NIBIB-Sponsored Research: Medical Imaging Technologies & Related Artificial Intelligence Applications

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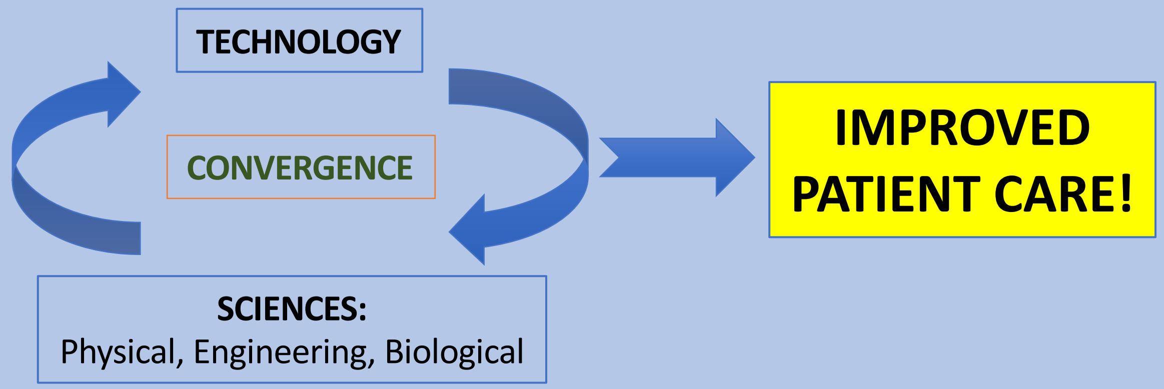
Director, Research Sciences & Strategic Initiatives

National Institute of Biomedical Imaging & Bioengineering

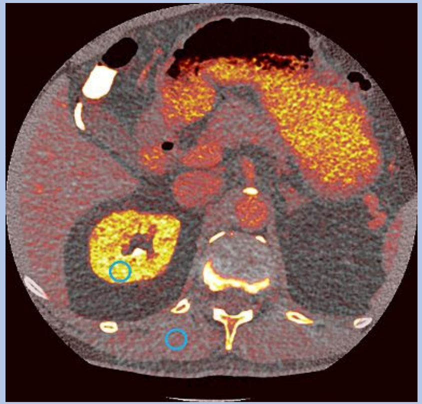
FULLY 3D IMAGE RECONSTRUCTION IN RADIOLOGY & NUCLEAR MEDICINE
July 18, 2023, 9:00-10:00 AM
Stonybrook, NY

National Institute of Biomedical Imaging and Bioengineering

- **Vision**: Engineering the Future of Healthcare
- **Mission:** Develop Accessible & Cost-effective Technologies for Disease Prevention, Diagnosis, Treatment, and Prolongation of Healthy Human Lifespans.
- NIBIB (Est. 2000) has **unique role** in NIH: **INNOVATIVE Technology Development**



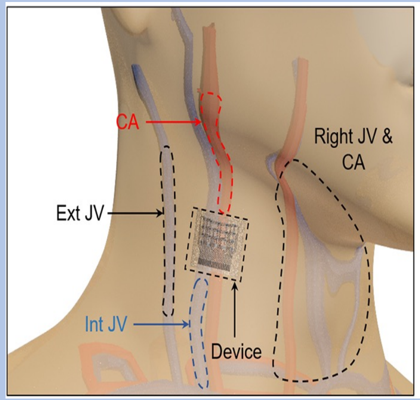
NIBIB Impact: *Technology & Innovation*



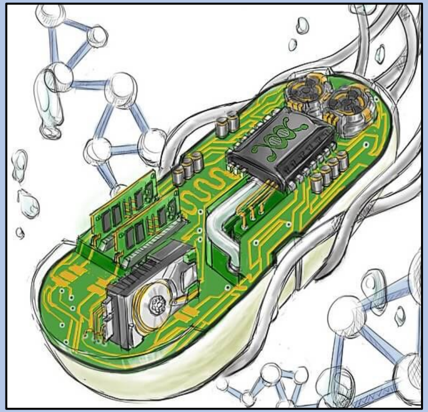
Imaging Technologies

Therapeutic Devices

Computational Methods: Data Science, Modeling, AI/Machine Learning



Sensors & Point of Care



Engineered Biology

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ENGINEERING MEDICAL IMAGING

Medical Imaging & Image-Guided Therapy

- Radiography/Angiography
- Ultrasonography
- Computed (XRAY) Tomography
- Radionuclides: Nuclear & Molecular Imaging
- Magnetic Resonance Imaging
- Optical Imaging

Trends in Medical Imaging

- Faster, Smaller, Less Expensive, Better and more Accessible Devices

- Multiscale Imaging

- Without compromising image quality or quantity of information content

➢ **Driving Diagnostic Precision**

Medical Imaging & Image-Guided Procedures are Evolving

- Anatomical ➡ Functional (Physiology, Motion)
- Image-guided ➡ Information-Guided
- Dawn of Artificial Intelligence: Machine Learning (segmentation, CAD) & Deep Learning (CNN) – and beyond!

Source: Kandarpa K, Jolesz FJ. Image-guided Vascular Interventions. Biomedical Imaging Research Opportunities Workshop II: Report and Recommendations (Special Reports). Radiology 2005; 236: 389-403.

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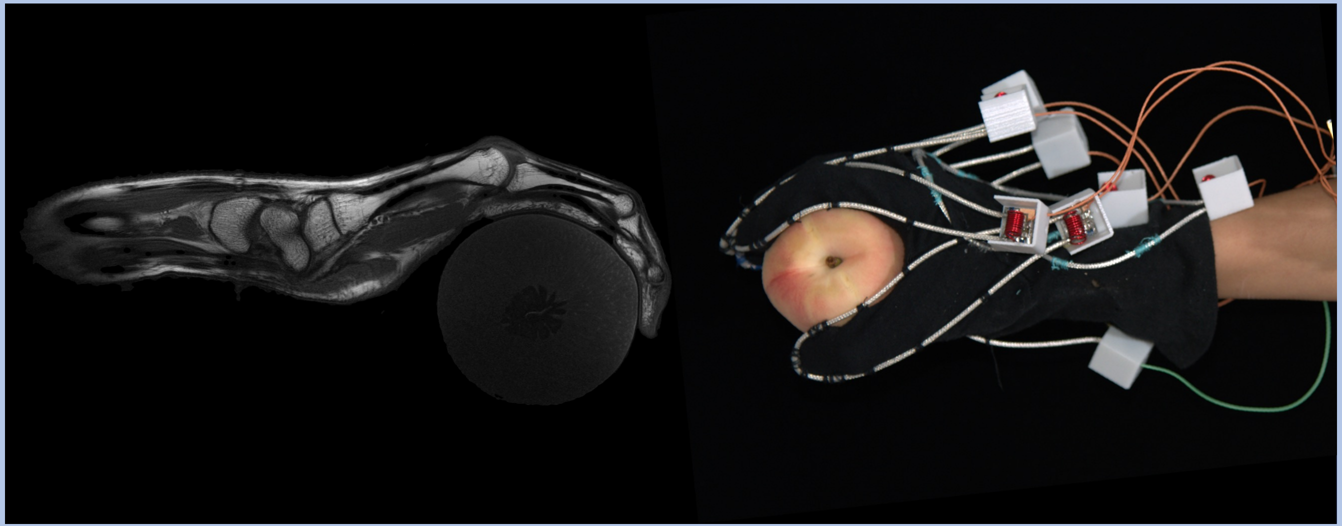
FASTER IMAGING

Improving Extremity Magnetic Resonance Imaging

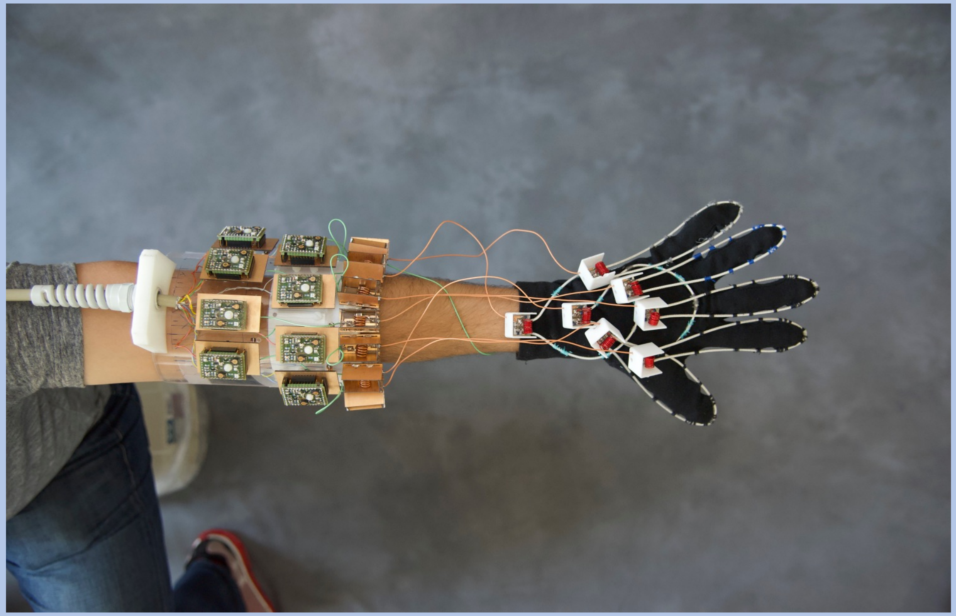
The **Glove Coil*** follows finger contours with individual flexible high-impedance elements allowing un-degraded high-resolution visualization of the mechanics of bones & adjacent soft-tissues in motion.



* Bei Zhang, Sodickson DK, Cloos MA. A high-impedance detector-array glove for magnetic resonance imaging of the hand. *Nature Biomedical Engineering*, 2018; DOI: 10.1038/s41551-018-0233-y

Improving Extremity Magnetic Resonance Imaging

The Glove (High-Impedance) Coil



Bei Zhang, Sodickson DK, Cloos MA. A high-impedance detector-array glove for magnetic resonance imaging of the hand. *Nature Biomedical Engineering*, 2018; DOI: 10.1038/s41551-018-0233-y

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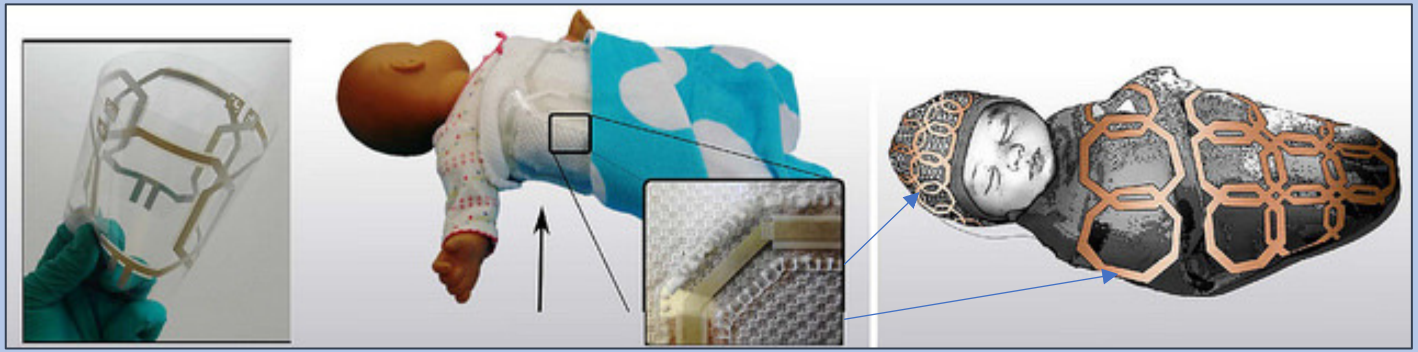
SMALLER IMAGERS

Improving Pediatric Magnetic Resonance Imaging

Coddling-coils* reduce motion-related image degradation, exam time, and sedative drug use



* ‘Radio’ signals received from the body by RF-coils are converted into images

Source: Ana Arias, University of California, Berkeley

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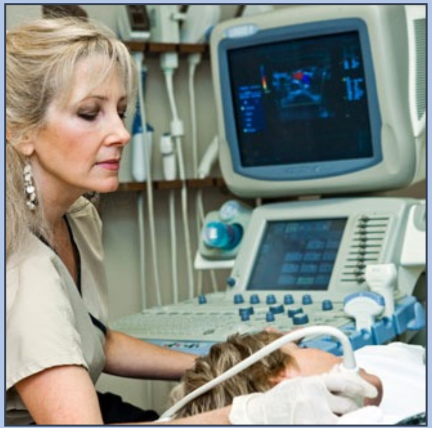
LESS EXPENSIVE IMAGING

More Accessible

Pocket-sized, Low-cost Ultrasound (Vscan™)

- NIBIB RFA ON LOW-COST IMAGING ('03)
- Product provides physicians with non-invasive point-of-care imaging capabilities!



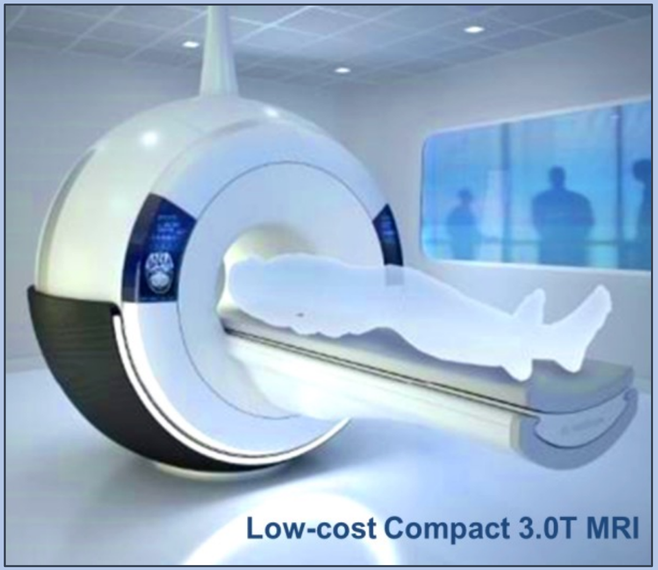
Traditional Systems: $150-200K

Popular Science Magazine
2010 Top Innovation!
V-scan: $8,000!

Lower Cost Compact 3T MRI

PI: M. Bernstein (Mayo Clinic)

- Motivation: Global shortage of MRI - wide disparities in access
- A lower-cost, easy installation, compact system for heads, extremities, and infants could significantly expand access → battlefield, TBI, Sports – potential use in neurosurgical suite
- Helium is a non-renewable resource in short supply



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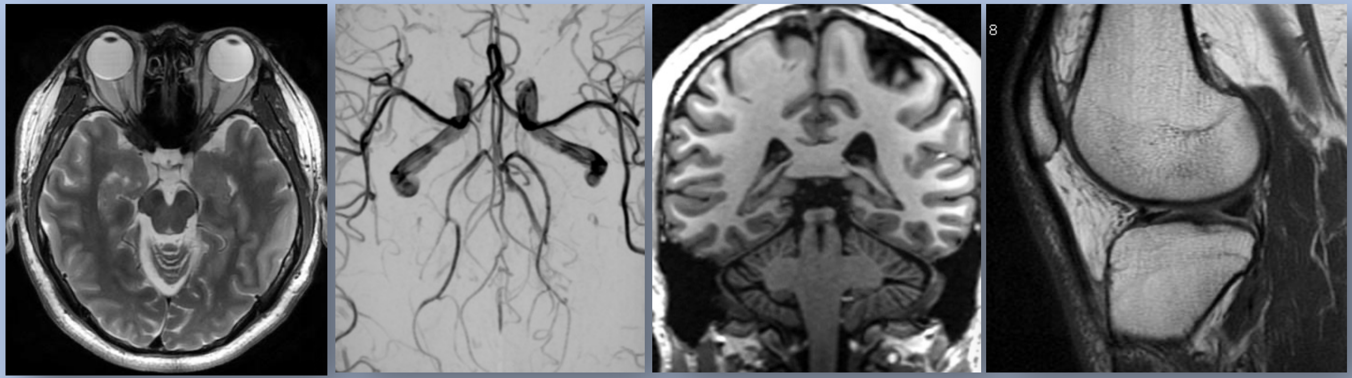
MAYO CLINIC

National Institute of Neurological Disorders and Stroke

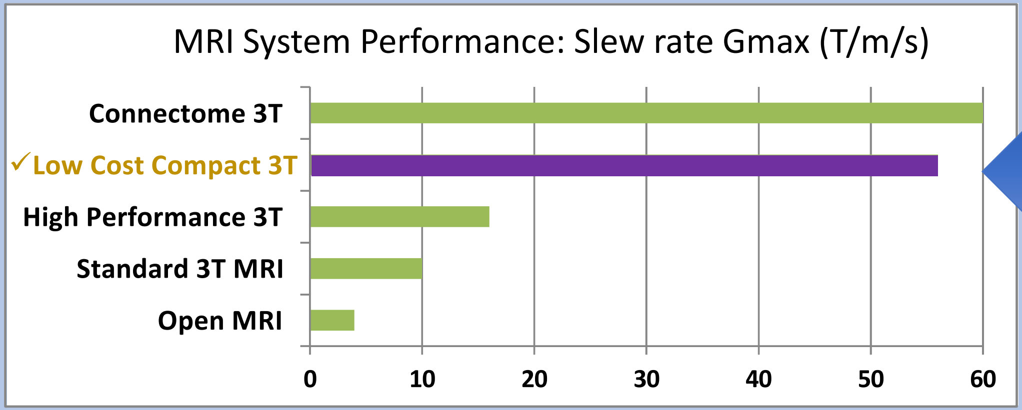
- ✓ A Public – Private - Academic Partnership
- ✓ NIH Grant: BRP-R01-EB010065 (2010)

Lower Cost Compact 3T MRI



2015: First Human Images from Low-cost Compact 3T System

Comparison to
Standard 3T MRI
~ ¼ weight
< 1% helium
< ½ space



Improved Performance

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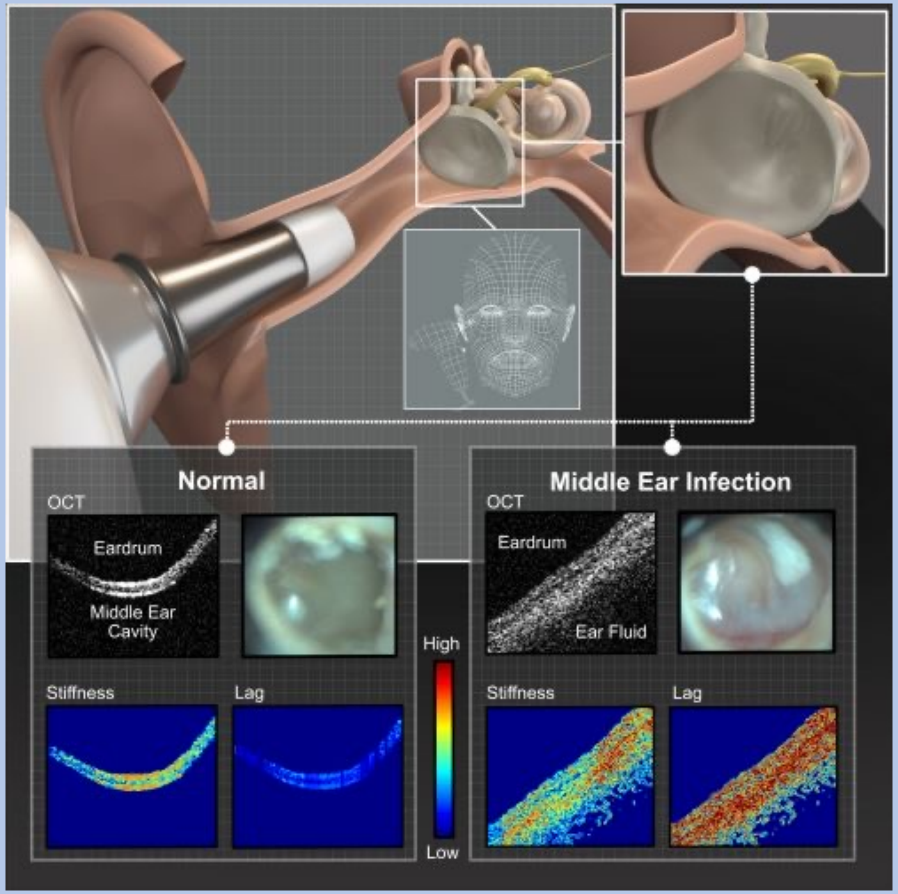
High Through-Put POINT-OF-CARE IMAGING
Increasing Accessibility

