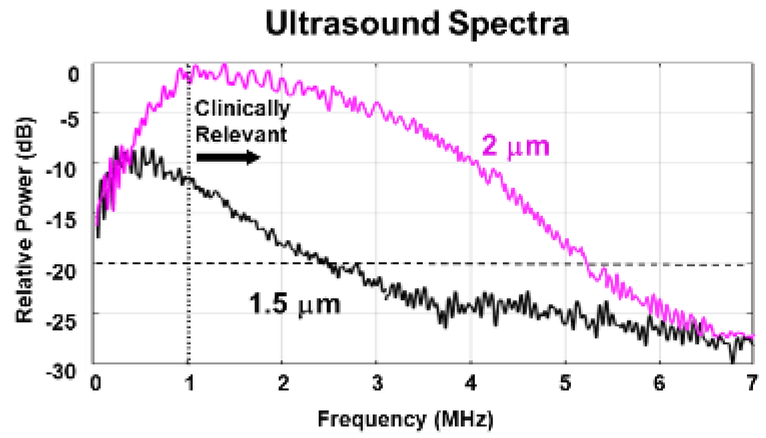


System Attribute	GEN - 1	GEN - 2	GEN - 3	Future Clinical Integrated Photonics
Platform Assembly	Bench Top	Multi-degree Freedom Armature, manual positioning	Multi-degree Freedom Armature, robotic positioning	Multi-degree Freedom Armature
Ultrasound Bandwidth	0.5 – 1.5 MHz	0.5 – 7 MHz	0.5 – 7 MHz	0.5 – 7 MHz
Image Type – Soft Tissue	A-mode (1D array)	B-mode (1D array)	B-mode (2D array)	B-mode (2D array)
Image Type - Bone		1D Refraction	2D Refraction	2D Refraction
Acquisition Frame Time Image SNR	• **20 minutes** • **20 dB**	• **50 seconds – 5 minutes** • **23 – 40 dB**	• **5 seconds** • **33 – 60 dB**	• **50 – 500 ms** • **60 dB**
Photoacoustic Laser ***PA - transmitter***	• 10 Hz PRF, scanned • 1.5 µm	• 0.2 - 5 kHz PRF, scanned • 2.0 µm *(improved SNR)*	• 0.2 - 5 kHz PRF, scanned • 2.0 µm	• 5 kHz PRF, scanned • 2.0 µm
Laser Doppler Vibrometer ***LDV - receiver***	1 channel, Polytec RSV150 moved by translation stage	2 channel, custom, scanned *improved SNR*	10 channel, custom, scanned *additional SNR improvements*	100 channel, custom, scanned

Delivering Ultrasound Power with Pulsed Light





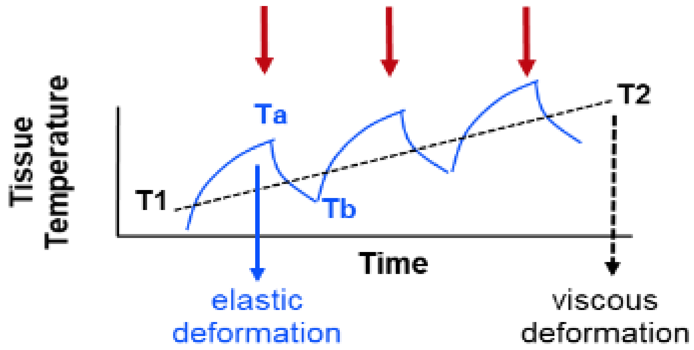


Thermoelastic amplitude increases proportionally with more rapid absorption of optical energy – largest yields at absorption peaks

US patent No. 10456044: "System and Method for non-contact ultrasound": – Issued October, 2019
US patent No. 10602931: "System and method for non-contact ultrasound with enhanced safety" – Issued March, 2020

NCLUS Challenges focus on meeting laser safety followed by minimizing ultrasound acquisition time

Pulsed laser light US excitation

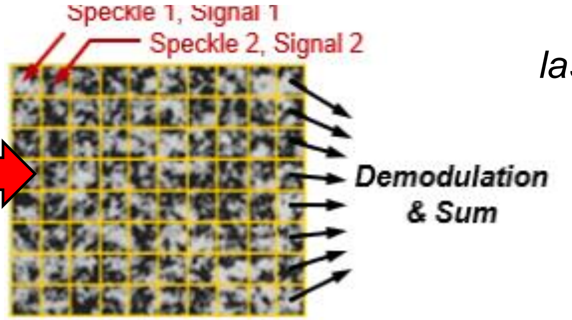


Cannot exceed the optical "dose" and dwell time on the tissue spot

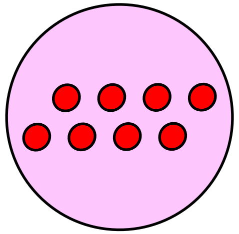
- causes heating and tissue damage with high laser power and repeated excitation in the same location
- thus we implement 2D array acquisition for minimal revisit strategy

Laser light measures US echo return

Light split onto many detectors



8 independent laser receive beams

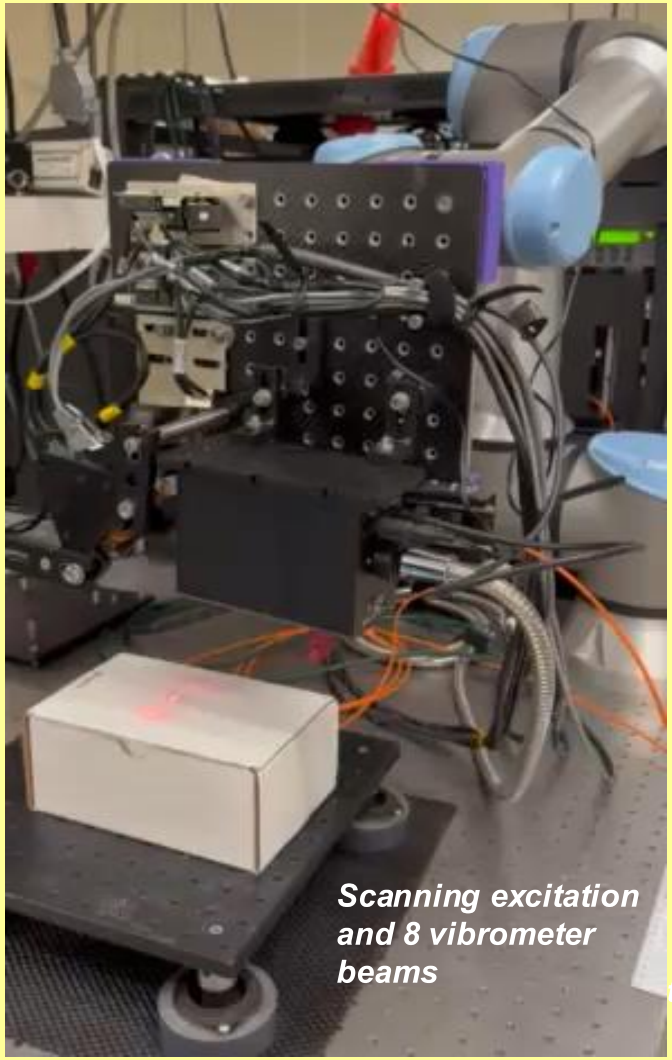


Laser light return to the vibrometer is the predominant challenge

- varying "speckle" controls the amount of light return to the receiver
- same rules apply for optical "dose" and dwell time on the tissue patch