Diagnosis of Middle Ear Infections (Otitis Media)

- More than 80% of children will have at least one ear infection by their third birthday.
- Handheld and non-invasive optical coherence tomography (OCT) is useful for diagnosing and monitoring *in vivo* response of biofilms and middle ear effusions to therapy



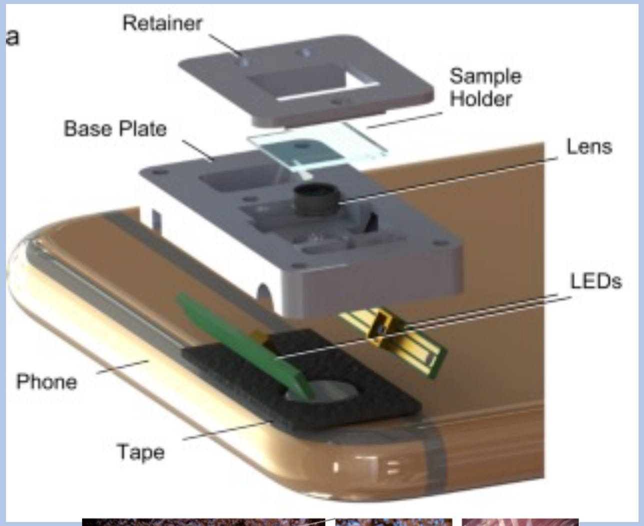
Credit: Boppart Laboratory; University of Illinois Urbana-Champaign

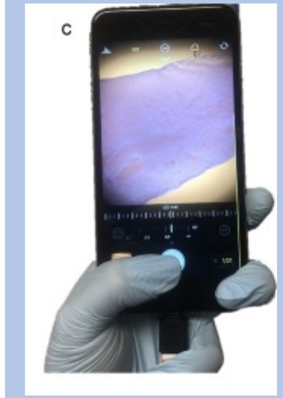
Fluorescence microscope using a smartphone

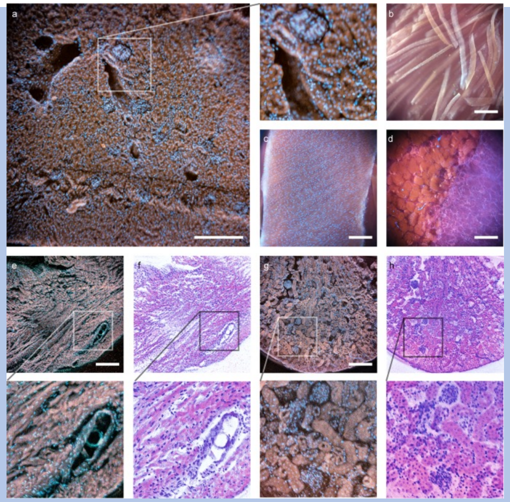
- Pocket MUSE: affordable, versatile and high-performance Microscopy based on Ultraviolet Surface Excitation

- Small optical module attaches directly over the rear lens of a smartphone

- Point-of-care diagnostics: thick sections, simpler sample prep





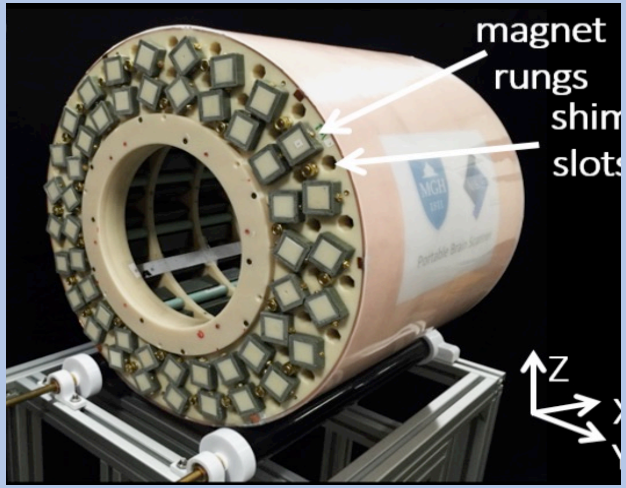


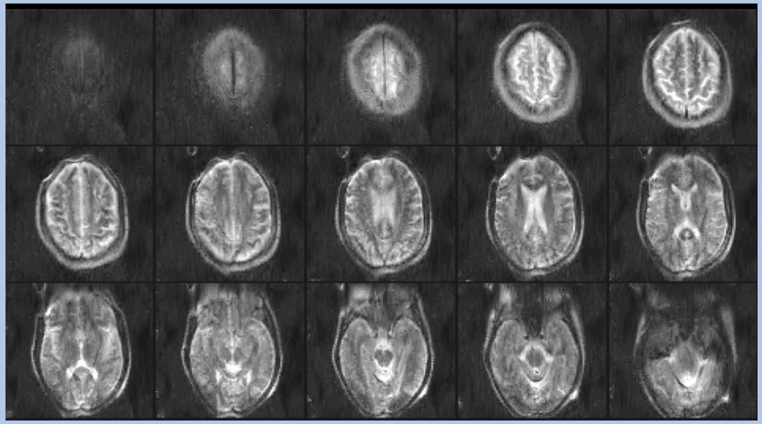
Portable, Low-Field MRI Brain Scanner

- A truly portable brain scanner for "point-of-care" detection and diagnosis.
- Lightweight (300 lb.) cryogen-free Halbach magnet with 77-mT field strength
- Rotating magnet for spatial encoding to eliminate conventional gradients

Prototype scanner

Rotating Halbach Magnet





Images of Human Brain

Credit: Larry Wald (MGH)

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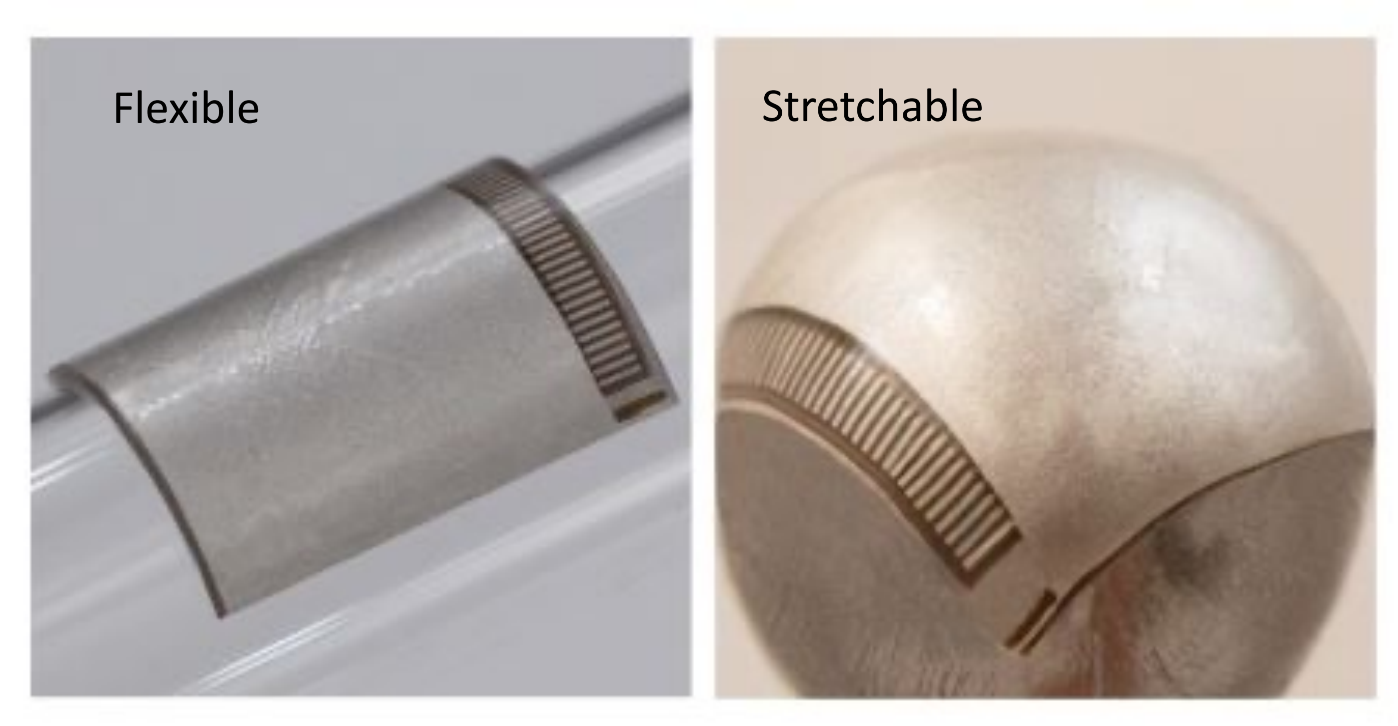
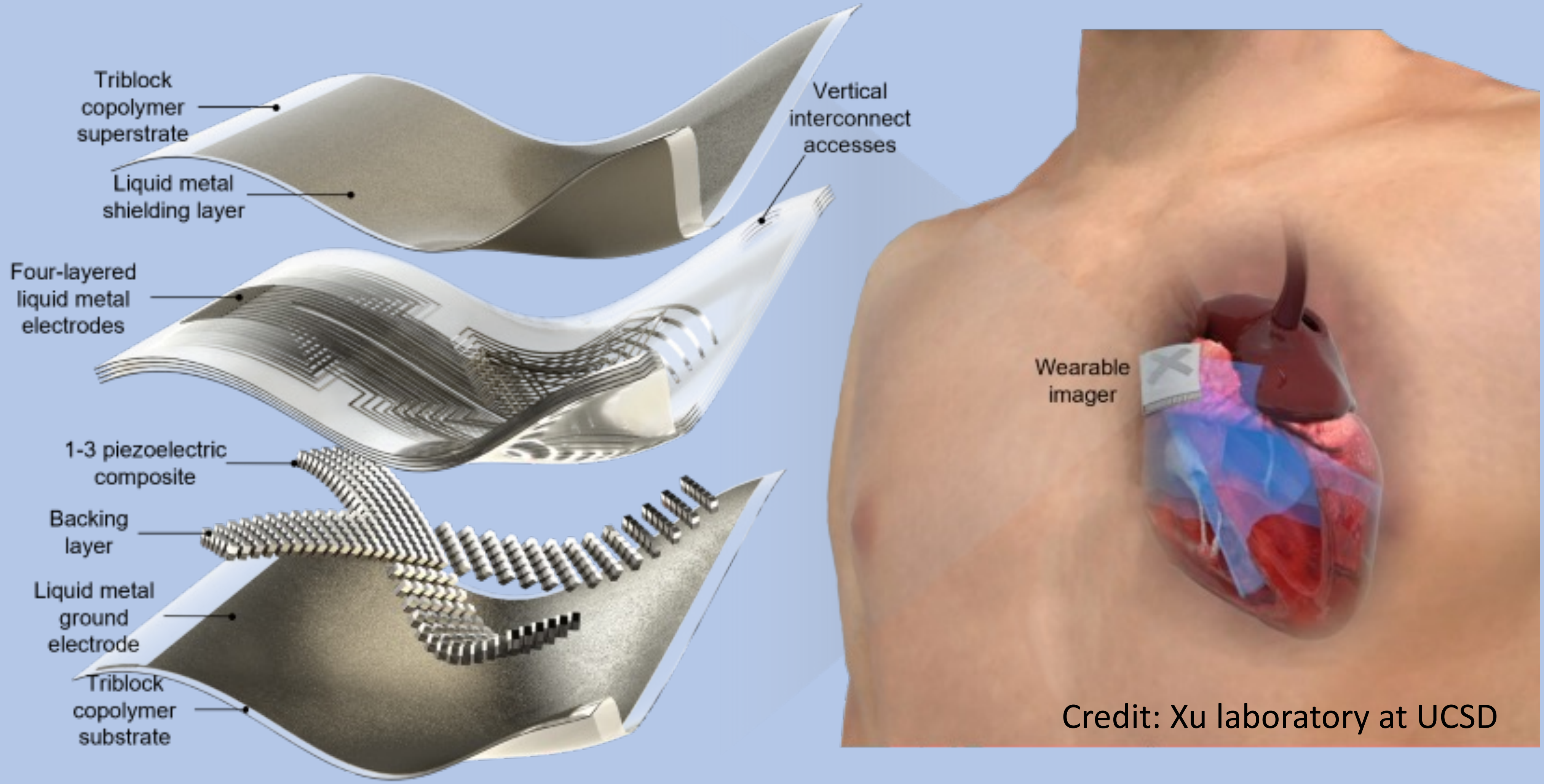
Creating Biomedical Technologies to Improve Health

WEARABLE ULTRASOUND PATCHES



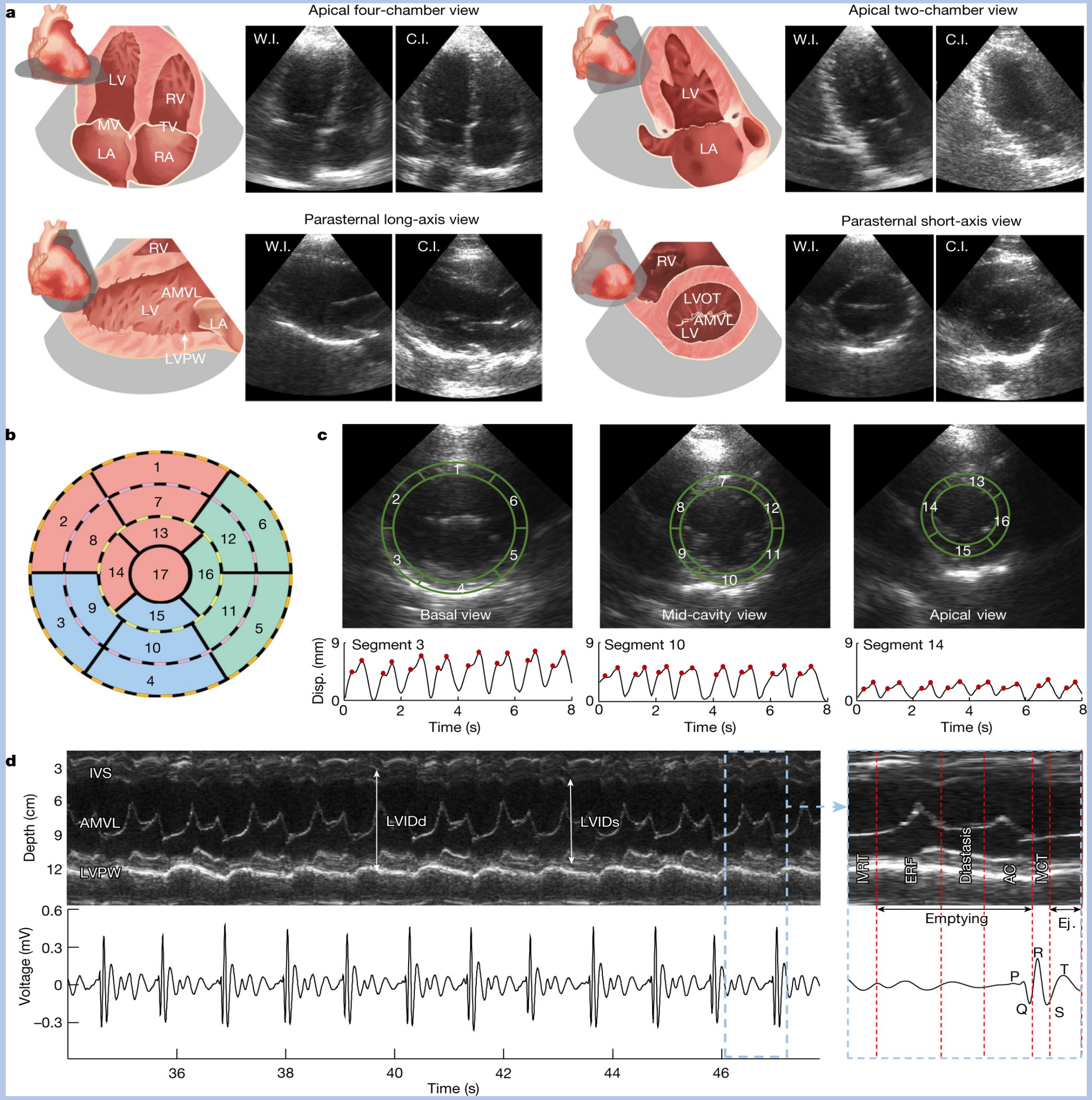
Credit: Xu laboratory at UCSD

Exploded view of POC Cardiac Ultrasound Imager



Credit: Xu laboratory at UCSD

Schematics and B-mode Images of Cardiac Anatomy



B-MODE - APICAL & PARASTERNAL VIEWS:
WI: Wearable Imager
CI: Commercial imager

Segmental B-mode views of LV Wall

Segmental Displacements

M-Mode Images

EKG

Hu, H., Huang, H., Li, M. *et al.* A wearable cardiac ultrasound imager. *Nature* **613**, 667–675 (2023). https://doi.org/10.1038/s41586-022-05498-z

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INNOVATIVE IMAGING FOR CARE-CHANGING MINIMALLY INVASIVE DIAGNOSIS & THERAPY

Improving Image Quality & Quantity of Information Content Drives Diagnostic Precision

Refining the Characteristics of Tissues:

1. Through new sources of Tissue Contrast

2. Determine Composition/Texture/Mechanical Properties

3. Fodder for Deep Learning Tasks → Precision Diagnostics

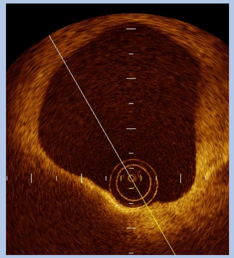
Improving Image Quality & Quantity of Information Content Drives Diagnostic Precision

Refining the Characteristics of Tissues

Composition

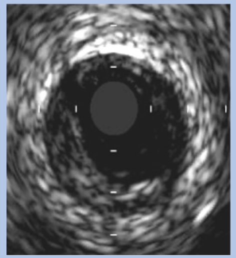
Endovascular Tissue Composition: Miniaturized ultrafast OCT+US System

Imaging and characterizing atherosclerotic plaques in vivo (2015)



IV Optical Coherence Tomography:
(Thin-cap fibro-atheroma ~ 60 μ)
High resolution, poor imaging depth

If IVUS and OCT are used separately to query the plaque, the modalities agree in only 2% of cases of thin-cap fibroatheromas (TFCA).



Intravascular Ultrasound:
(Full thickness of plaque)
Low resolution, good imaging depth

"The combined use of these complementary imaging modalities should be considered a feasible approach for more precise detection of vulnerable plaque" K. Fujii, *et al*., JACC imaging (2015).