- **Laser Power and Dwell time present limitations and challenges to acquire the required ultrasound SNR and acquisition frame rate while meeting patient skin safety and minimizing patient motion artifacts**
- **These limitations become the drivers of the NCLUS system development**

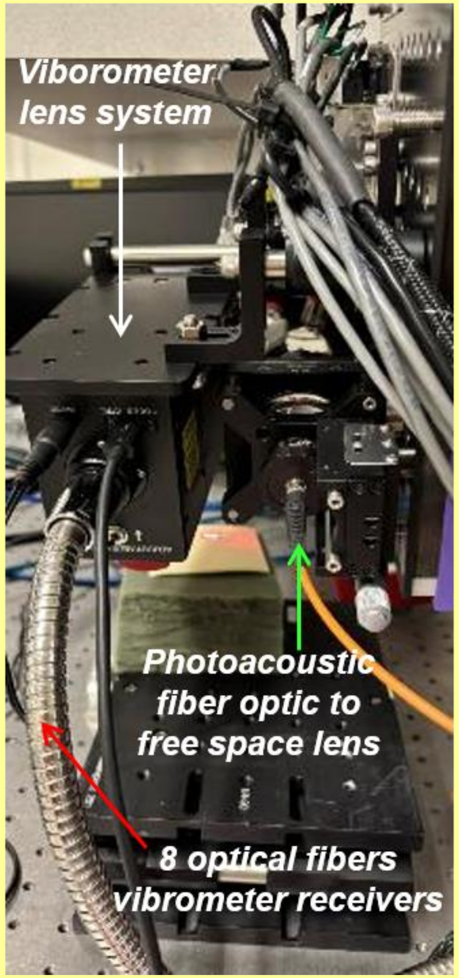
GEN-3 NCLUS Hardware Core Components and System
Human Subject Test System



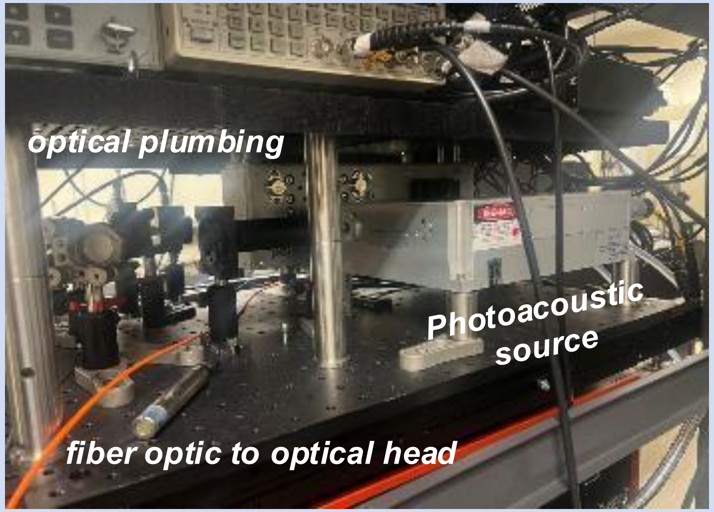
NCLUS Optical Head

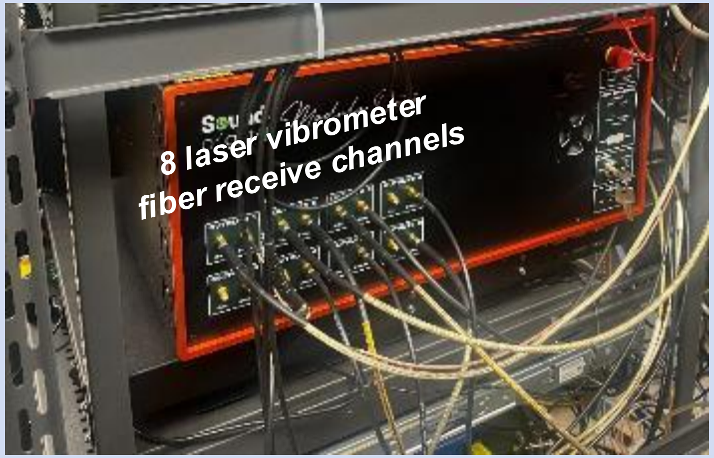
- 7-degree of freedom robotic arm positioning patient viewing
- 2 Independent fast scanning mirrors
  - *- Photoacoustic beam*
  - *- 8 Vibrometer beams*
- High frame rate 2D laser camera provides
  - *- skin topography map*
  - *- tracks laser beams*

Side View



Side Cabinet houses electronics





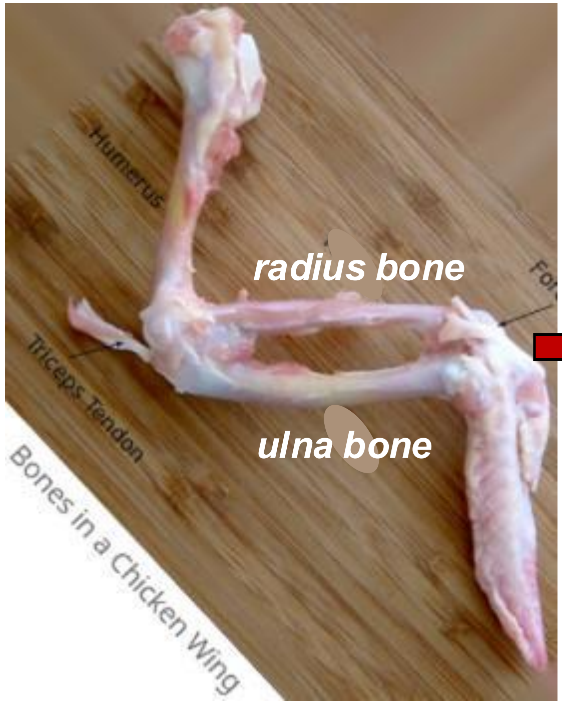
NCLUS Biological Tissue Target for 3D Imaging

Anatomy of a chicken wing

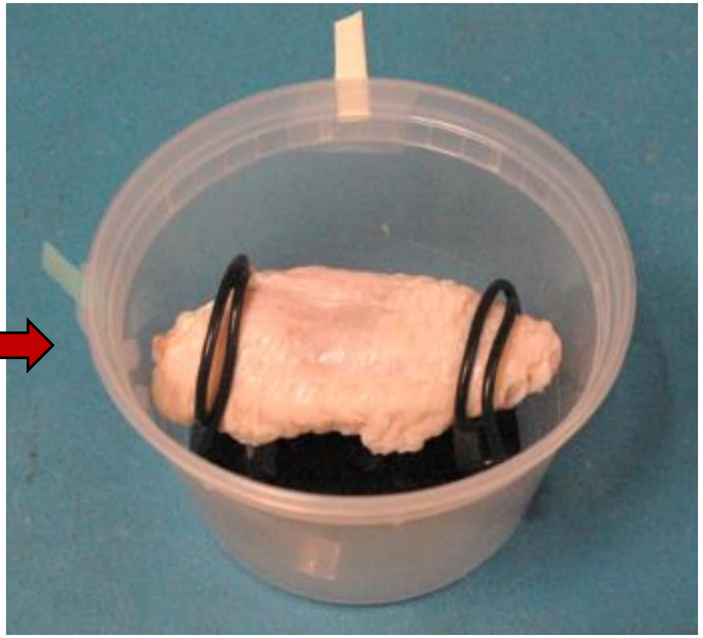
Target Sample - chicken wingette

Wing Components

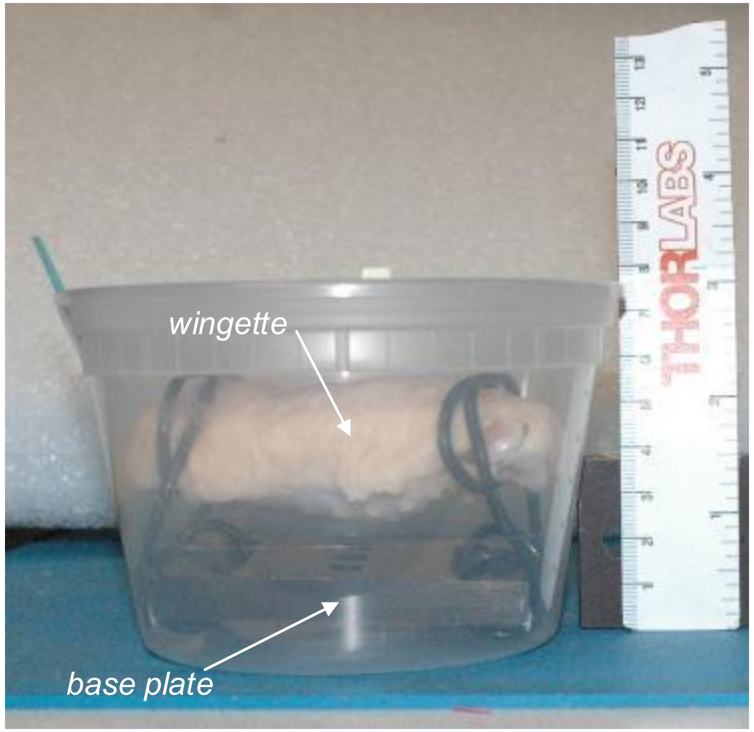
Ground Truth of Bone



top view

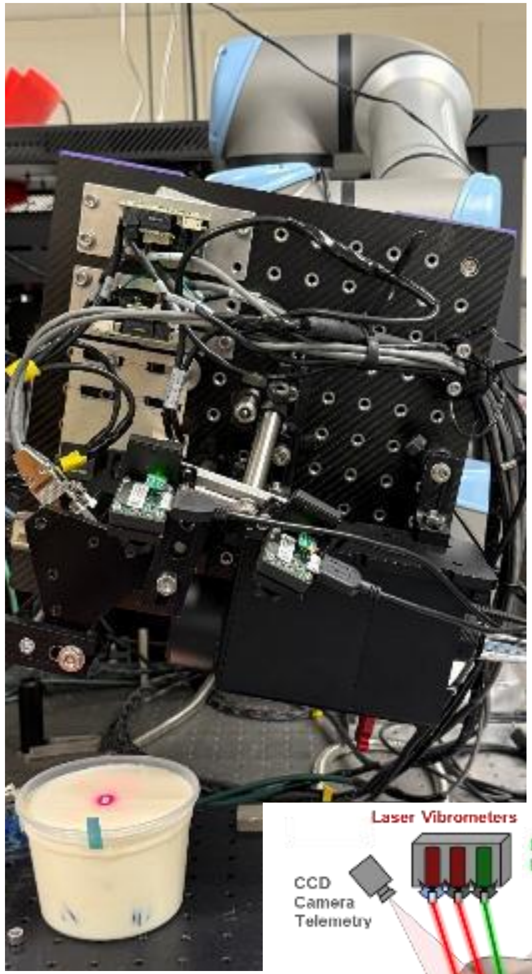


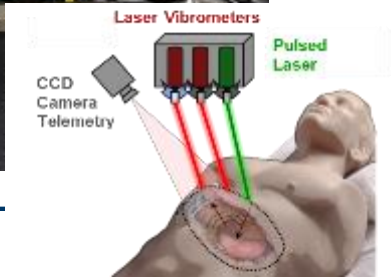
side view



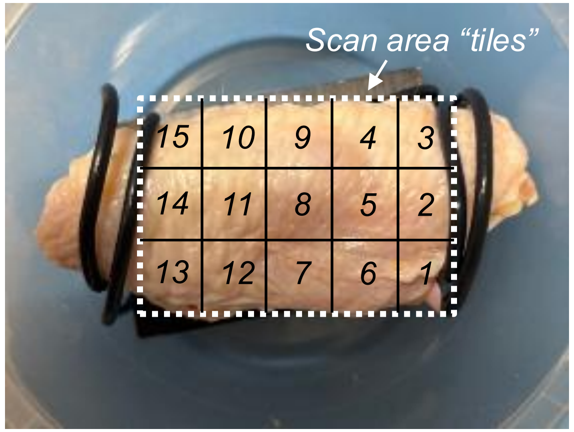
NCLUS System on Robotic Arm – 3D Data Acquisition