J. Li et al., Scientific Reports, 5:18406 (2015)

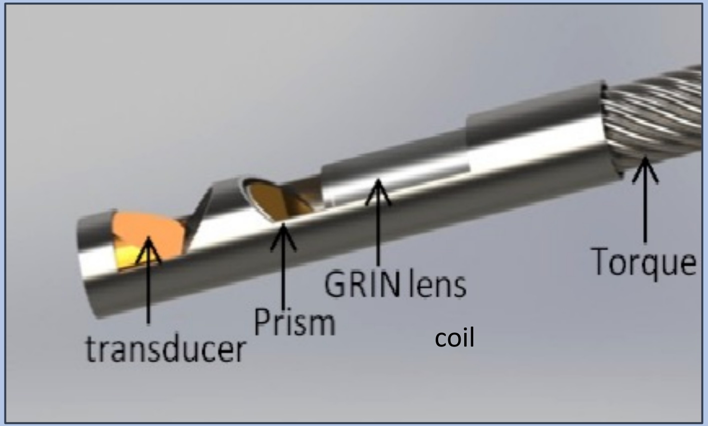
Endovascular Tissue Composition: Miniaturized ultrafast OCT+US System

Current Limitations:

- Available: IVUS images at 30 fps & OCT @ 100fps
- Employed serially – highest usable speed is limited by IVUS, prolonging procedure time

New High Speed IVUS/OCT:

- Simultaneous images @ 72 f/s, without necessity for contrast injection
- Visualizes entire plaque burden – cap and a necrotic lipid core - 72 mm of artery in 4 seconds,
- Shortens procedure time; reduced risk of spasm and other complications



120 cm, 0.014” OTW

Clinical trials ongoing

High Speed IV: US/OCT Imaging of Rabbit Abdominal Aorta at 72 f/s

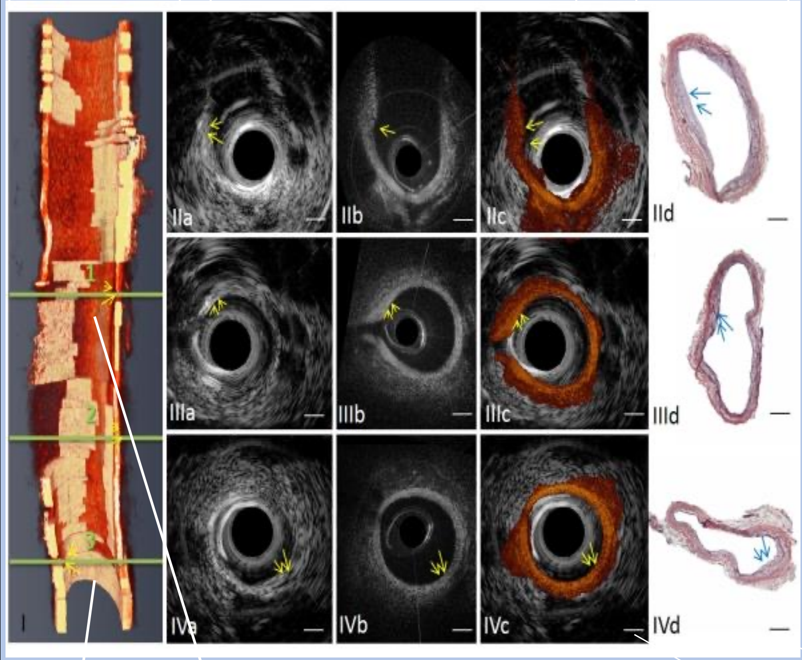
IVUS

OCT

3D-Vol

Fused X-sections

Histo.



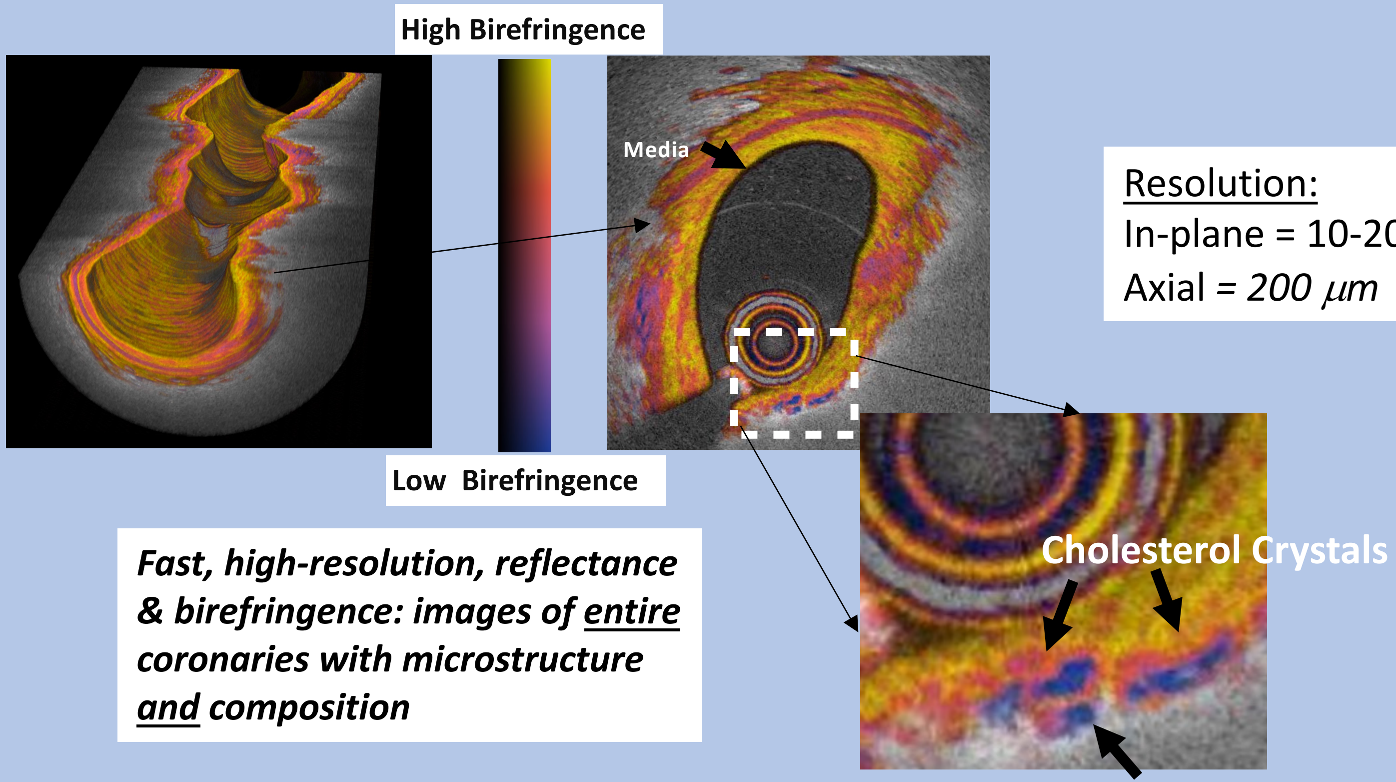
Lipid

Artery Wall

Scale: 5mm

J. Li et al., Scientific Reports, 5:18406 (2015)

Optical Frequency Domain Imaging (IR-OFDI) of Human Coronary Disease



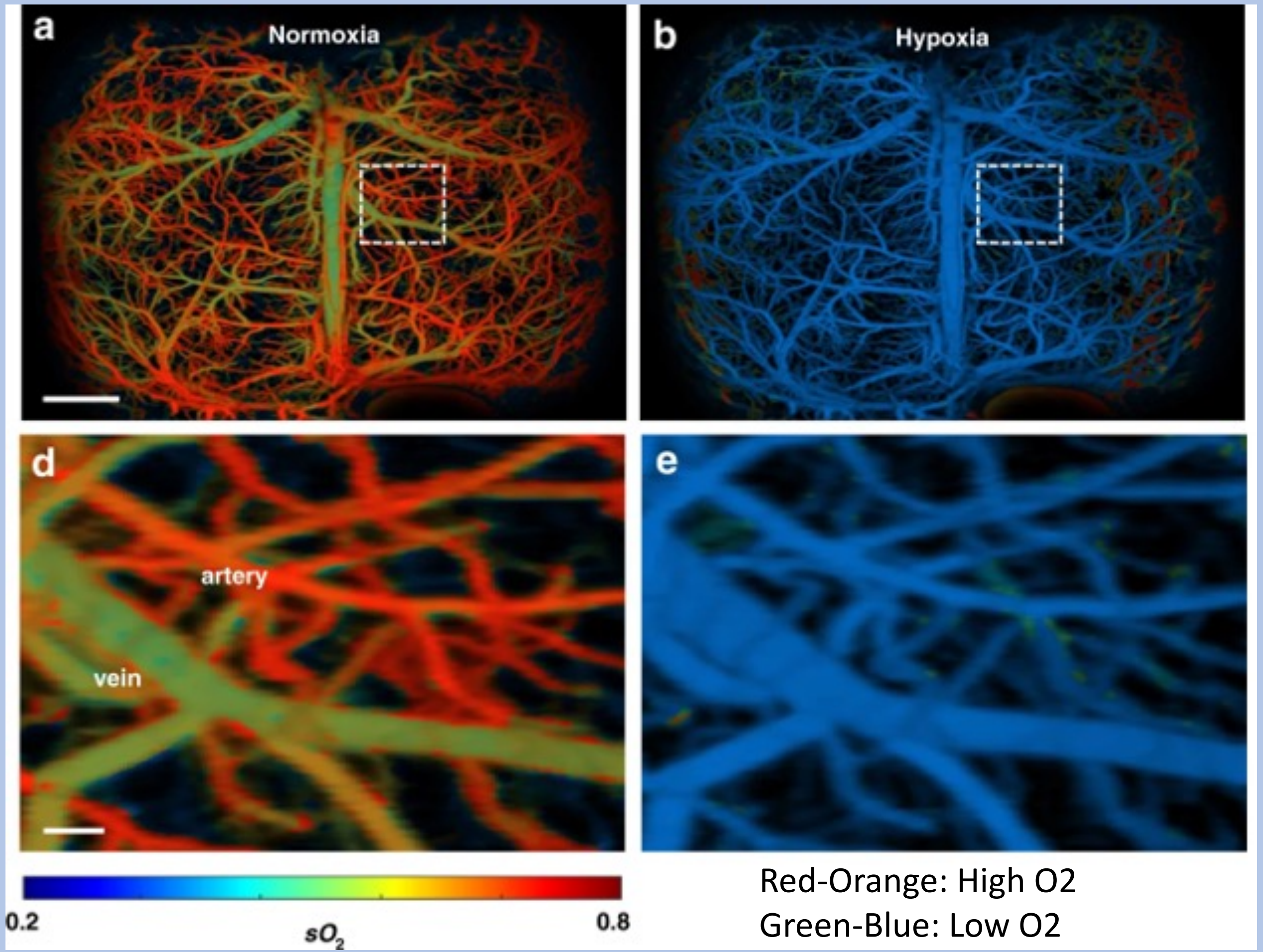
Resolution:
In-plane = 10-20 μm
Axial = 200 μm

Fast, high-resolution, reflectance & birefringence: images of entire coronaries with microstructure and composition

Timmins L et al. U of Utah (2018)

Imaging Microvasculature

Imaging Blood (Hgb) Oxygenation



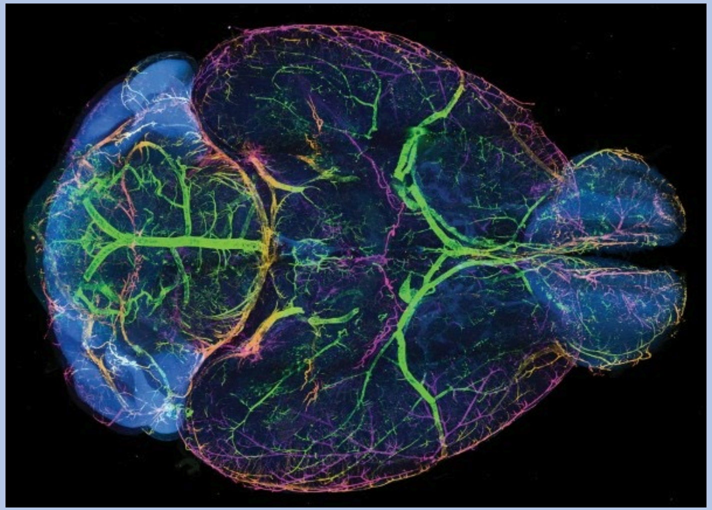
Red-Orange: High O2
Green-Blue: Low O2

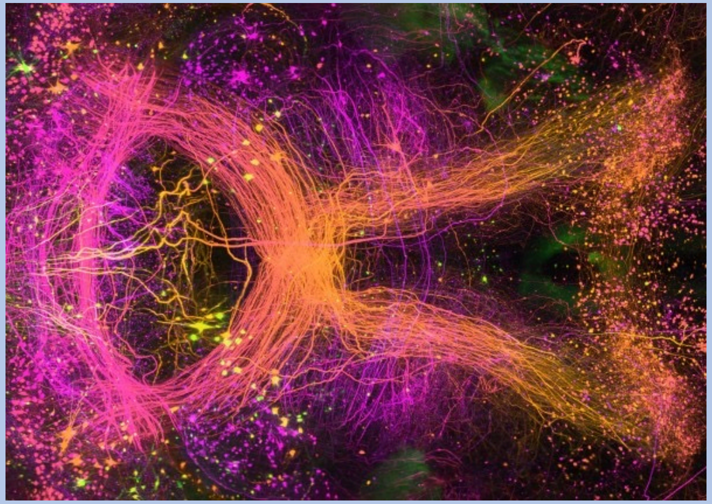
Ultra-fast photoacoustic microscopy (UFF-PAM) tracks blood O2 & wall dynamics of brain disorders in mice

Credit: Zhu, X., et al. Light Sci Appl 11, 138 (2022)

Multi-scale Hybrid Microscopy

- Development of hybrid open-top light-sheet (OTLS)
- Open-top platform allows imaging the specimen in wide open arrangement
- Increases efficiency of multiscale (*in vivo*) imaging while also being accessible to several research and pathology laboratories





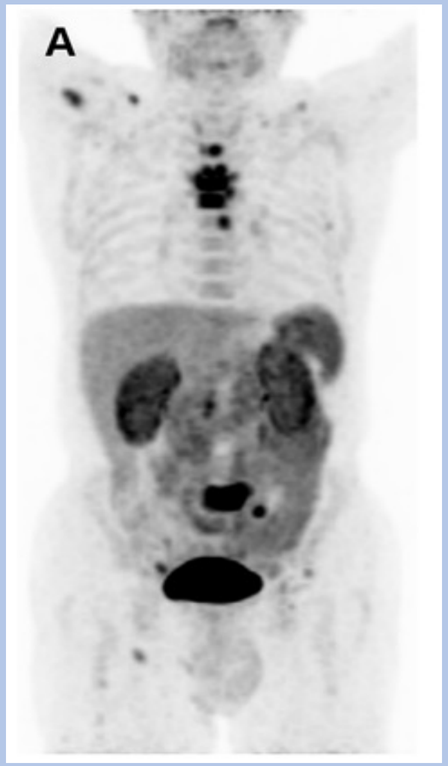
IMAGING ANGIOGENESIS

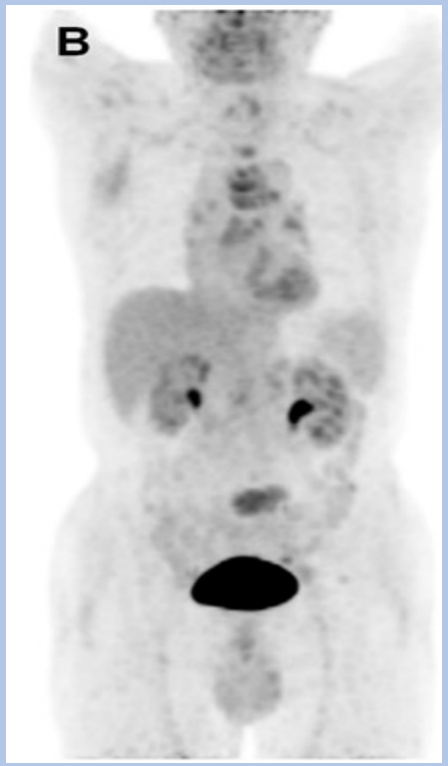
Improving PET Imaging

RGD Peptide (18F-alfatide) binds to Integrin receptor which is overexpressed in angiogenesis, complementing FDG PET (glycolysis imaging)!

Developed at NIBIB (IM):
Shaun Chen, Ed. Theranostics

Imaging ANGIOGENESIS with PET





RGD **FDG**

Intense Tumor Uptake

RGD shows more intense bone uptake than FDG

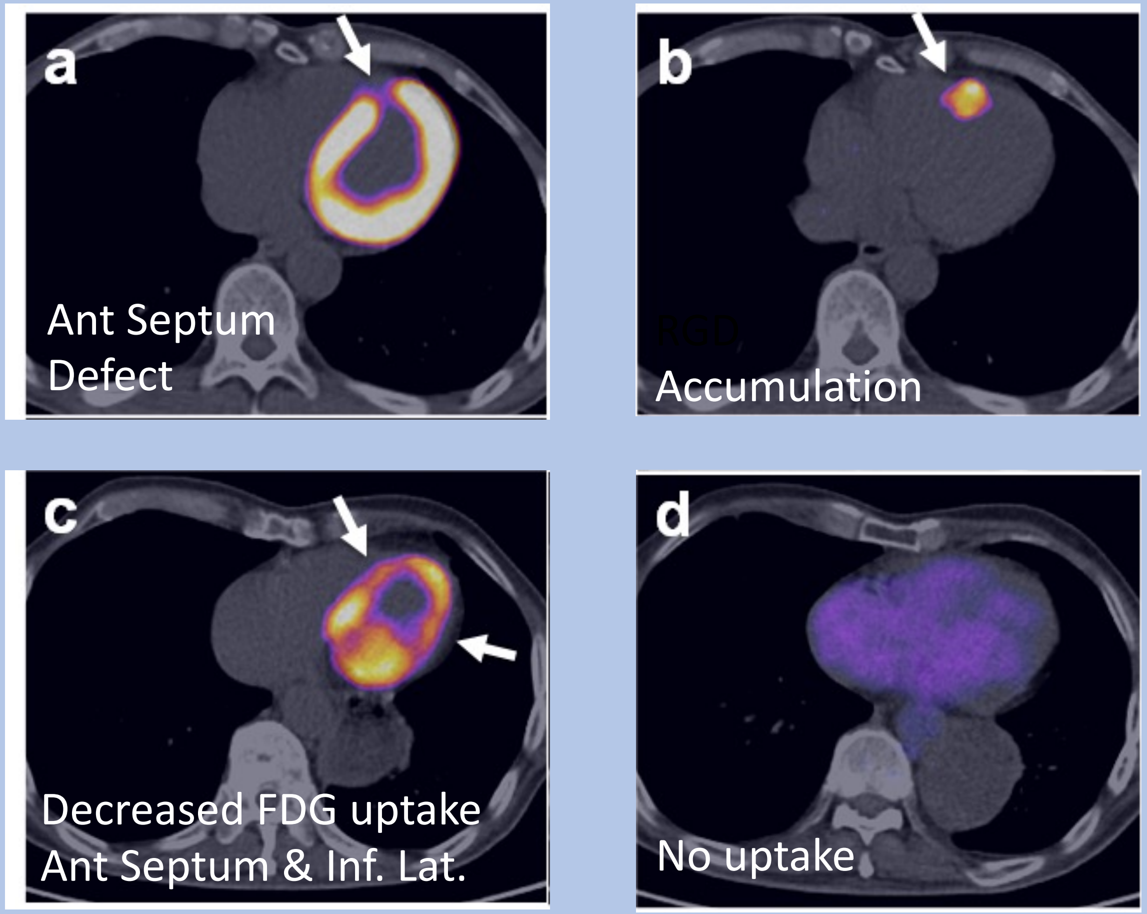
Wan L et al. J Nucl Med, 2013; 54(5):691-8.