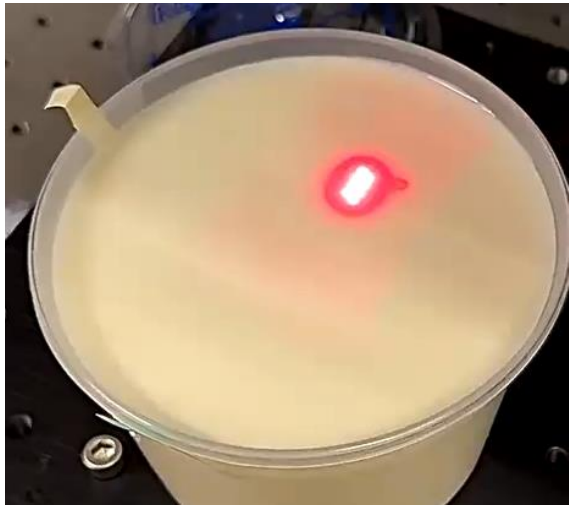
NCLUS Optical Head on Robotic Platform





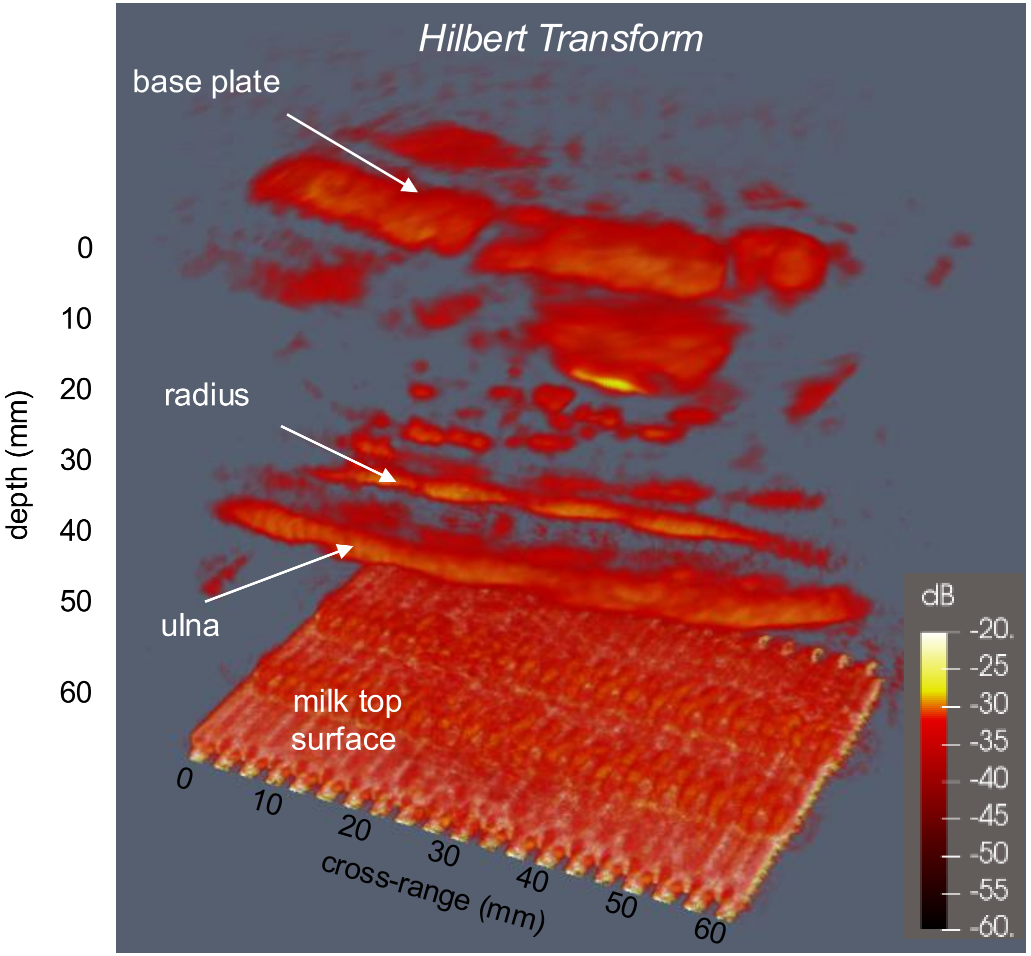
Chicken Wing Target





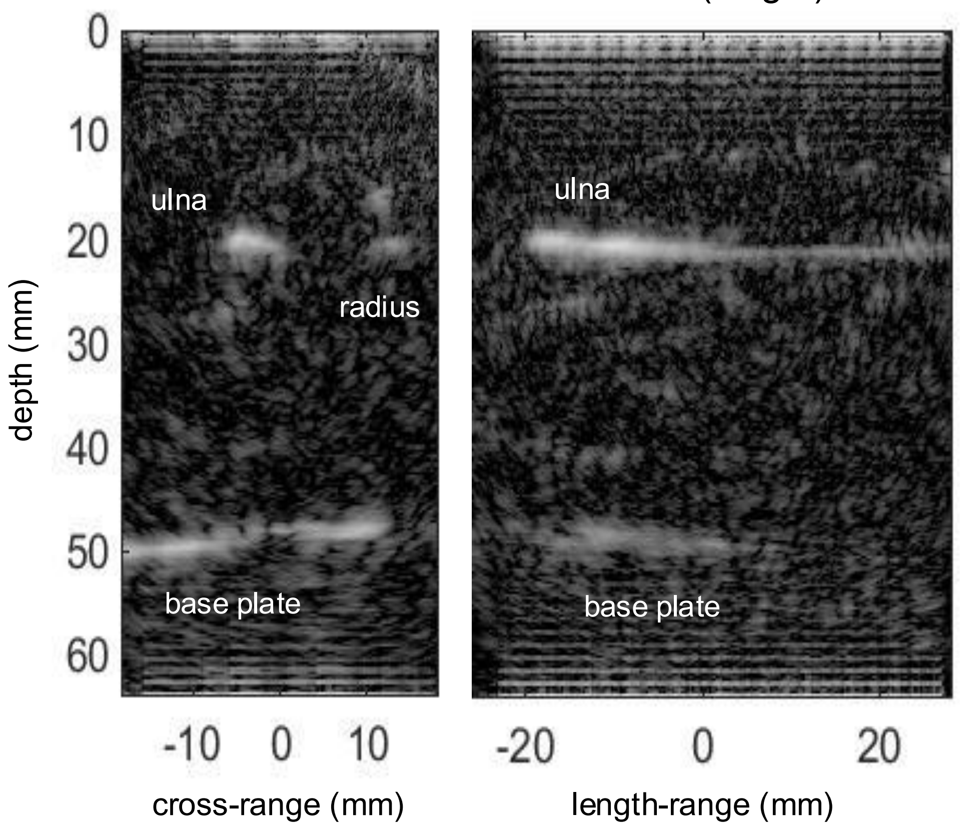
3D NCLUS Chicken Wing and Background

(vertically inverted)



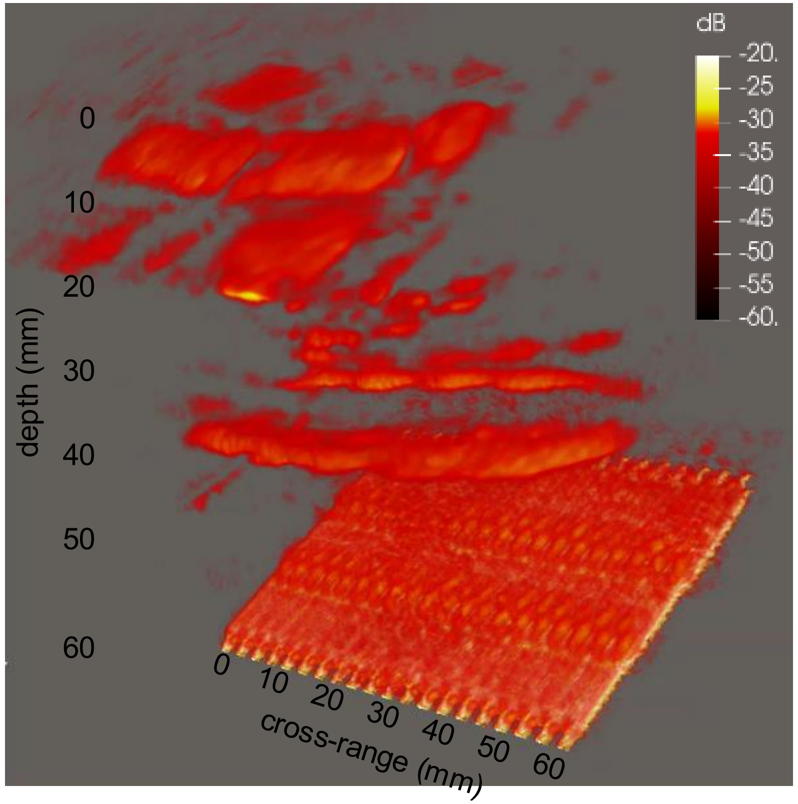
NCLUS Wingette RF B-mode and 3D point cloud volumetric images

RF B-Mode 2D Depth Images
(actual view)



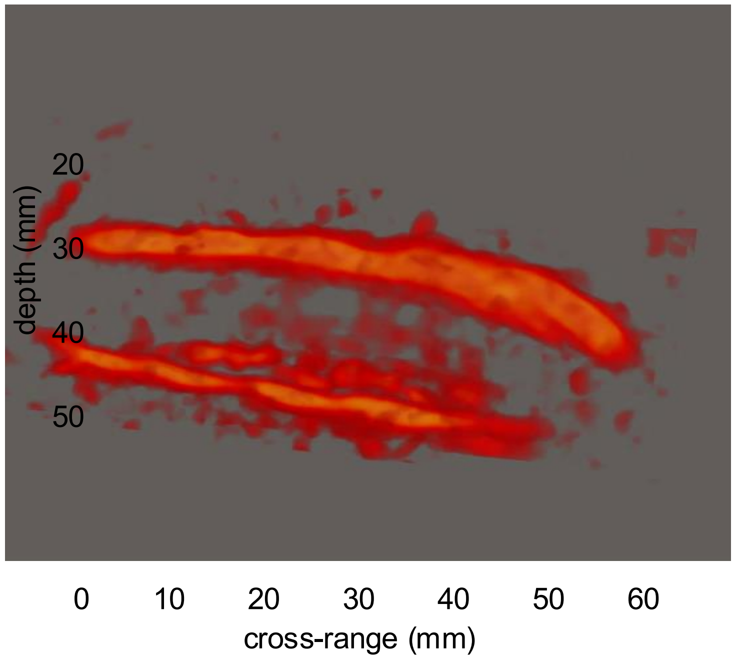
3D Point Cloud Image
Chicken Wing and Background
(vertically inverted)

Hilbert Transform



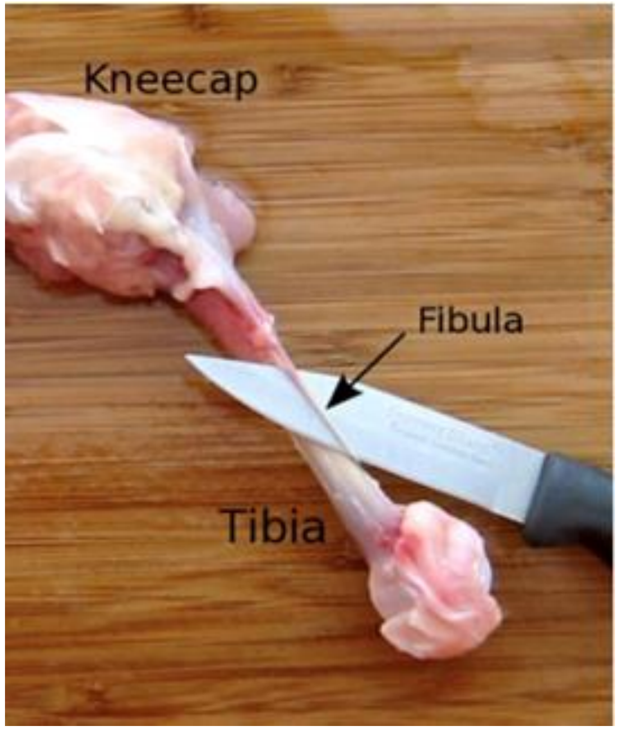
3D Chicken Wing
Point Cloud Image
(actual view)

Hilbert Transform



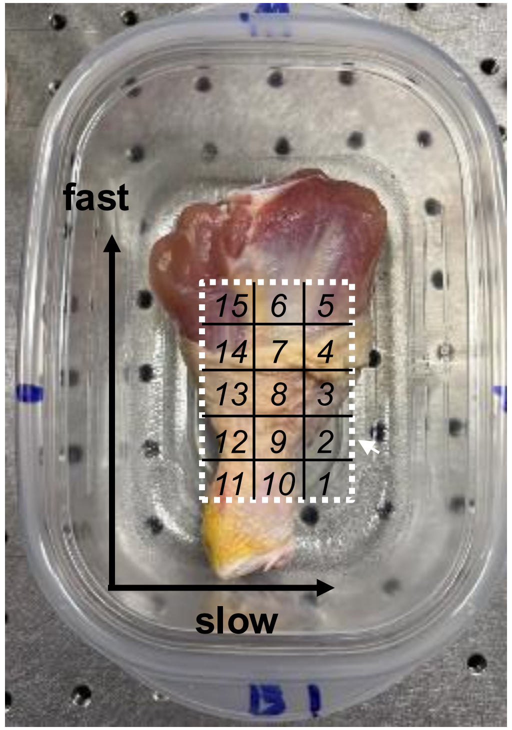
NCLUS Comparison to CT – Fracture Imaging Study