Mi B et al. Theranostics 2015; 5: 1115-1121.

Myocardial Infarction Imaging

Pt#1
Acute
1 week

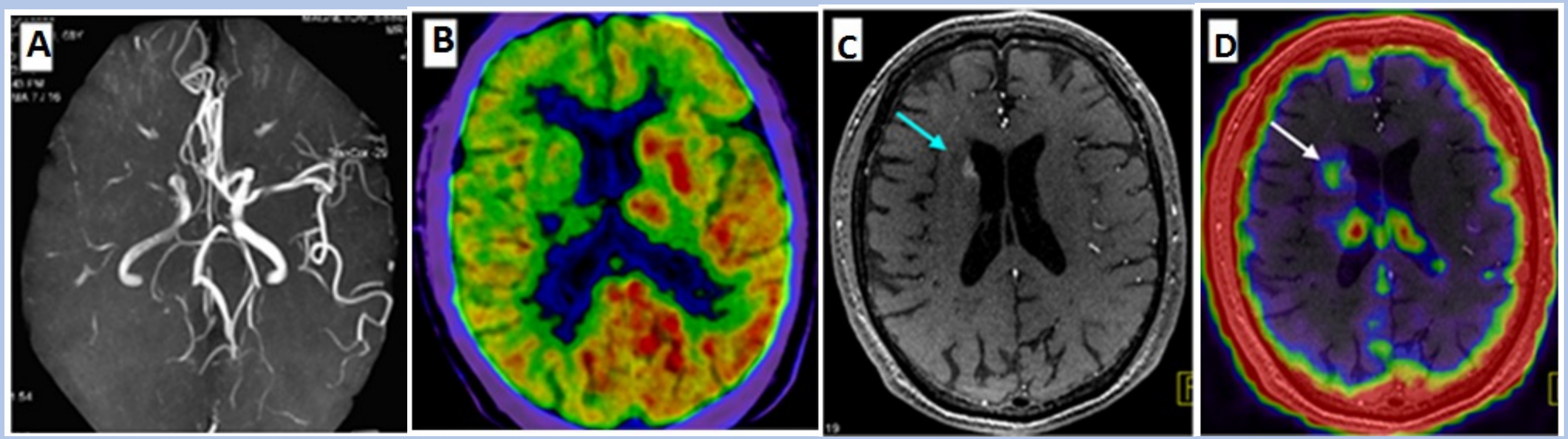
Pt#2
Chronic
~ 2 yr.



FDG RGD

Sun Y et al. Theranostics, 2014;4(8):778-786.

Stroke Imaging



MR Angio
Obstruction of right middle cerebral artery

FDG
Diffuse low metabolism (right hemisphere)

CE-MRI
Infarct near anterior horn of right lateral ventricle

RGD
Increased uptake anterior to the right choroid plexus

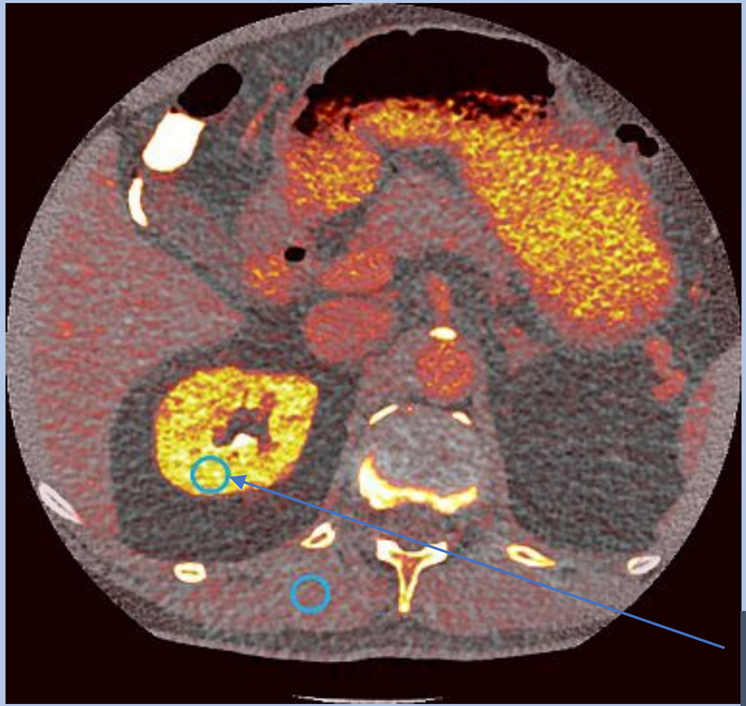
Improving Image Quality & Quantity of Information Content Drives Diagnostic Precision

Refining the Characterization of Tissues

Texture

Refining Tissue Characteristics using Photon-Counting CT

NIH Clinical Center and Mayo Clinic



NIH CLINICAL CENTER IMAGE

BRIGHTER YELLOW =
MORE IODINE CONTRAST

- CONVENTIONAL CT SCANNERS DETERMINE AN AVERAGE ENERGY PER VOXEL (Bone/Fat/Soft Tissue/Air)
- SPECTRAL-CT COUNTS PHOTONS (SPECTRUM) WITHIN A VOXEL
  - **IMPROVES TISSUE CHARACTERIZATION** (Composition & Texture)
  - EXCLUDES ELECTRONIC NOISE (ALLOWS VERY LOW-DOSE PROTOCOLS)
  - INCREASES SIGNAL-TO-NOISE RATIO
  - IMPROVES SPATIAL RESOLUTION (0.15mm) – IMPROVING IMAGE QUALITY!
  - SIMULTANEOUS single-kV SPECTRAL IMAGING IMPROVES EDGE RESOLUTION
  - DISTINGUISHES MULTIPLE K-edge CONTRAST AGENTS

Next Steps: Develop Contrast Agents

Pourmorteza A, et al. Radiology 2016; 279: 239-245.

Dynamic Myelography using Photon Counting CT

Detection of Occult Cerebrospinal Fluid Leaks

Ajay Madhavan; Mayo Clinic

A New Era of CT!

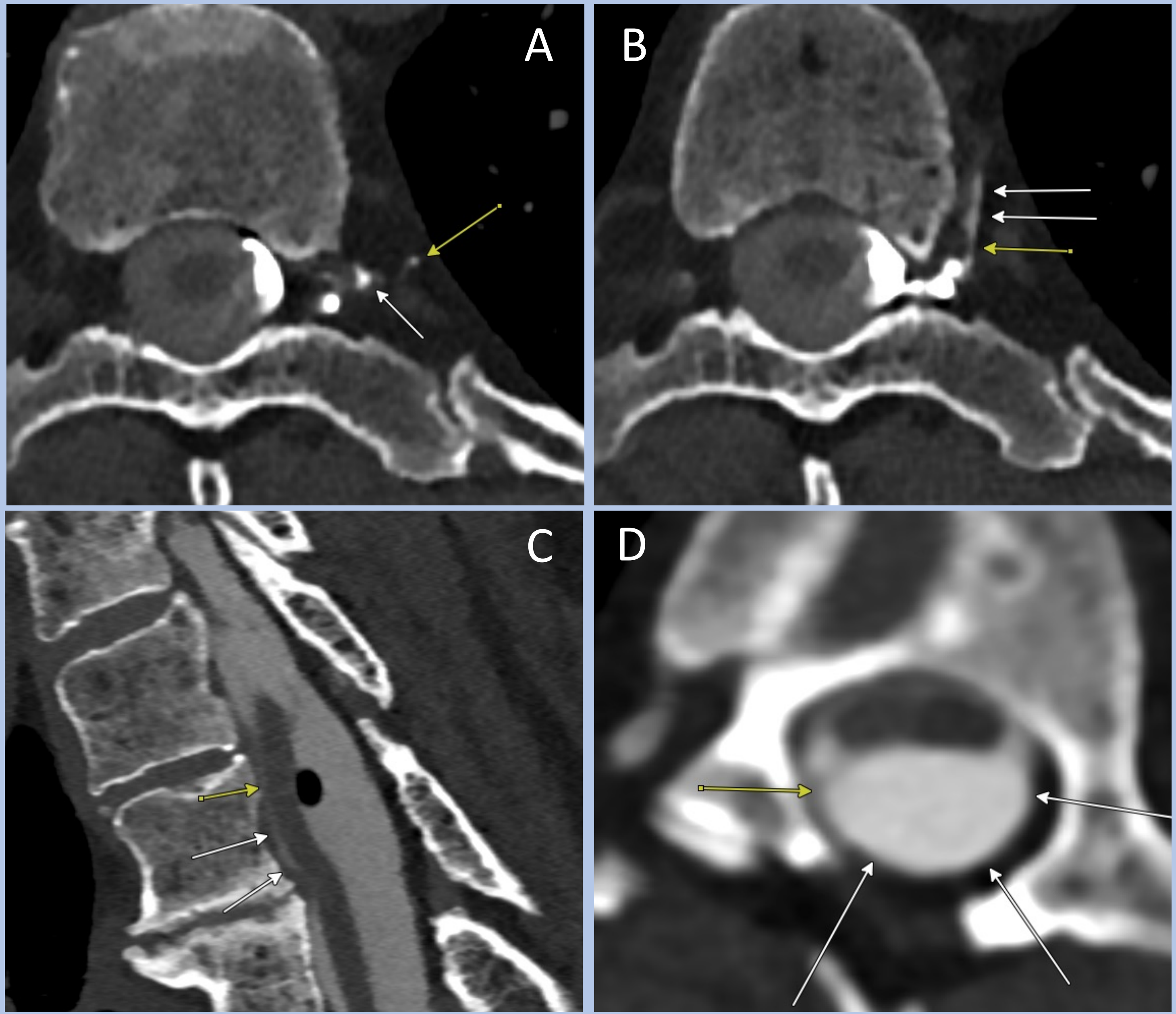
- **Ability to exclude electronic noise**
- **Increased iodine SNR**
- **125-micron resolution**
- **Simultaneous, single kV, multi-energy CT**
- **Multi-energy UHR and cardiac CT**
- **Image multiple k-edge contrast agents**

Dynamic Myelography with PCD CT

74-year-old woman with several months of orthostatic headaches. Brain MRI showed diffuse pachy-meningeal enhancement.

Left lateral decubitus ultra-high resolution images from her **PCD CT myelogram** demonstrates a left **CSF-venous fistula** at T-9 level (A-B, arrows).

Focal ventral displacement of her spinal cord at T-3; findings suggest a **dorsal arachnoid cyst** (C-D).



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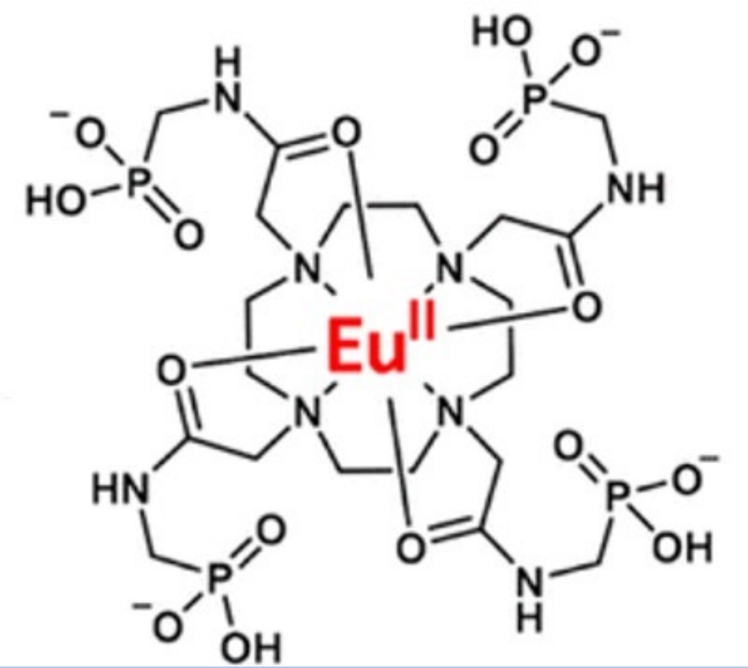
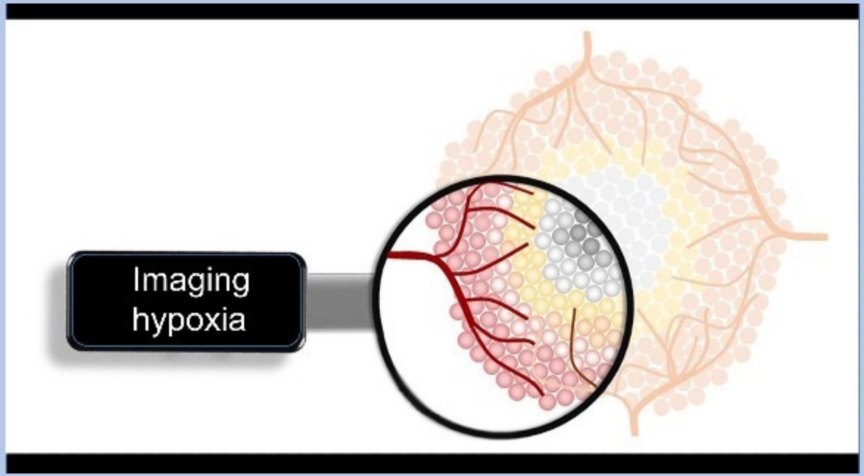
Creating Biomedical Technologies to Improve Health

Refining Tissue Characterization: Novel MR Contrast Agents



Protective "molecular cage" surrounding an atom of europium.



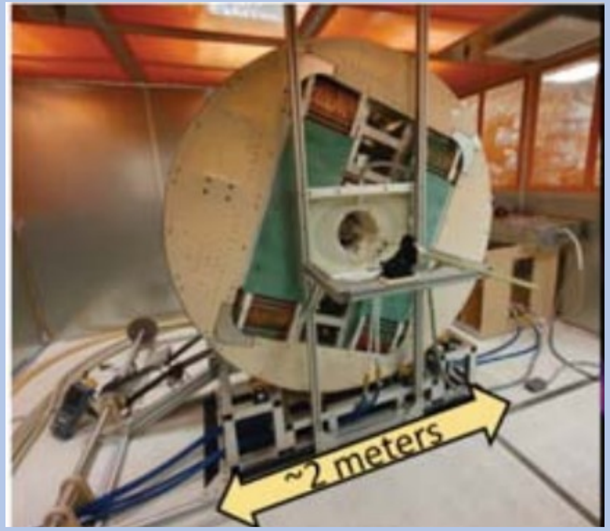
Decreasing oxygen levels from the periphery to the center of a solid tumor

Rare-earth metal—**europium (Eu)—**to obtain enhanced **MR** images of **areas of hypoxia in tumors**.

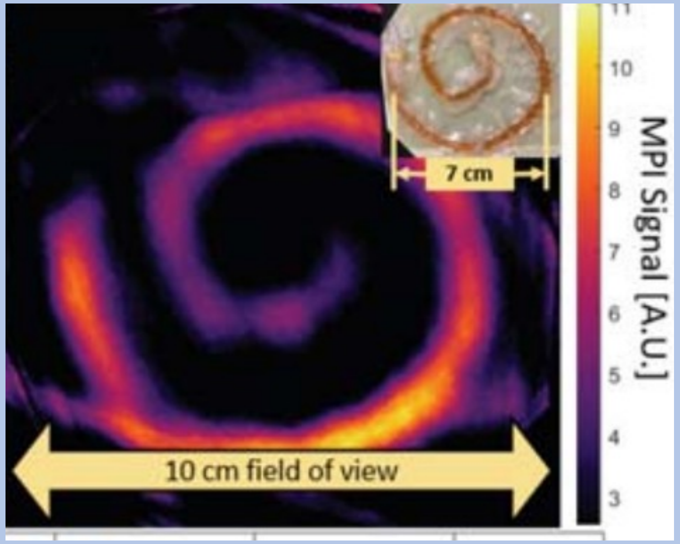
Credit: M.J Allen Wayne State University.

Magnetic Particle Imaging for Brain Functional Study

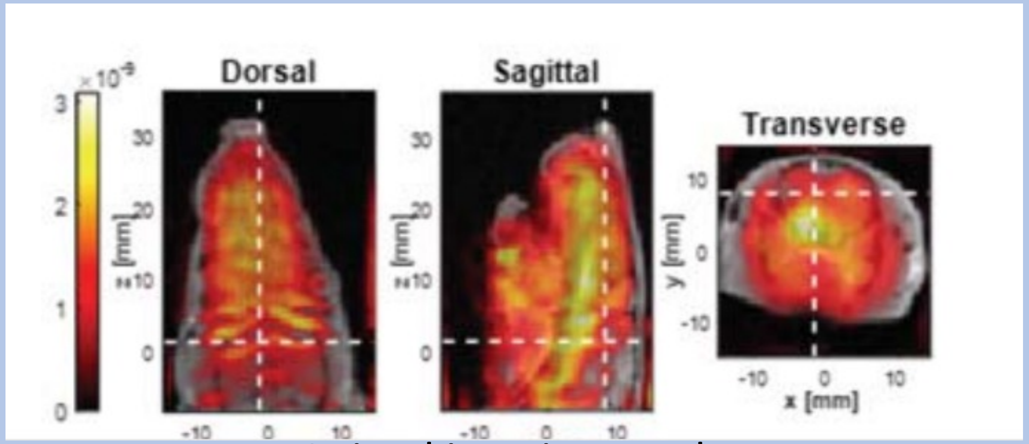
- MPI uses the non-linear magnetic response of iron-oxide nanoparticles to localize their presence in the body.
- It detects the nanoparticle's magnetization rather than using secondary effects on the Magnetic Resonance relaxation times.
- It could result in a potential 10-fold increase in the contrast-to-noise ratio (CNR) of cerebral blood volume (CBV) imaging of neuronal activation.