Ground Truth of Bone

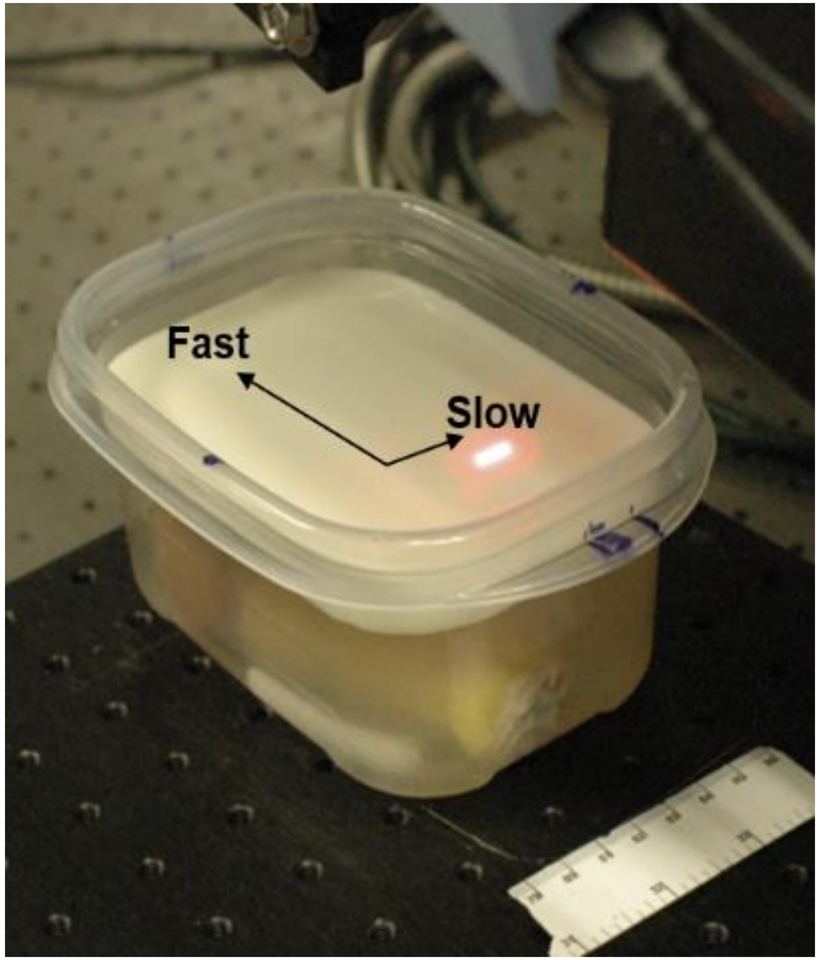


Chicken Leg Intact

Chicken Leg Tiled Scan Area

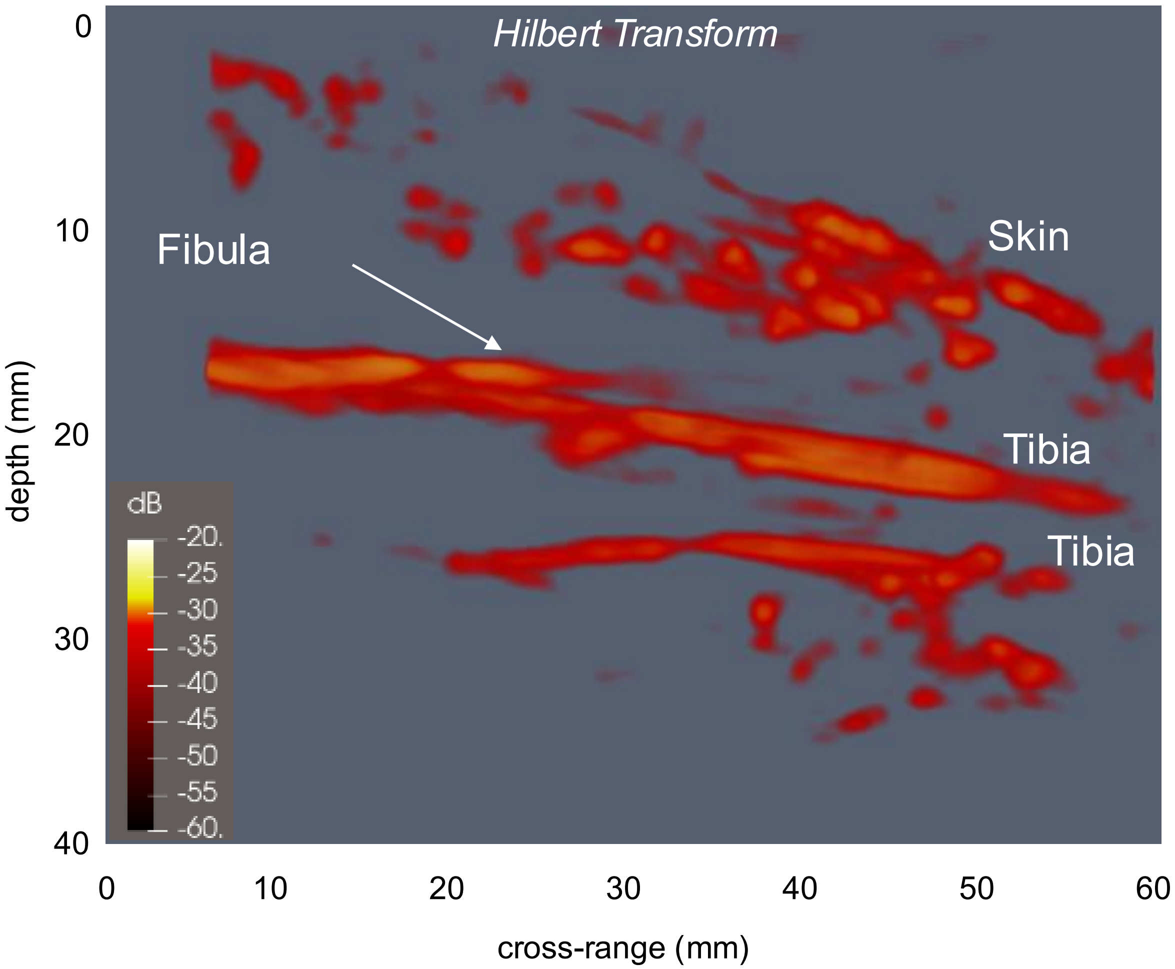


Chicken Leg Immersed in Milk Gel

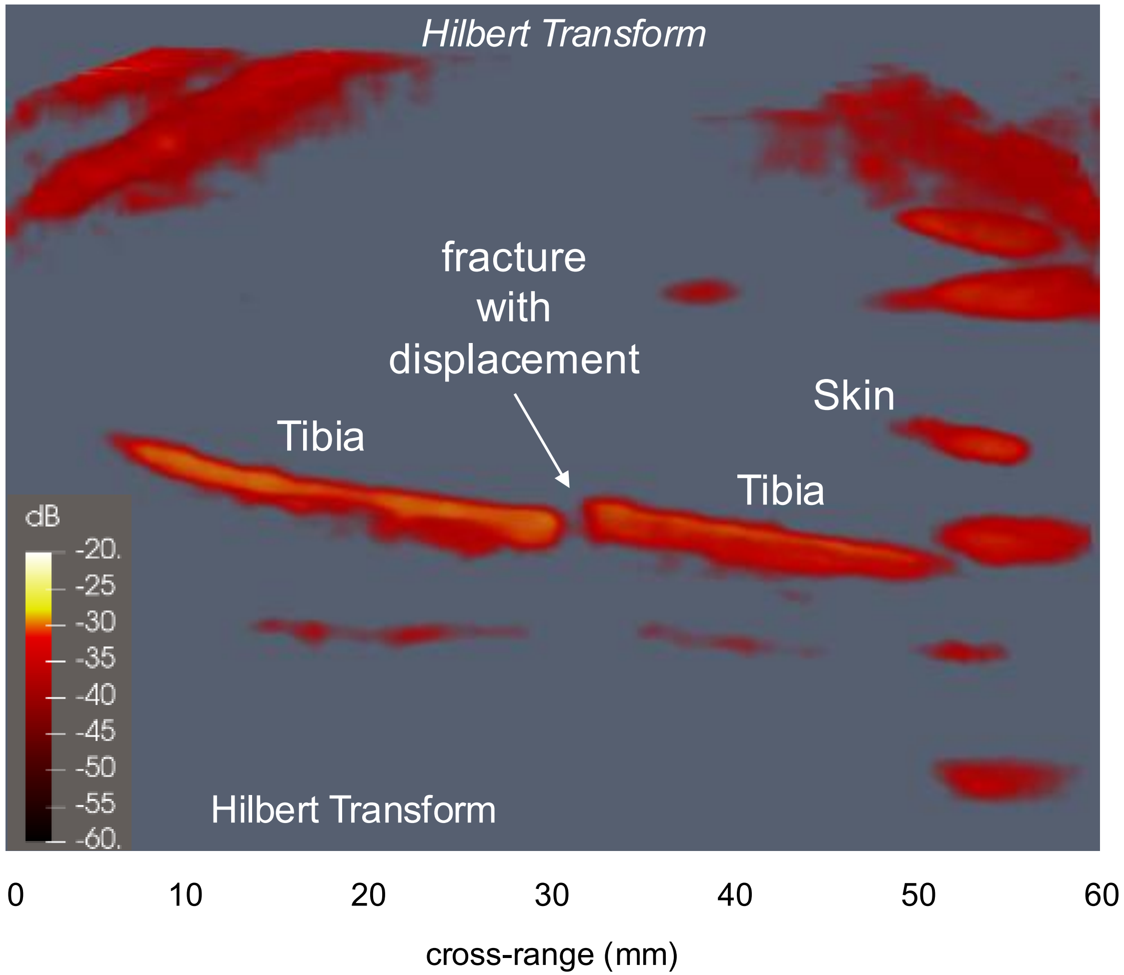


NCLUS Imaging – Chicken Leg Intact vs Induced Tibia Fracture

Chicken Leg and Bone - Intact

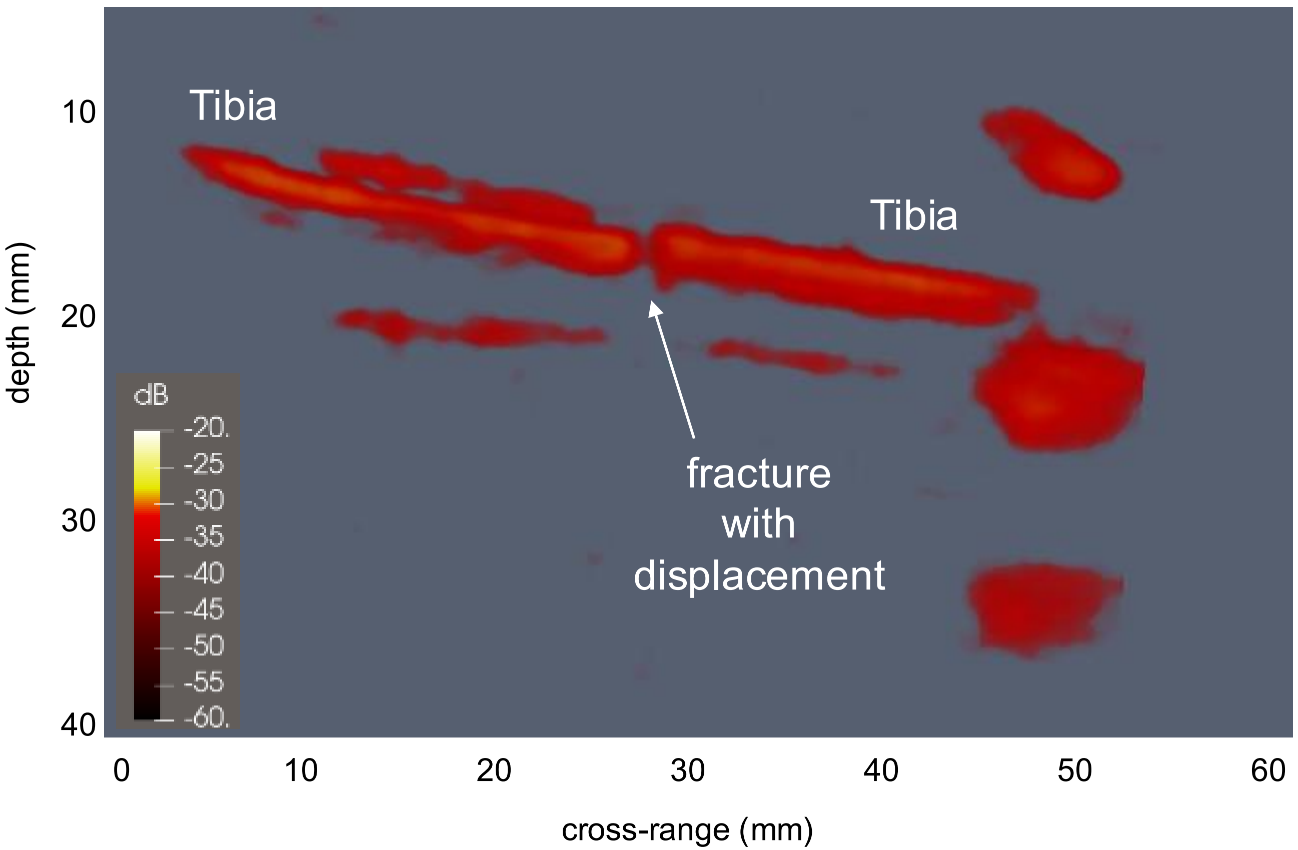


Chicken Leg and Bone – Imposed Fracture in Tibia

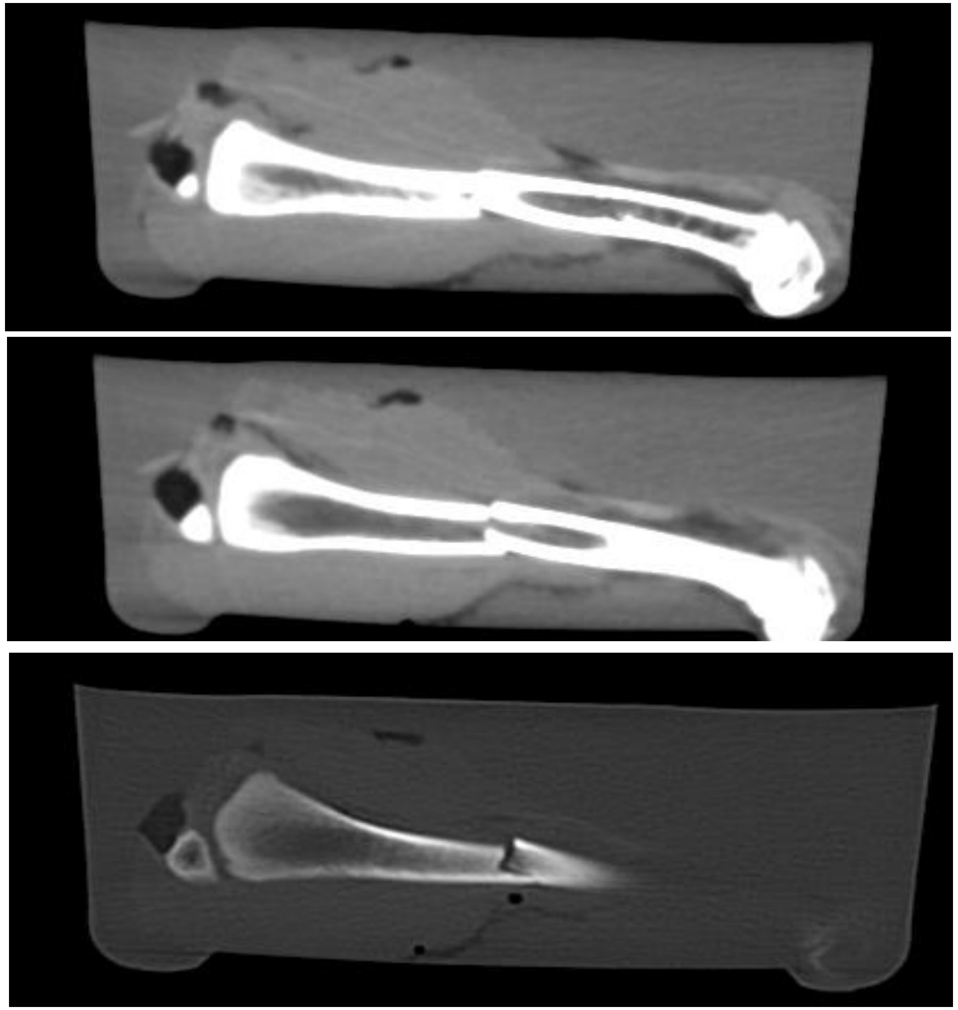


NCLUS Comparison to CT
Fracture Imaging Study in Chicken Leg

NCLUS Image of Imposed Tibia Fracture

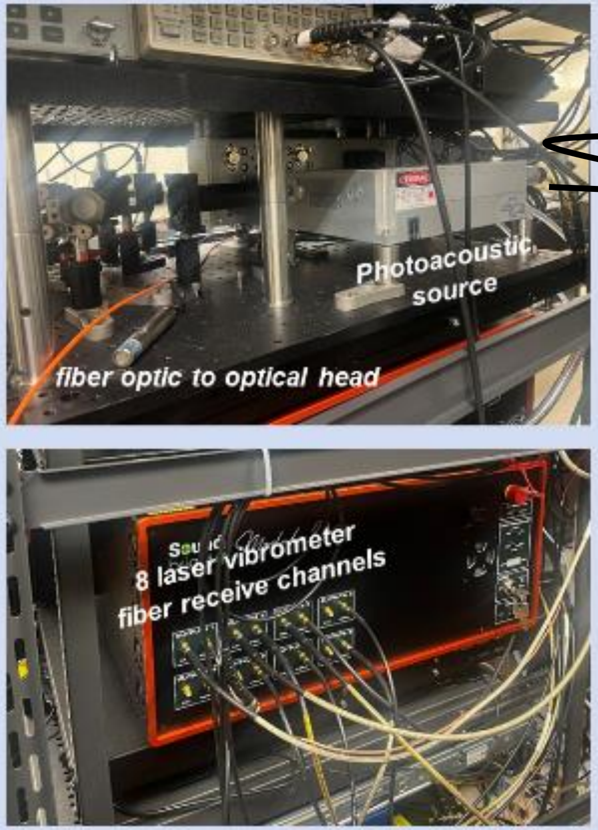


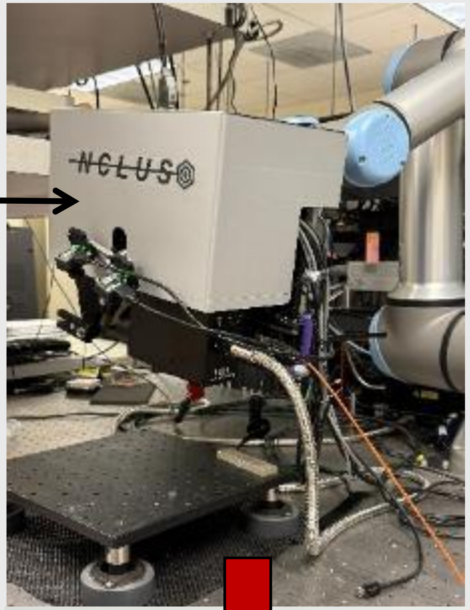
CT Elevation Images of Imposed Fracture in Tibia



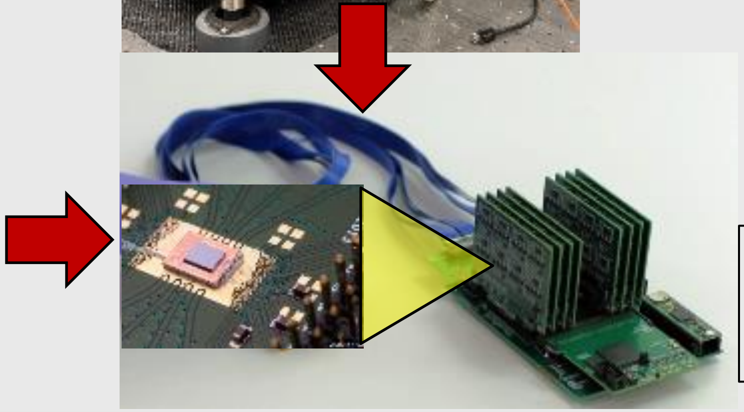
NCLUS Transition to Commercialization

Side Cabinet houses electronics





GEN-3
8 LDV
receivers



Laser Skin-Safe Acquisition	
NCLUS System Evolution	Frame Acquisition Time (sec)
GEN-3 (8 LDVs) *Sensor Scaling Demo*	1 - 60
Photonics (128 LDVs) *Goal System*	0.04
Handheld Probe (128 receivers) *Standard Medical Ultrasound*	0.03

Integrated Photonics
128 LDV Receivers &
increased # of detectors with improved algorithms

Miniaturization through integrated photonic circuitry construction investments will enable strong positioning for competitive commercialization with high impact for new ultrasound capabilites

Publications & Presentations

Patents Issued:

US patent No. 10456044: “System and Method for non-contact ultrasound”: – October, 2019
US patent No. 10602931: “System and method for non-contact ultrasound with enhanced safety” – March, 2020
US patent No. 10835202: “System and Method for Analyzing Shear Waves” - November, 2020.

New Patent Application:

1) RF to Ultrasound for Brain Imaging, Elastography, and Neuromodulation (2022)

Awards:

MIT Lincoln Laboratory Best Invention, 2019, “Noncontact Laser Ultrasound for Biomedical Applications”
R&D 100 and special recognition, 2023, “Noncontact Laser Ultrasound Medical Imaging System”,

Best Invention 2019

100 Award winner

Special Recognition: Disruptor Market Silver Medal

Publications:

Haupt, R.W., R. Gurjar, J. Shaw, B. Green, B. Boitnott , M. Jakoljevic, K. Thomenius, and A. Samir, September, 2023, “Noncontact laser ultrasound (NCLUS): Clinically Relevant Imaging System”, IEEE International Ultrasound Symposium, Montreal, Canada.

Haupt, R.W., A. Samir, A. Fenn, R. Laher, D. Brigada,, 2022, “Noninvasive Ultrasound for Brain Imaging”, IEEE International Ultrasound Symposium, Venice, Italy.

Haupt, R.W., K. Thomenius, A. Samir, M. Johnson, B. Boitnott and M. Jakoljevic, October, 2022, “Noncontact laser ultrasound (NCLUS): Path to Operational Medical System”, IEEE International Ultrasound Symposium, Venice, Italy.

Haupt, R., C. Wynn, J. Fincke, X. Zhang, B. Anthony, and A. Samir, 2019, “Non-contact laser ultrasound for biomedical applications”, *MIT Lincoln Laboratory Journal,* Vol 24, No.1.

Invited Speaker: Haupt, R. and A. Samir, 2020, “Non-contact laser ultrasound system for medical imaging and elastography”, American Institute of Ultrasound in Medicine (AIUM), New York City, U.S.A.

Haupt, R, X. Zhang, J. Fincke, J. Richardson, J. Hughes, B. Anthony, and A. Samir, 2019, “Noncontact laser ultrasound system for medical imaging and elastography”, IEEE International Ultrasonics Symposium, Glasgow, Scotland.