Prototype scanner



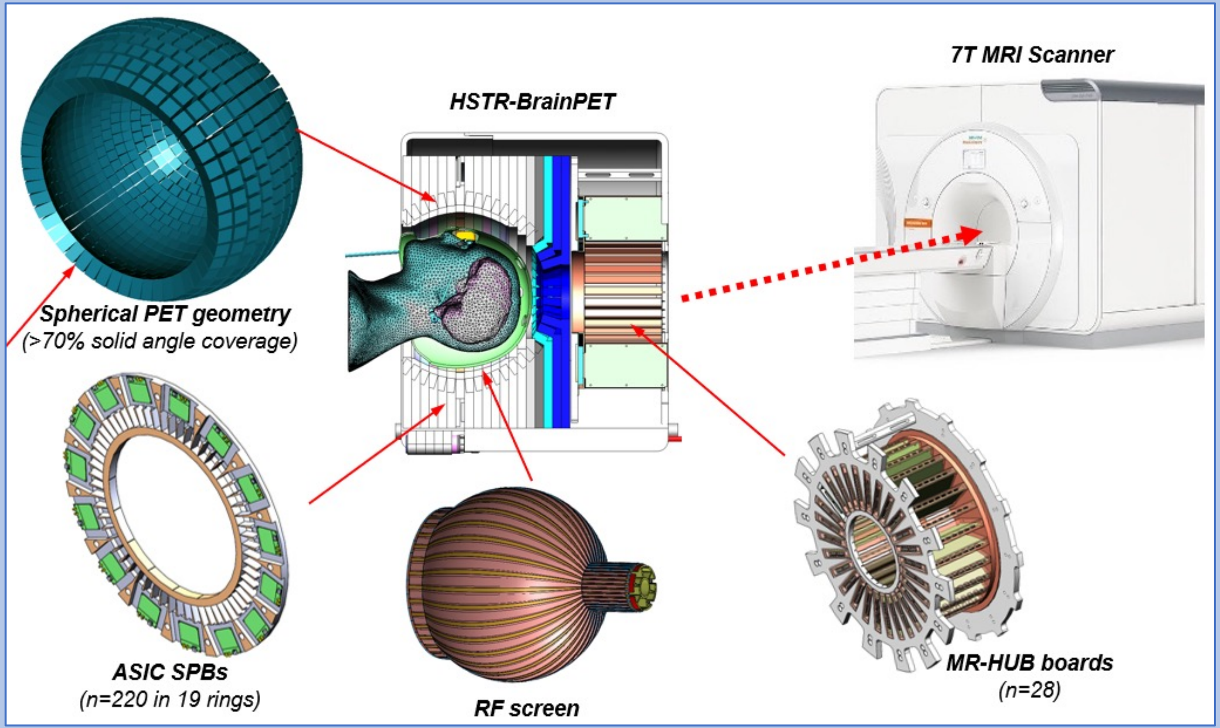
Phantom image



Animal imaging result

Credit: Larry Wald (MGH)

Dynamic Neurochemical Connectome Scanner



Credit: Catana, C; MGH

Spherical Human Brain-PET insert, integrated with the 7-T MR scanner with unprecedented PET S&S:

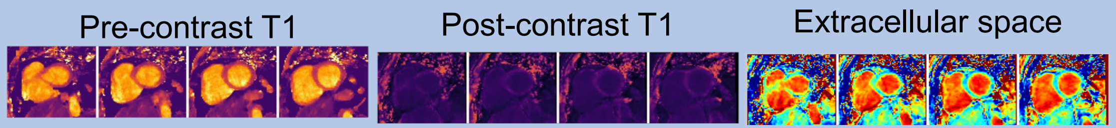
- Spatial Resolution (~ 1mm) and
- Sensitivity (>10x higher)

compared to conventional PET cameras

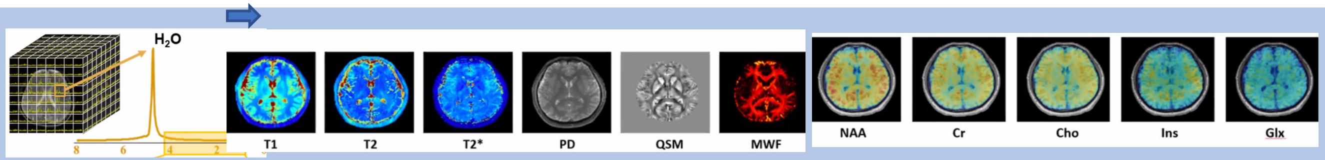
Center for Molecular Imaging Technology & Translation (P41 PI: El Fakhri)

To Develop & Disseminate cutting-edge PET/MR imaging Agents & Technologies

- **TR&D 1**: Ultrafast multi-parametric MR imaging methods for quantitative PET/MR

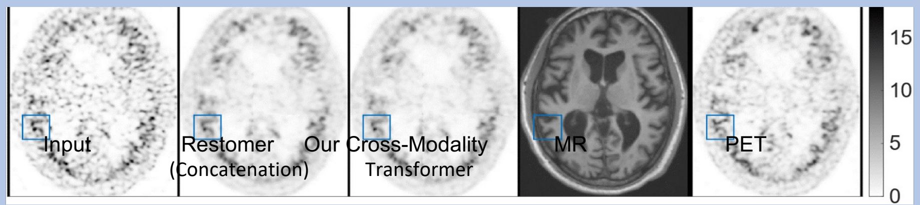


Free-breathing extracellular myocardial space 3D imaging for membrane potential mapping using [18F]TPP⁺ PET/MR

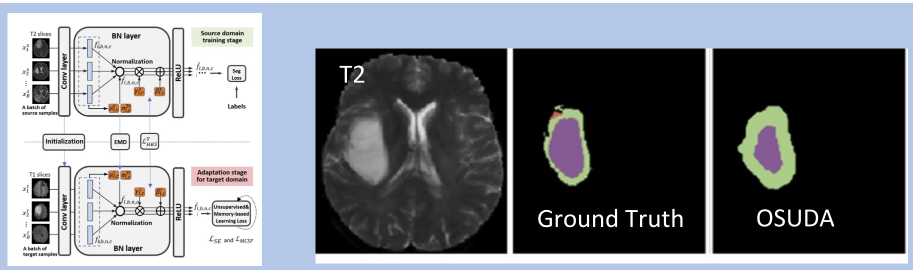


Simultaneous high-resolution MRS imaging & parametric mapping using SPICE.

- **TR&D 2**: Advanced Statistical Image Reconstruction & Physics Informed AI for Quantitative PET/MR

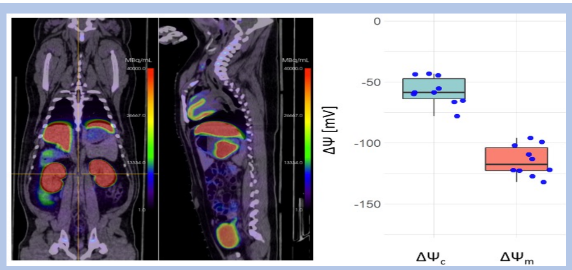


Tau PET denoising using cross-modality (PET&MR) DL transformer through self-attention mechanism

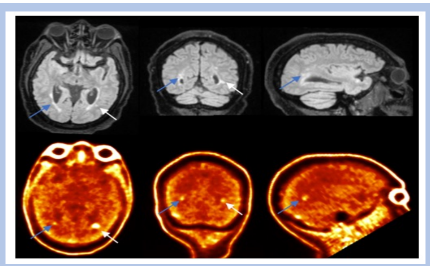


Brain tumor MR segmentation using DL with unsupervised domain adaption

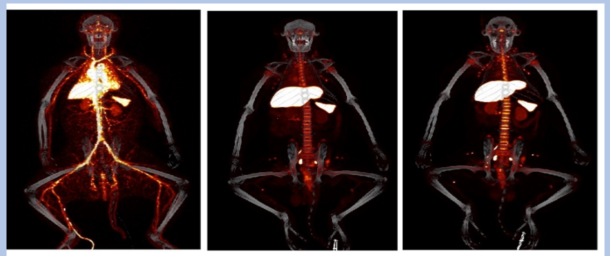
- **TR&D 3**: Novel Imaging Agents & Physiological Modeling for Quantitative PET/MR



Mapping mitochondrial and cellular membrane potential with [^{18}F]FTPP⁺ and T1-mapping MRI



Imaging demyelination (e.g., in multiple sclerosis) using radiolabeled 4AP derivatives

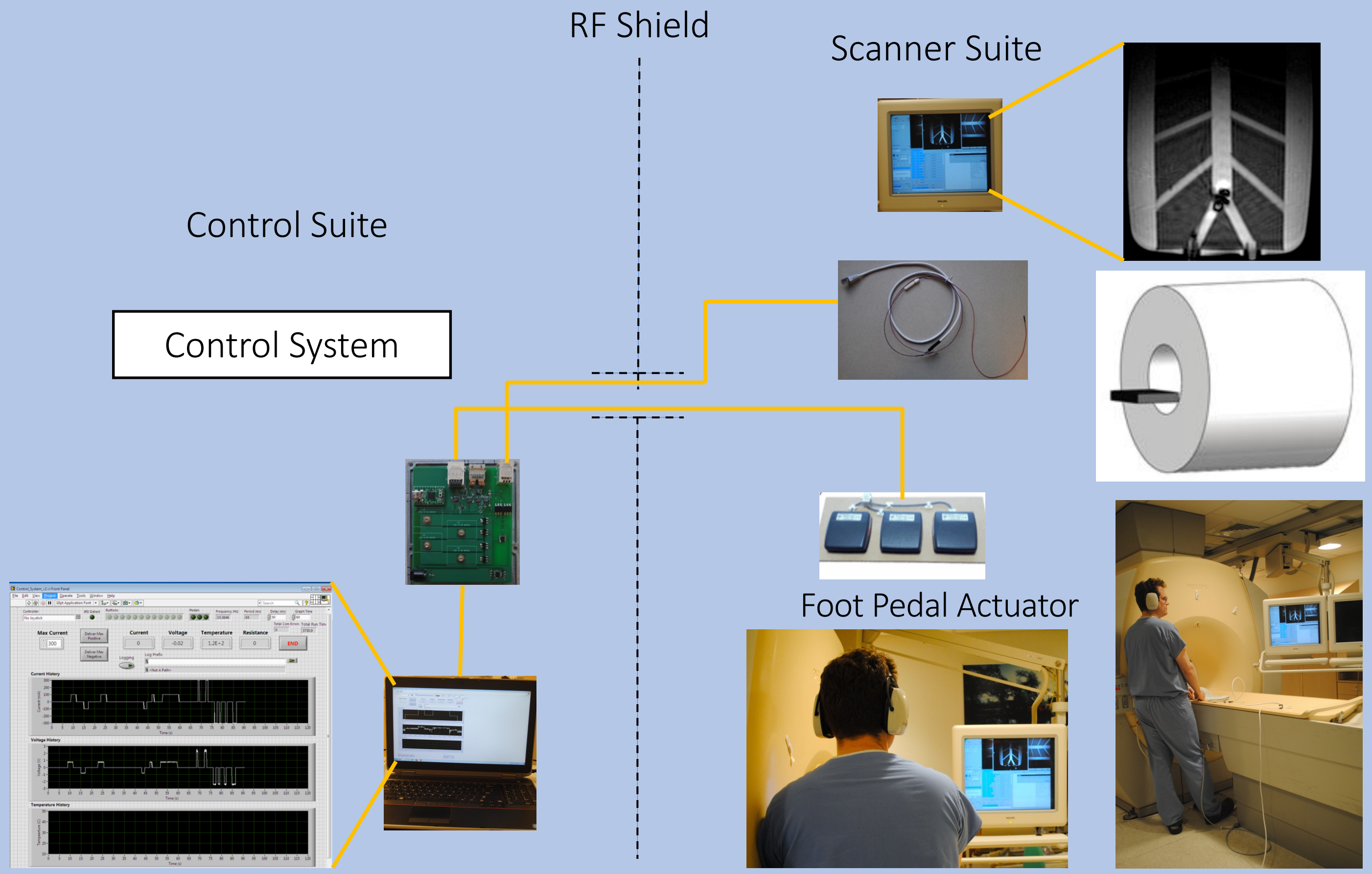


Immune cell tracking using magnetic nanoparticles tagged with long-lived isotopes

National Institute of Biomedical Imaging & Bioengineering

Advancing Modalities for Image-guided Interventions

Magnetically Assisted Remote Controlled (MARC) Catheter for Endovascular Interventional MRI:



Steven W. Hetts, MD
University of California, San Francisco

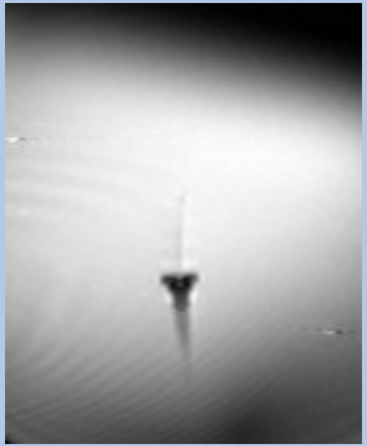
National Institute of Biomedical Imaging and Bioengineering
Creating Biomedical Technologies to Improve Health

MARC Catheter: From Concept to Preclinical Development

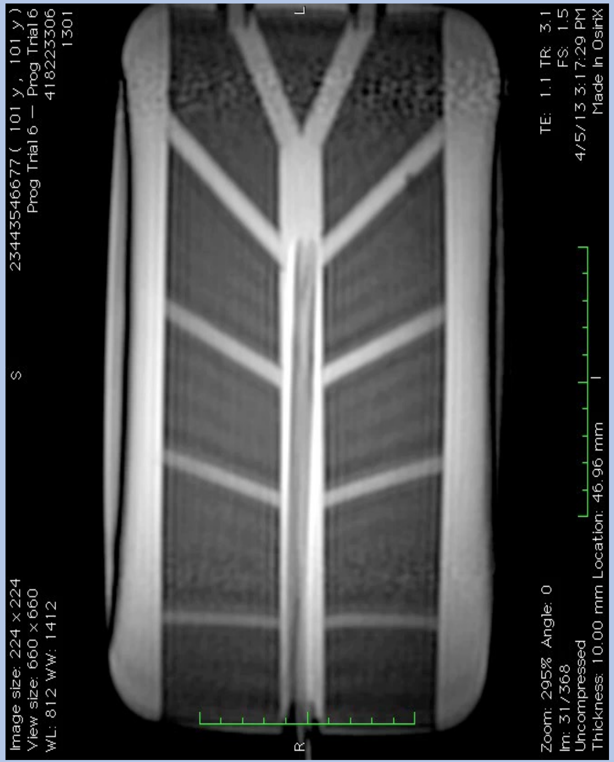
Catheter Deflection

- Deflection Strength – R-L Alignment
- (AP deflection is possible as well)

- Current: +/- 50 to +/- 100 mA
- Deflection Angles
  - 50 mA = 11.5°
  - 100 mA = 17°
- HC-2 catheter

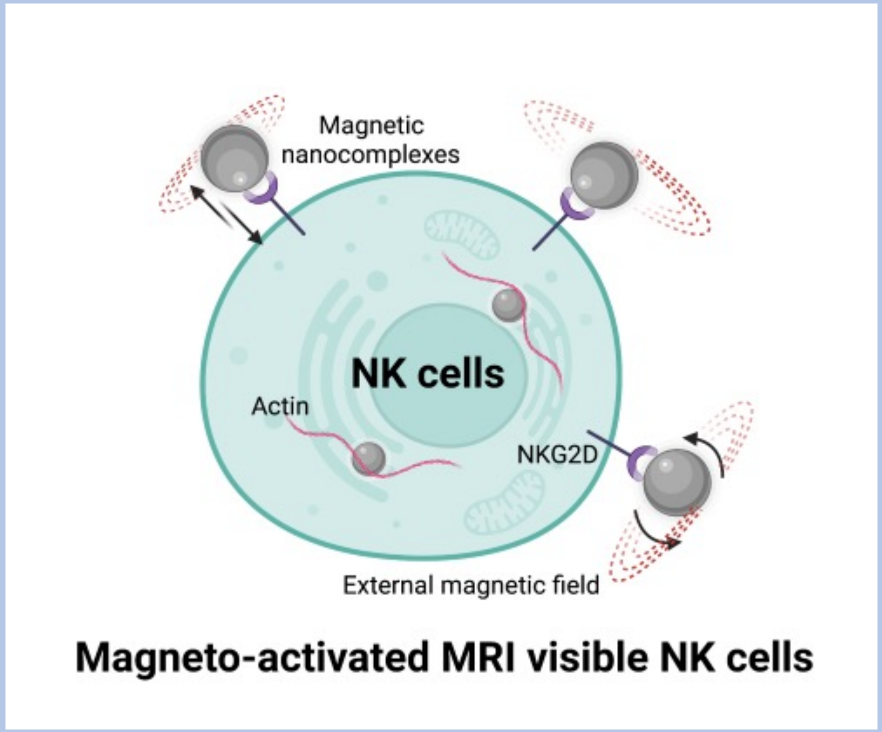


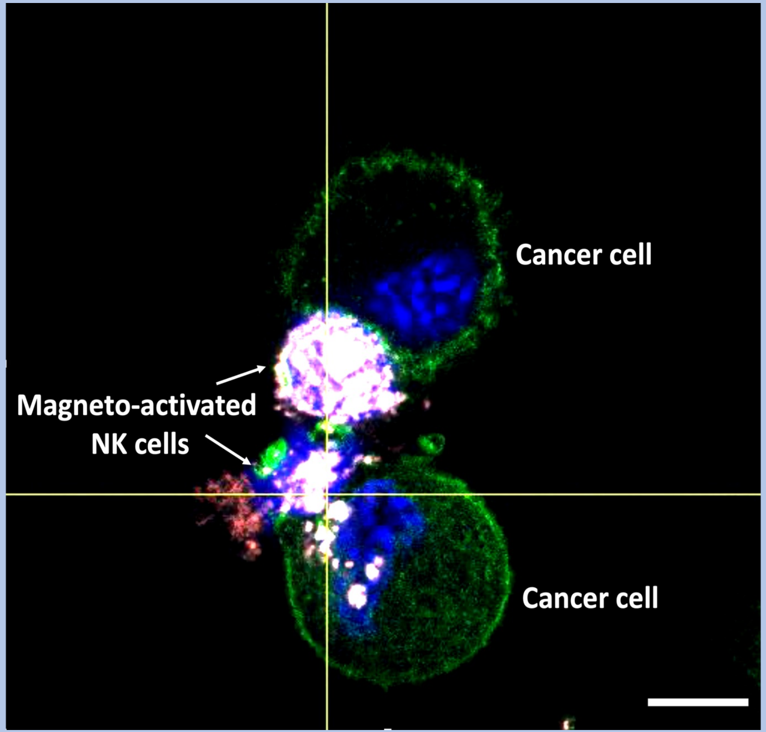
Catheter Navigation at 1.5T



Steven W. Hetts, MD
University of California, San Francisco

Preclinical study uses magnetic field to activate and track natural killer cells





External magnetic field-activated natural killer (NK) cells had significantly enhanced cytotoxicity compared with unmodified NK cells in cell culture experiments & reduced tumor growth in rat liver cancer model.

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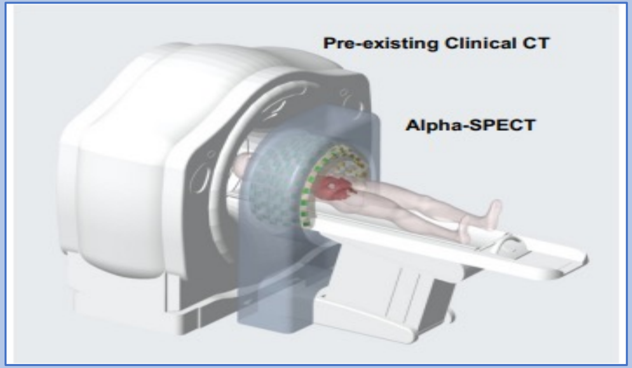
Credit: Kim Laboratory; Northwestern University.

High Energy and Spatial Resolution Multi-Isotope SPECT Imaging of Targeted *Alpha-Emitters* and their Daughters



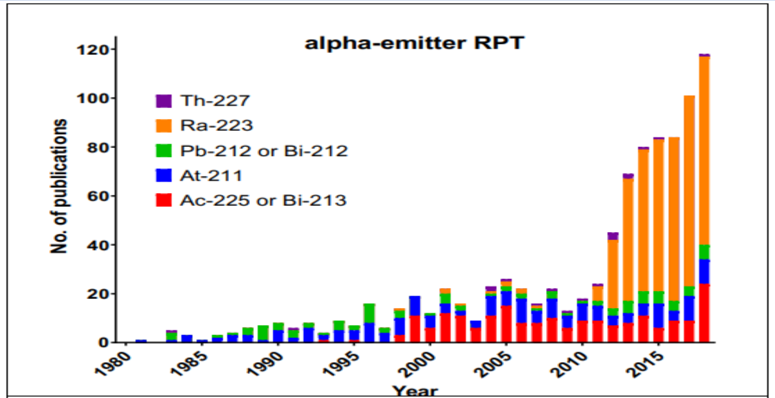


Figure 1. Interest in αRPT has surged over the past 10 years.