Xiang Zhang, Jonathan R. Fincke, Charles M. Wynn, Matthew R. Johnson, Robert W. Haupt, Brian W. Anthony, 2019, “Full Non-contact Laser Ultrasound: first in-vivo human data”, *Nature: Light: Science and Applications”,* 8(1), 1-11.

Fincke, J., R. Haupt, C. Wynn, S. Xiang, D. Rivera, and B. Anthony, 2018, “Characterization of laser ultrasound source signals in biological tissues”, *J. of Biomedical Optics, 24(2)*.

Backup

Human Test Subject Imaging and Beyond FY26-28

- **IRB in process – Skin Safe Lasing, Safety Protocols** *Completed by 05/2026*

- **Patient Recruitment** *Performed by MGH – Summer FY26 - FY27*
- **Healthy baseline - B-mode and registered 3D volumetric imaging**
- **Repeatable, automated multi-scan tissue imaging for serial feature change tracking for stress fractures in ribs and forearm bones**
- **Refraction tomography to perform elastography and assess bone injury**
- **Comparison to stand US probe imaging**
- **Emphasize where noncontact laser ultrasound can open new areas for medical imaging**

- **Seeking external funding towards commercialization** *In process and through FY27 - 28*

Transition to Clinical Imaging Market

- **GEN-3 System has demonstrated we can acquire a useful US image in less than 1 minute**
- **Commercial system needs to acquire image data in less than 1 second to be competitive with standard US systems**
- **Translation progression requires miniaturization of NCLUS components and increasing 8 LDV channels to 100.**
- **US SNR improvements can be made by scaling more detectors per LDV channel from current 24 to 48 or more**
- **System miniaturization and efficiency can be achieved by converting NCLUS components through integrated photonics circuitry**
- **Lincoln Laboratory is a national expert in the design and fabrication of integrated photonics components**