Increasing use of alpha-emitting radiotherapy agents

Partnership for instrumentation development that will be applied to:

- dosimetry demands of new treatments that deliver highly potent alpha-emitting radiation to disseminated cancer cells,
- building imaging instrumentation that will serve much broader clinical needs in oncology, cardiology and neurology.

Credit: Sgouros, G; Johns Hopkins University

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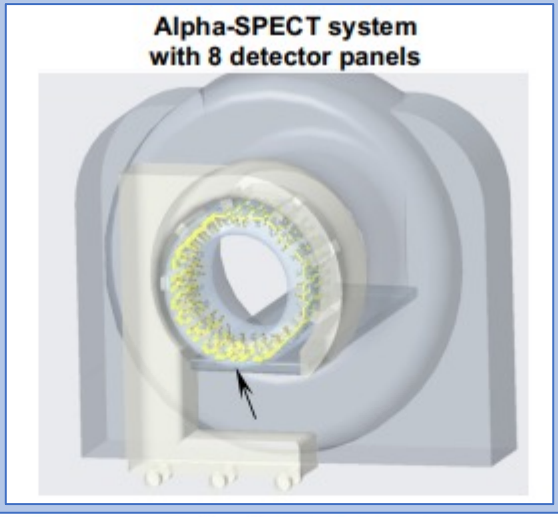
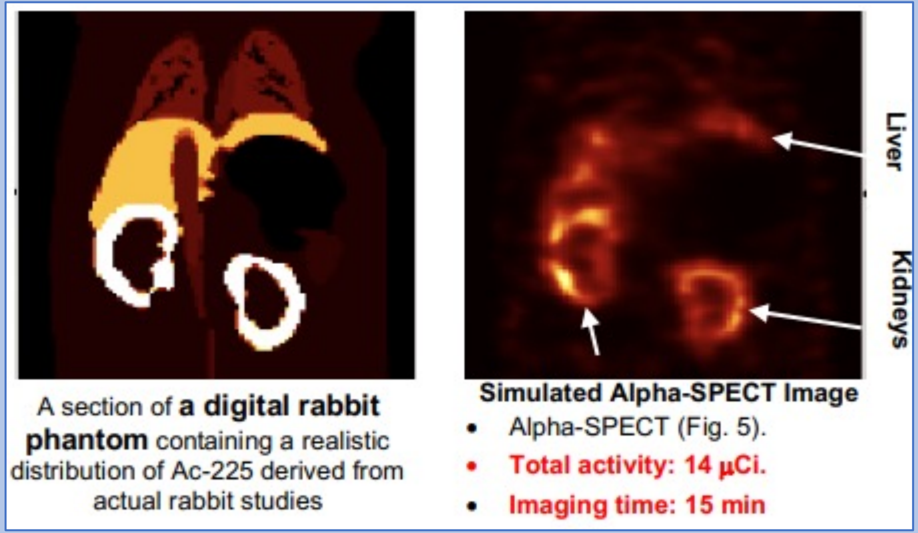
Hyper-spectral Single Photon Imaging of Targeted *Alpha-Emitters*





This project will serve as a critical step to:

1) Bring the unique high-energy SPECT imaging capability to end users who are currently developing targeted radionuclide therapies in animal models
2) Potentially lead to a state-of-art spectral-CZT detector platform for use by the research community and industry in developing the next generation clinical SPECT instrumentations for applications beyond targeted radionuclide therapies.

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Credit: Du, Y; Johns Hopkins University

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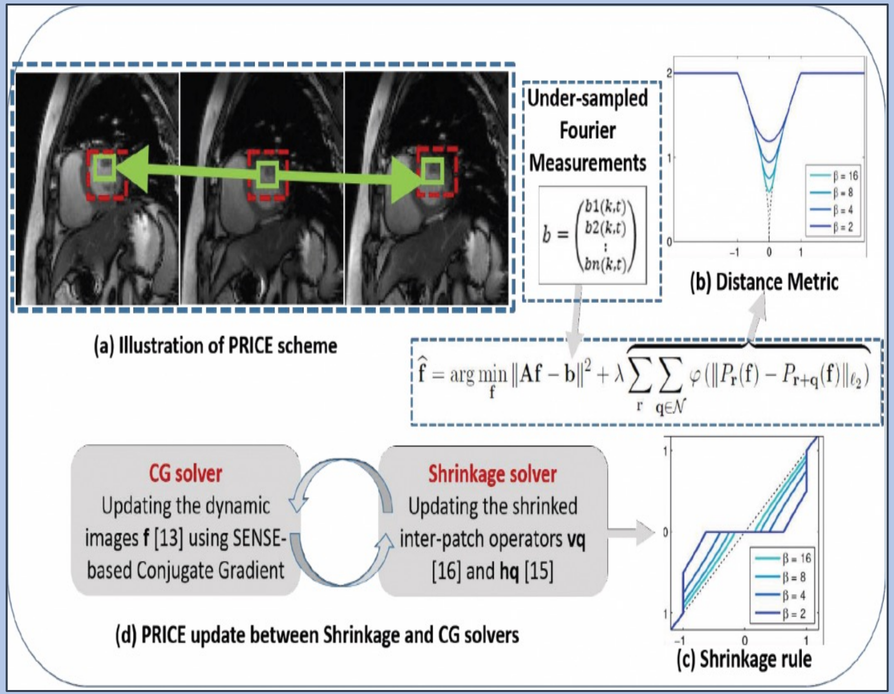
National Institute of Biomedical Imaging & Bioengineering

Medical Imaging:
Machine Intelligence & Informatics

Rapid Free-Breathing and Ungated Cardiac Imaging

- **Challenges**:
  - Breath-holding and gating are difficult for patients with pulmonary diseases or arrhythmia.
  - Long scan (~ 1 hr.) for acquiring multiple image contrasts aggravates claustrophobia and patient discomfort.
- **Aims:**
  - To enable cardiac imaging ***without*** breath-holding and gating
  - To reduce multi-contrast image acquisition time within ***15 minutes – HIGH VALUE IMAGING!***
- **Innovations**:
  - Explore the similarity between spatially and temporally adjacent image frames for implicit motion correction, accelerated acquisition, and improved image quality
  - A novel mathematical framework that significantly enhances the speed of image reconstruction



Proposed fast image acquisition technique

PI: M Jacob (U of IOWA)

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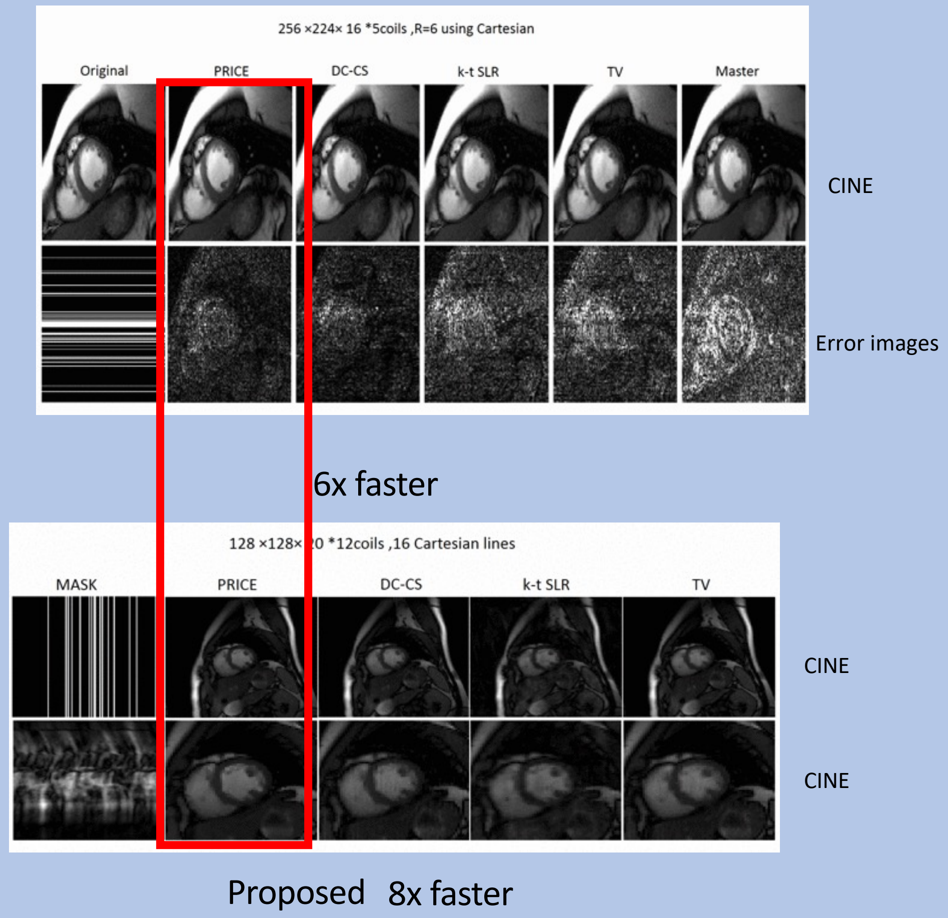
Rapid Free-Breathing and Ungated Cardiac Imaging

- **Results**:
  - Compared with conventional techniques: 4 to 8 times faster with comparable image quality
  - Compared with other acceleration techniques:
    - Significantly improved image quality for similar reconstruction speed
    - Reconstruction is 5 to 9 times faster for similar image quality
- **Clinical implications**:
  - Obese patients with pulmonary diseases
  - Pediatric subjects who cannot cooperatively control their breadth
  - High-throughput imaging protocol in general



Mohsin YQ et.al., "Accelerated dynamic MRI using patch regularization for implicit motion compensation." Magn Reson Med. 2017 Mar;77(3):1238-1248.

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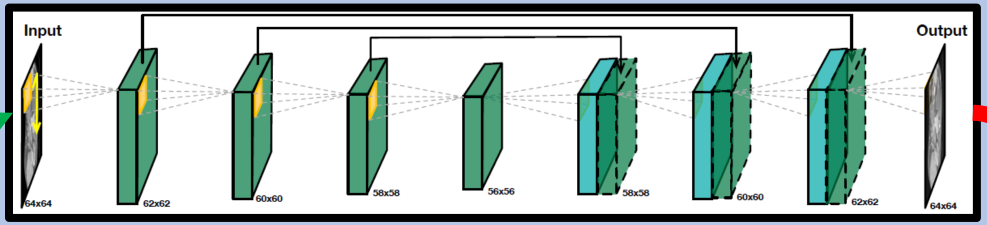
Deep Learning
Extracting Hidden Information

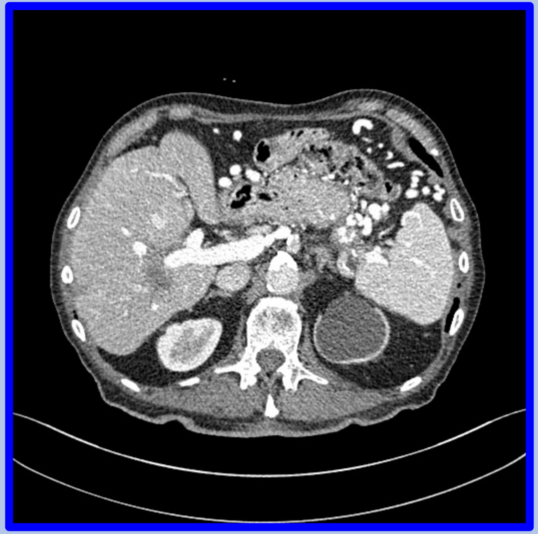
Low-dose CT Denoising

RPI, Sichuan University, & Harvard University



CT Denoising Neural Network

Low-quality CT Scan (1/4 Radiation Dose)



High-quality CT Scan (Standard Radiation Dose)

Machine Learning Turns Low-quality CT Image into High-quality Counterpart

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IEEE Trans. Medical Imaging 37:1522-1534, 2018 (for details, see https://arxiv.org/abs/1802.05656 or https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8353466)

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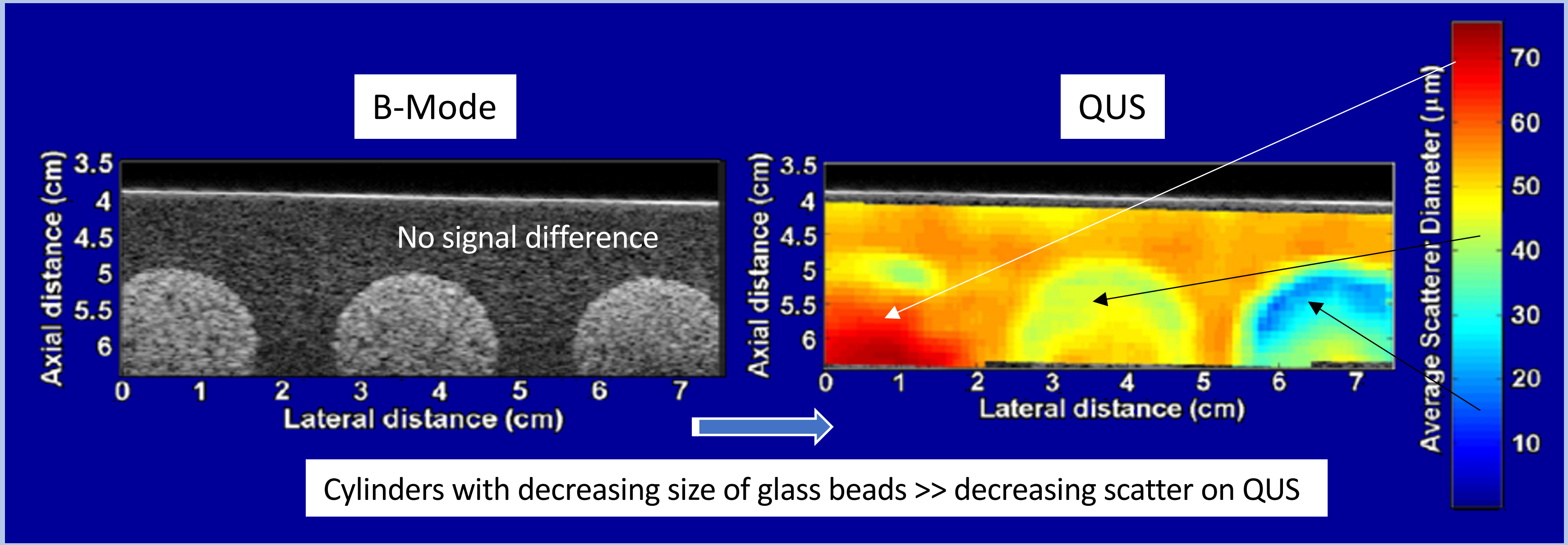
Refining Tissue Characteristics: Quantitative Ultrasound

Provides geometrical interpretation of underlying tissue microstructure (L << US wavelength) – i.e., ‘statistical information’ as a new source of tissue contrast, increases specificity and possibility of system and operator independence



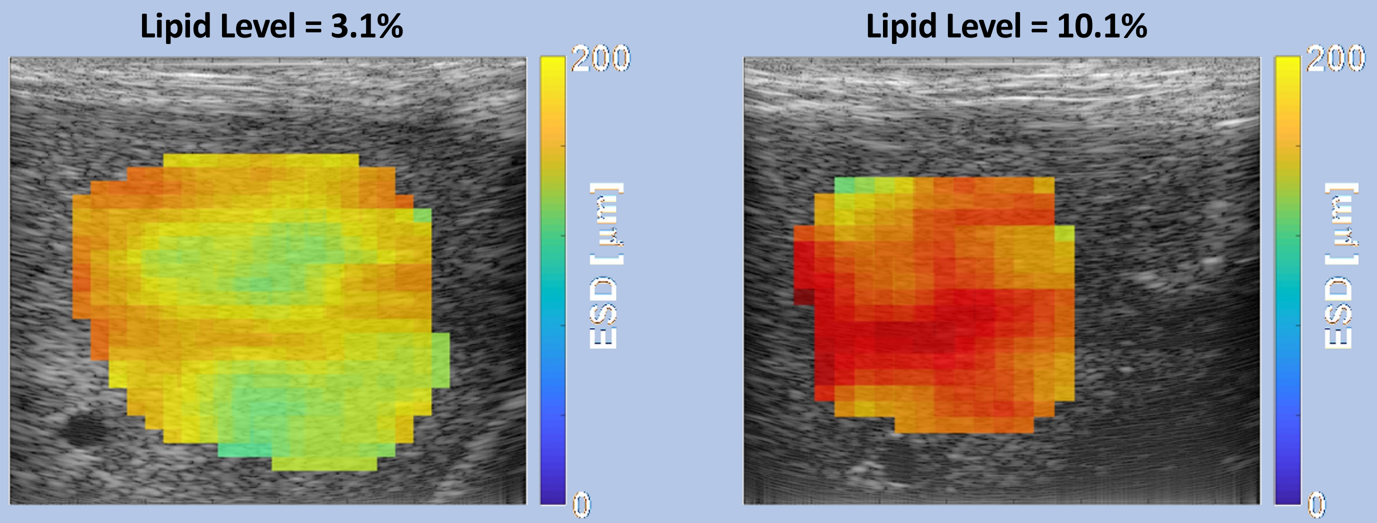
Oelze M, et al: U of Illinois – Urbana/Champaign

Quantitative Ultrasound: Fatty Liver & Fibrosis

Hypothesis: QUS is sensitive to both Fat and Fibrosis?

Rabbits fed fatty diets to induce fatty livers*, plus CCl4 to induce fibrosis**

QUS Maps of Rabbit Livers: SonixOne @ 4MHz



Higher Fat level = Higher Scattering

* Folch Assay
** Hydroxyproline Assay

Oelze M, et al: U of Illinois – Urbana/Champaign

Quantitative Ultrasound: Fatty Liver & Fibrosis

Classification Accuracy: Hi (>8%) vs Lo (<8%) Fat

Classification Method	Accuracy (%)	
Attenuation	89	
BSC – Linear Fit + SVM	68	ML
BSC – PCA + SVM	69	ML
Raw signals - CNN	73	DL

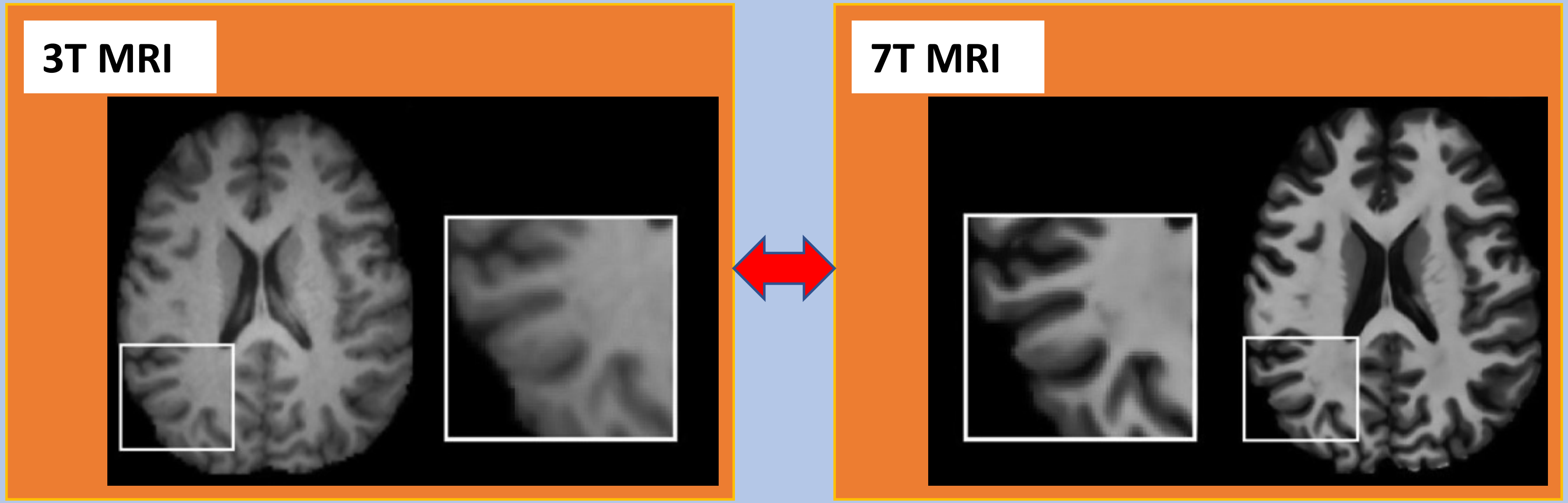
1. Best Accuracy with Attenuation and raw signal-CNN
2. Back scatter coefficient (BSC): sensitive to liver fat, but insensitive to liver fibrosis
3. Employ US Shear Wave Imaging (not sensitive to fat) can serve as a complimentary modality sensitive to fibrosis
4. Combine QUS and US SWI to quantify both fatty liver and fibrotic liver

ML: SVM-Support Vector Machine; PCA-Principle Component Analysis;
DL: CNN-Convoluted Neural Networks (based on 1.2M data samples)

Oelze M, et al: U of Illinois – Urbana/Champaign

Reconstruction of 7T-like images from 3T MRI

PI: D Shen (U. of North Carolina)

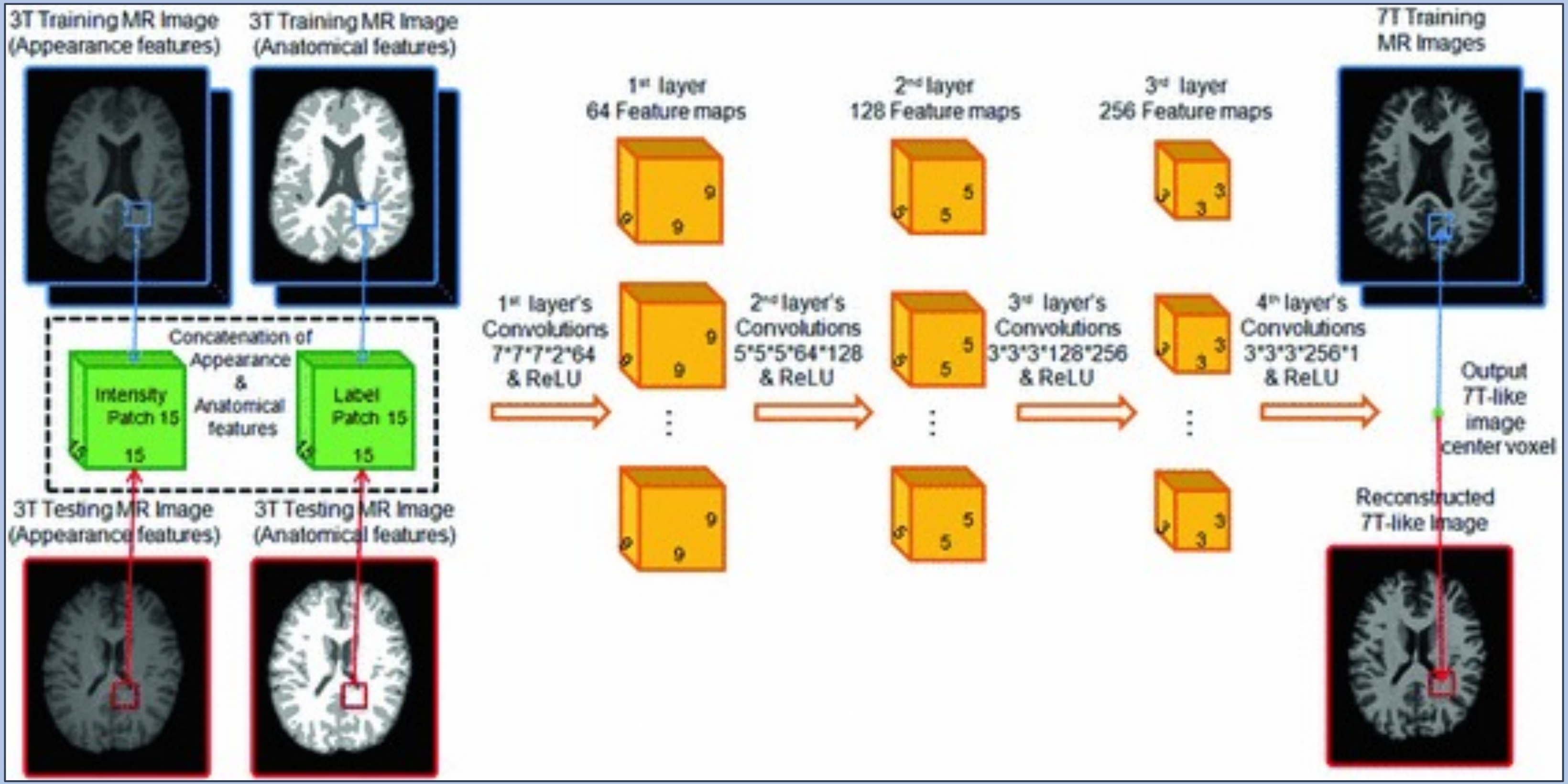


- With 3T MRI, can improvements be realized in:
  - Anatomical Details?
  - Tissue Contrast?

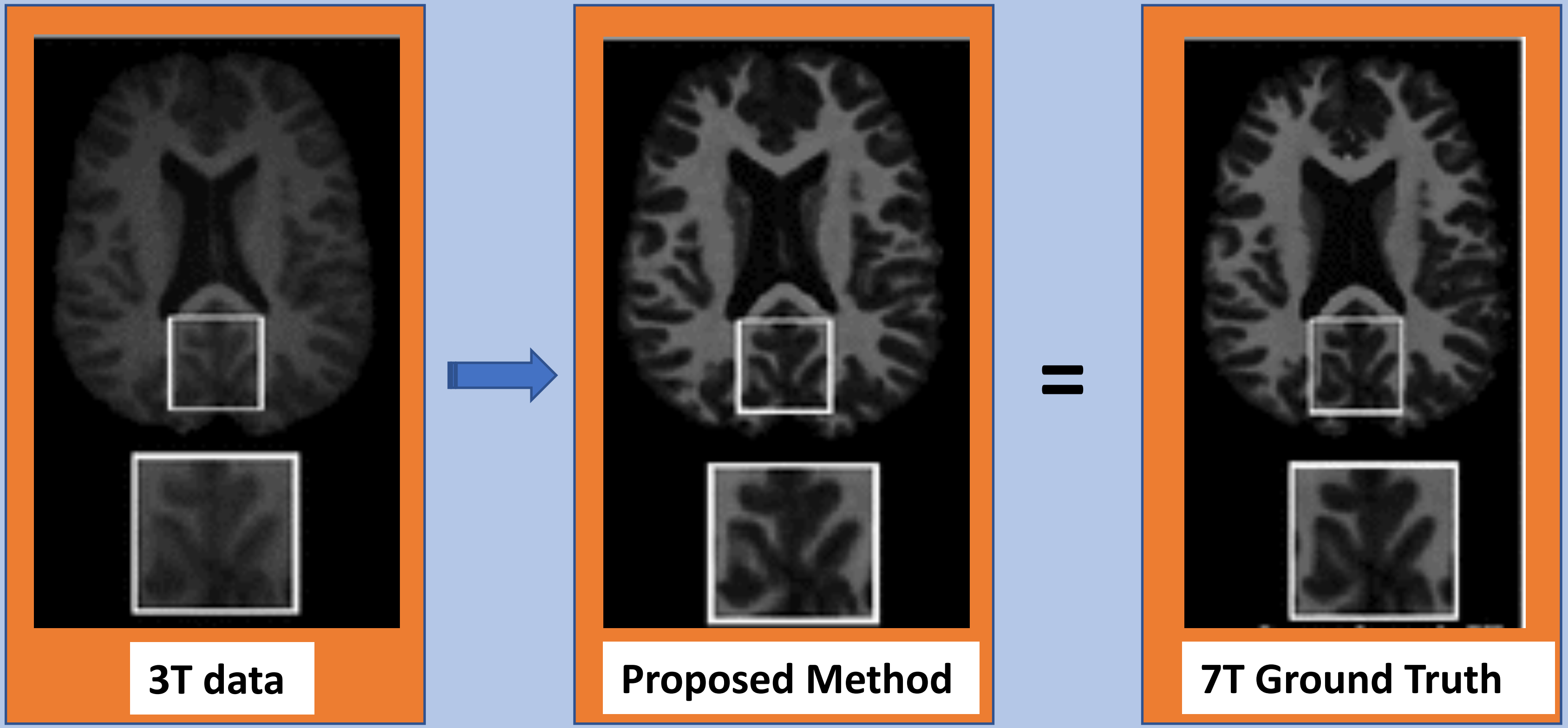
Bahrami K., et al., LABELS 2016, DLMIA 2016: pp. 39-47

Reconstruction of 7T-like images from 3T MRI

Convolutional Neural Network (CNN)



Reconstruction of 7T-like images from 3T MRI



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L. Qu, S. Wang, P.-T. Yap, D. Shen, "Wavelet-Based Semi-Supervised Adversarial Learning for Synthesizing Realistic 7T from 3T MRI," MICCAI 2019.

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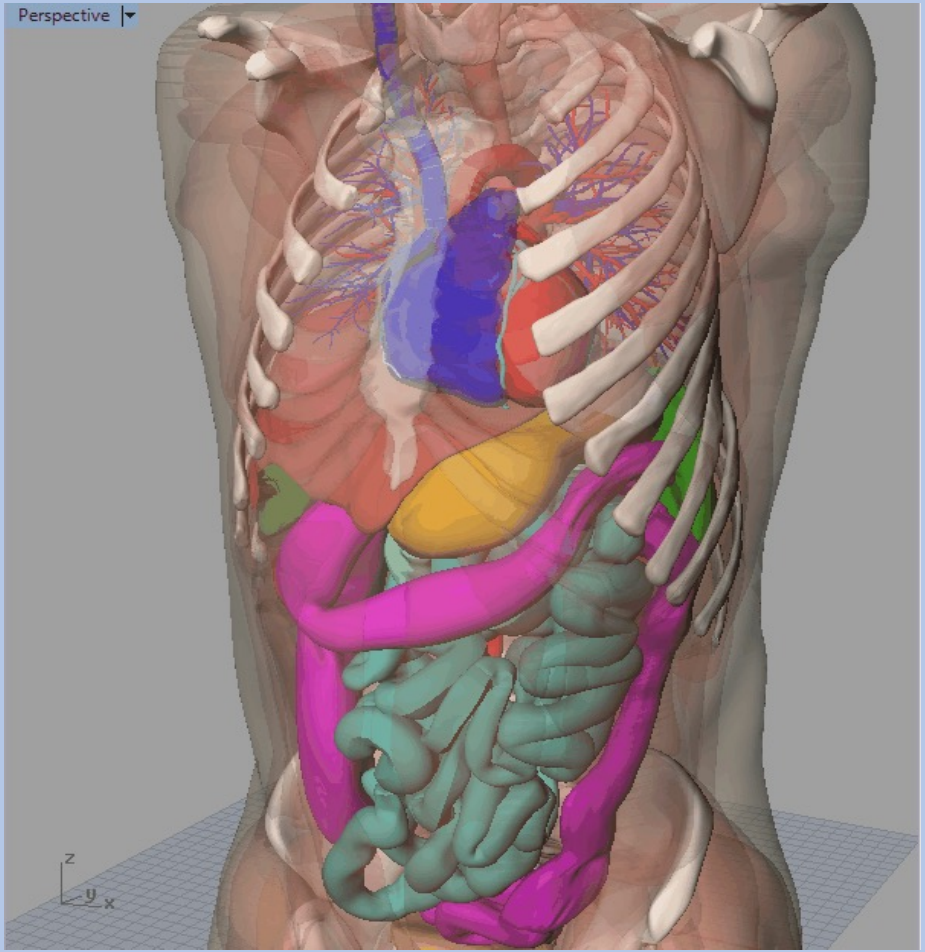
Modeling & Simulation

Minimizing Surgical Invasiveness

Computational Patient Models: realistic, dynamic, anthropomorphically diverse.



Computational GPS map tell where every sensor is installed;
sensors to measure the radiation dose to the breast, heart or pancreas

Rendering of phantoms aboard the Artemis I mission to the moon and back to Earth. NASA/Lockheed Martin/DLR image

Ehsan Samei, Ph.D., Director
Duke University's Center for Virtual Imaging Trials (CVIT)

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Mixed Reality & Hand-Controlled Software For Navigating Images

PI: B L Daniel (Stanford University)

National Institute of Biomedical Imaging & Bioengineering

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Medical Imaging & Data Resource Center (MIDRC)

NIBIB Response to the COVID-19 Pandemic

The Medical Imaging and Data Resource Center (MIDRC)

MIDRC is a partnership of the AAPM, ACR and RSNA

- A curated image and data commons
- A means by which researchers can address topics no single image archive could yield independently
- Supported by NIBIB and hosted at The University of Chicago

There are two scientific components of MIDRC:

1. *Open Discovery Data Commons*

   Creation, testing, quality assurance, and data connectivity

2. *Machine Intelligence Computational Capabilities*

   Clinically relevant algorithms and software tools

The Medical Imaging and Data Resource Center (MIDRC) is funded by the National Institute of Biomedical Imaging and Bioengineering (NIBIB) of the National Institutes of Health under contract 75N92020C00021.

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Facilitating translation to the Real World

Total ingested into MIDRC
# of Imaging Studies
309,270

Released by MIDRC
# of Imaging Studies
135,629

AI / ML Development
27 Algorithms

- De-identification
- Curation
- Quality control
- Annotation
- Harmonization

(incl. LOINC mapping)

GEN3 DATA COMMONS

Public commons
Available on data.midrc.org
~80% of all cases

Public facing DATA
- AI/ML ready
- FAIR
- Trustworthy
- Representative
- Searchable

Sequestered commons
No public access
~20% of all cases

Sequestered DATA
- Not publicly available
- Real-world testing of algorithm performance
- Translation / support of regulatory submission

54,292	12.80TB	488	100+	347	38	103
Cases	Total size Published	Registered Users	Investigators	Collaborating Institutions	Publications	Presentations

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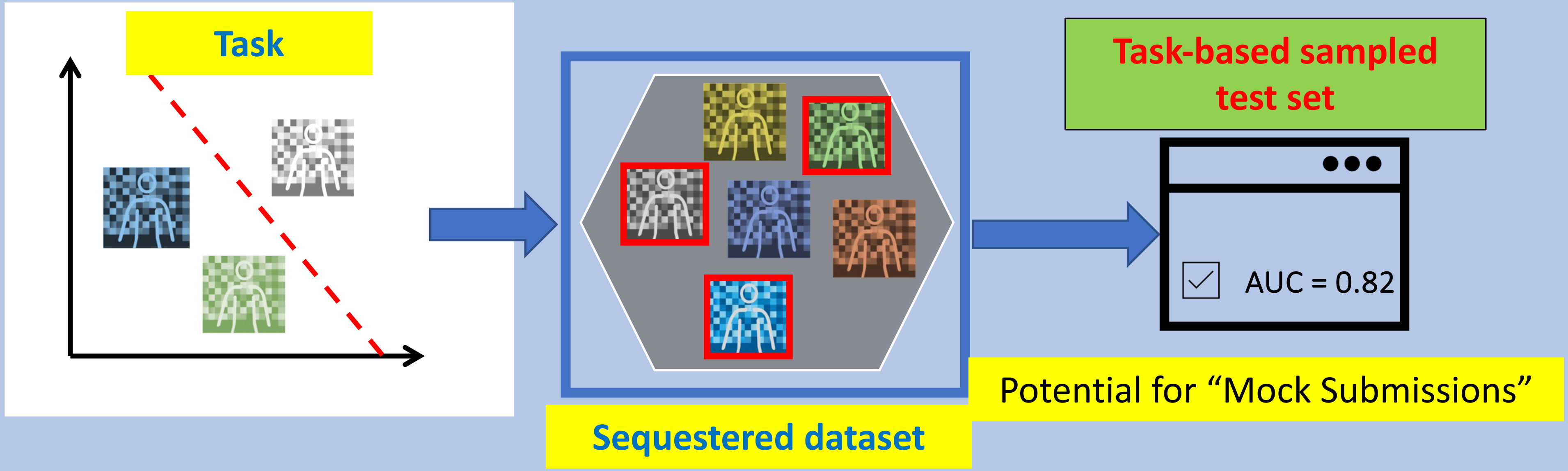
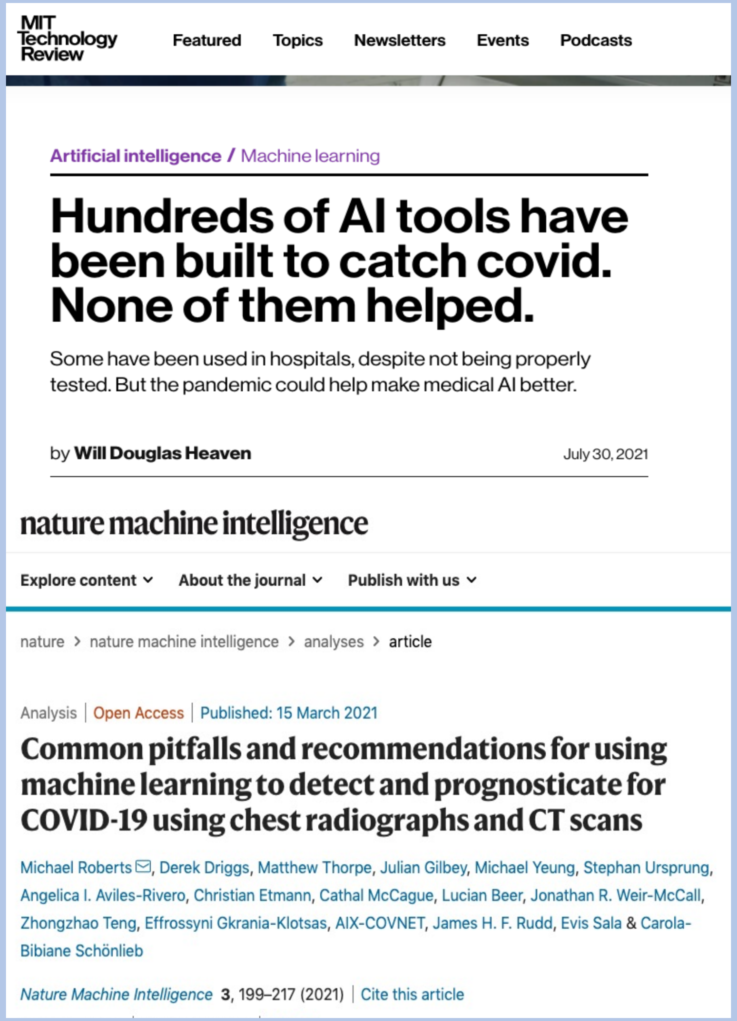
Sequestered Commons for Real-World Evaluations and Translation through Regulatory to Clinical Care

For performance evaluation using the sequestered dataset - test cases will be drawn from the sequestered set according to the distributions related to the specific task (clinical task, claim, and population), that is, the sequestered set in its entirety will not be used in the test



What went wrong with AI/ML methods for COVID imaging?



MIT Technology Review
Featured Topics Newsletters Events Podcasts

Artificial intelligence / Machine learning

Hundreds of AI tools have been built to catch covid. None of them helped.

Some have been used in hospitals, despite not being properly tested. But the pandemic could help make medical AI better.

by **Will Douglas Heaven** July 30, 2021

nature machine intelligence

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nature > nature machine intelligence > analyses > article

Analysis | Open Access | Published: 15 March 2021

Common pitfalls and recommendations for using machine learning to detect and prognosticate for COVID-19 using chest radiographs and CT scans

Michael Roberts, Derek Driggs, Matthew Thorpe, Julian Gilbey, Michael Yeung, Stephan Ursprung, Angelica I. Aviles-Rivero, Christian Etmann, Cathal McCague, Lucian Beer, Jonathan R. Weir-McCall, Zhongzhao Teng, Effrossyni Gkrania-Klotsas, AIX-COVNET, James H. F. Rudd, Evis Sala & Carola-Bibiane Schönlieb

Nature Machine Intelligence 3, 199–217 (2021) | Cite this article

1) Poor quality of COVID imaging data
- Mislabeled data
- Multiple unknown sources
- Duplicate data (training and testing)
- No traceability, limited quality control
- Lack of external validation

2) Lack of collaboration/communication between AI/ML experts and biomedical experts
- Need for valid ground truth
- Need for independent test set

3) Bias and lack of diversity
- Data collected for a specific clinical task
- Specific populations, lack of diversity
- Single expert score, data sources correlated with ‘truth’, …

MIDRC – Addressing Bias and Diversity in AI Datasets

Drukker, et al. (2023) “Towards **fairness** in artificial intelligence for medical image analysis; **Identification and mitigation of potential biases** in the roadmap from data collection to model deployment” JMI 2023

https://doi.org/10.1117/1.jmi.10.6.061104

Whitney, et al. (2023) “Longitudinal **assessment of demographic representativeness** in the Medical Imaging Data and Resource Center Open Data Commons” JMI, *in press*.

https://arxiv.org/abs/2303.10501

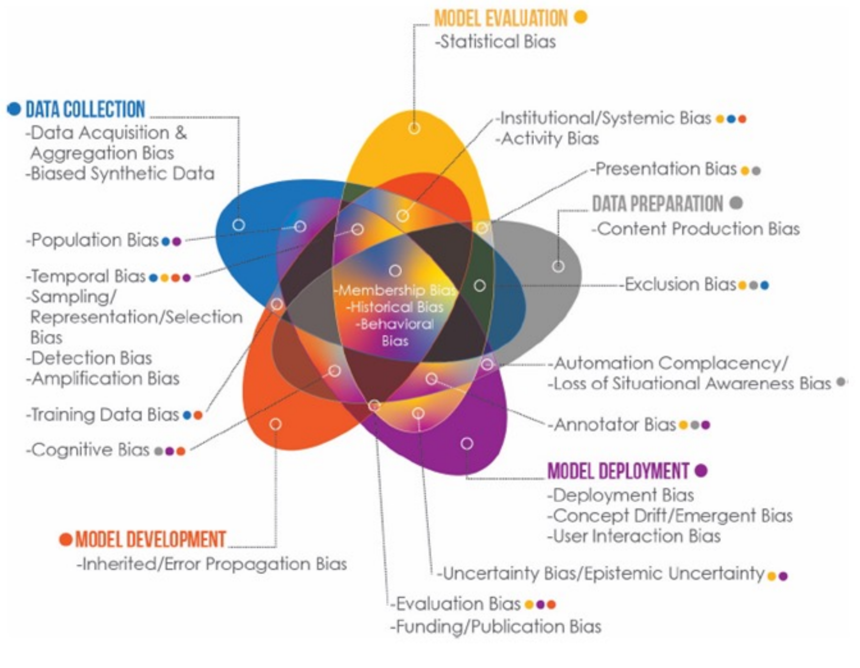

Figure 2. Venn diagram of the identified potential biases and main bias categories (Figure 1). Biases associated with a single category are listed under the applicable category. For biases associated with multiple categories, colored dots indicate which category each bias belongs to.

https://www.midrc.org

MIDRC AI/ML Bias Awareness Tool Portal

https://www.midrc.org/bias-awareness-tool-1

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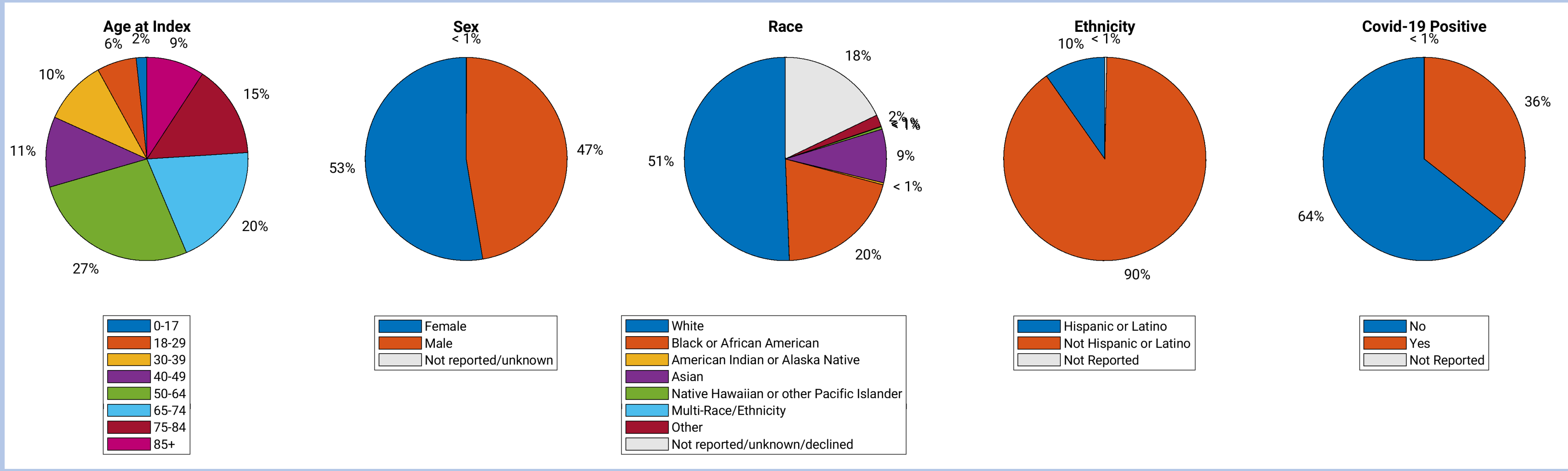
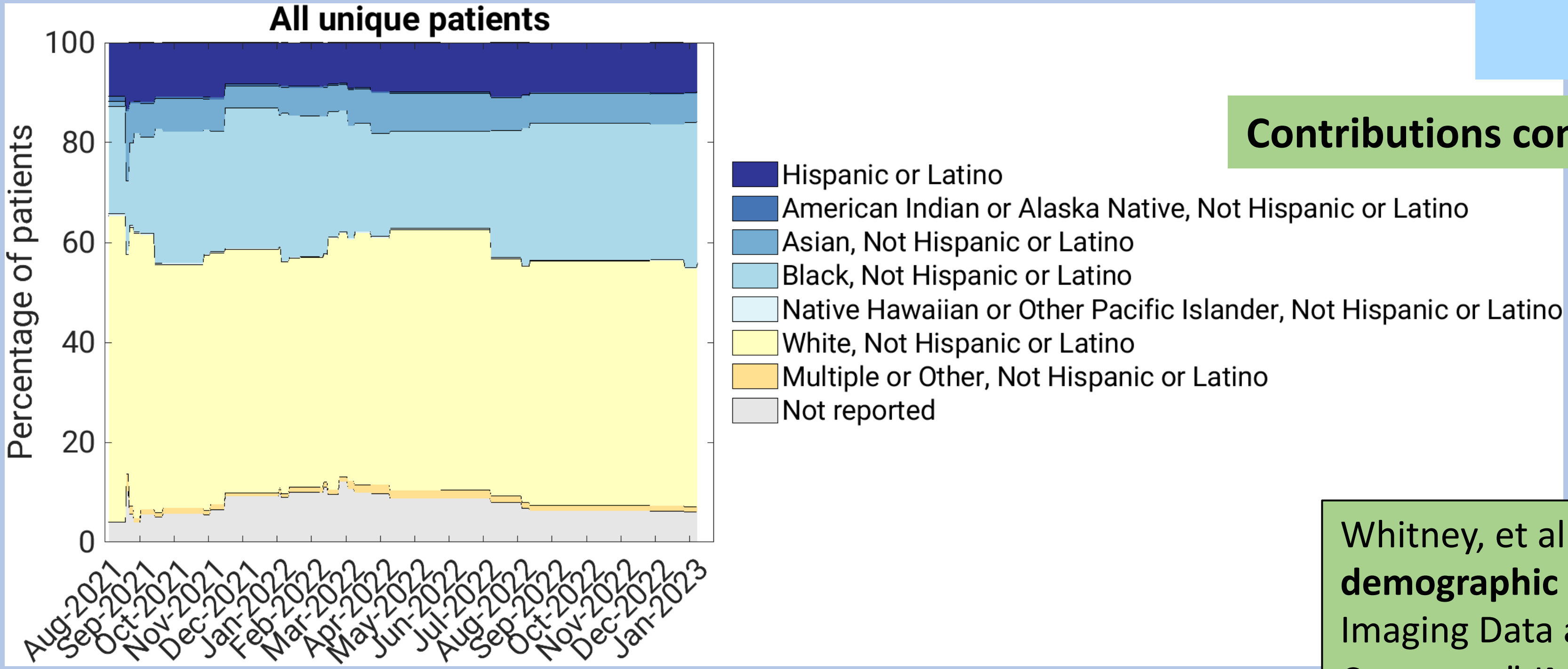
Collection and curation of diverse imaging data

- To ensure data sets are **representative of the population** of the region or country of origin, and actively seeking data contributions from rural and under-represented community hospitals and smaller healthcare systems.
- For the development of **ethical and trustworthy machine learning algorithms** that account for and reduce data bias.



Race and Ethnicity over time



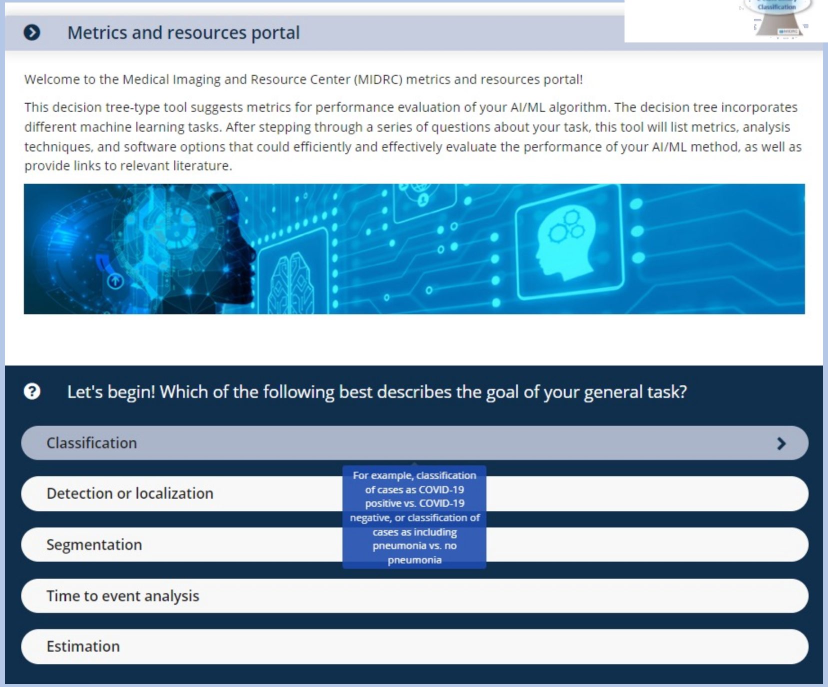
Contributions coming from 23 states

Whitney, et al. (2023) “Longitudinal **assessment of demographic representativeness** in the Medical Imaging Data and Resource Center Open Data Commons” JMI, *under review*. https://arxiv.org/abs/2303.10501

Impact: Metrology Decision Tree

- Developed a decision tree to assist MIDRC users in selecting metrics and reporting performance
  - Ask users a series of questions to guide them through a decision tree for metric selection
    - Final leaf: Metrics and suggested resources
- Utility:
  - Help researchers from different fields who employ MIDRC data select task-based performance metrics
  - Encourage use of consistent metrics for similar tasks
    - Help comparison of results from different studies
  - Help stakeholders put reports from MIDRC data into proper perspective

https://www.midrc.org/performance-metrics-decision-tree



Predicting the Need for Intensive Care for COVID-19 Patients using Deep Learning on Chest Radiography

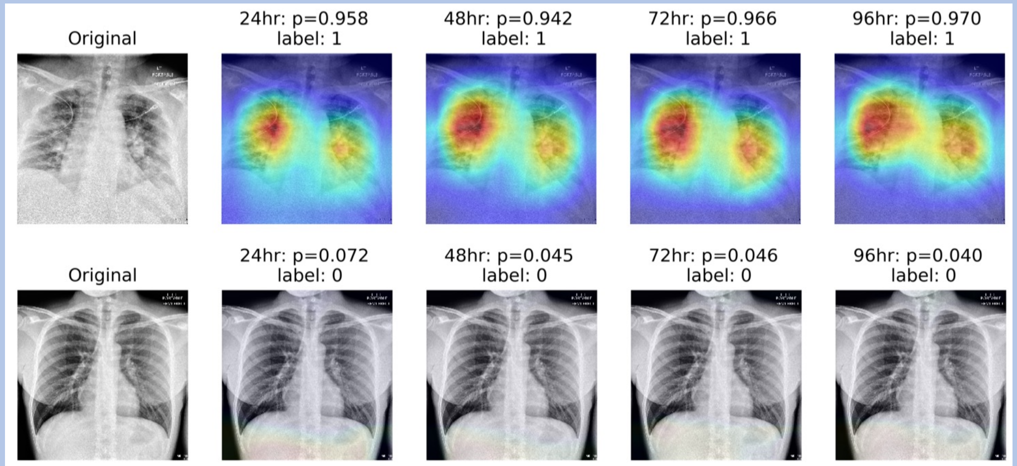
Qiyuan Hu, Karen Drukker, Maryellen L. Giger
Committee on Medical Physics, Department of Radiology, University of Chicago
{qhu,kdrukker,m-giger}@uchicago.edu

- Goal to assess severity (prognosis) of COVID-19 in Chest Radiograph from UChicago (1670 CXR from 1178 COVID-19+ patients; now evaluating on >5000)
- Predicted patients' needs for intensive care, defined as intubation (invasive mechanical ventilation) and/or ICU admission. Output – probability of needing ICU care in the next 24,48,72,or 96 hours

AN EARLY PUBLICATION

YES

NO



Courtesy:
Maryellen Giger
U of Chicago

THE UNIVERSITY OF CHICAGO BIOLOGICAL SCIENCES

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AI Recognition of Patient Race in Medical Imaging: a modelling study

Judy Wawira Gichoya et al. (IR and NIBIB Data Scholar; Emory U.) May 2022
***Lancet Digit Health* 2022; 4: e406–14;** https://doi.org/10.1016/ S2589-7500(22)00063-2

Images included CXR, Chest CT (CA & PE), Cervical Spine, Mammography, & Digital Hand Films.

Interpretation: The results from our study emphasize that the ability of AI deep learning models to predict self-reported race is itself not the issue of importance. However, our finding that AI can accurately predict self-reported race, even from corrupted, cropped, and noised medical images, often when clinical experts cannot, creates an enormous risk for all model deployments in medical imaging.

Funding National Institute of Biomedical Imaging and Bioengineering, MIDRC grant of National Institutes of Health,
US National Science Foundation, National Library of Medicine of the National Institutes of Health, and Taiwan Ministry of Science and Technology.

Real-world interoperability between the MIDRC Open Data Commons and NCATS/National COVID Cohort Collaborative (N3C)

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National COVID Cohort Collaborative

Log in as user on the MIDRC Open Data Commons https://data.midrc.org/

Download MIDRC CXR images with N3C IDs

Calculate AI-based severity scores on the CXRs using local computer and create table

Log in as user on N3C Enclave https://covid.cd2h.org/

Search for N3C cases with MIDRC IDs

Gather clinical information on patient characteristics, co-morbidities, outcome data and temporal data and create table

Within a freeport enclave, which for now is the N3C enclave, join tables to connect image-based descriptors and clinical descriptors — MIDRC + National COVID Cohort Collaborative

Conduct association studies and **develop predictive models** merging image-based and clinical descriptors

Real-world interoperability between the MIDRC Open Data Commons and NIH/NHLBI BioData Catalyst

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MIDRC
Create API key
Image data

dbGaP
GENOTYPES and PHENOTYPES

dbGaP
Data access approval

BioData Catalyst
Create API key
Clinical data

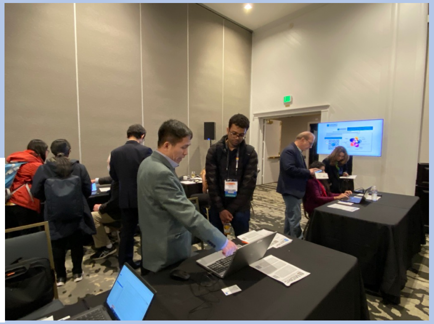
NIH National Heart, Lung, and Blood Institute | BioData CATALYST
Powered by Gen3

Biomedical Research Hub
Powered by Gen3

Biomedical Research Hub
Gen3 SDK
Command Line Interface

Multimodal dataset
Ready for AI development

Real-time demonstration at SPIE Medical Imaging February 2023



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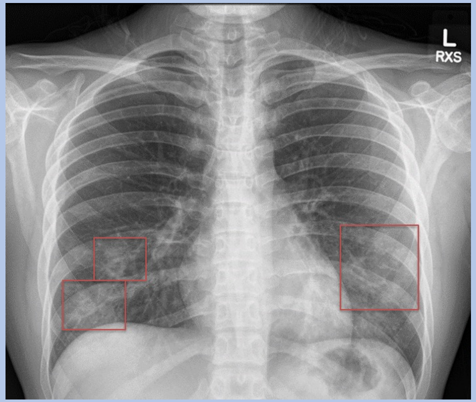
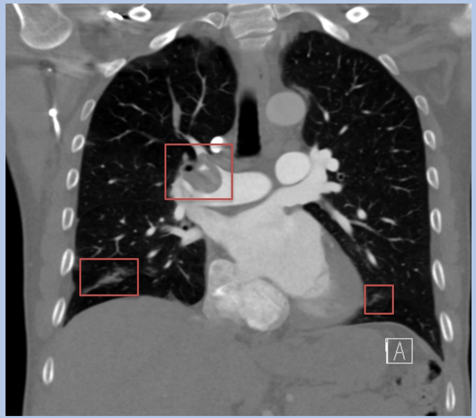
COVID-19 Pandemic Response



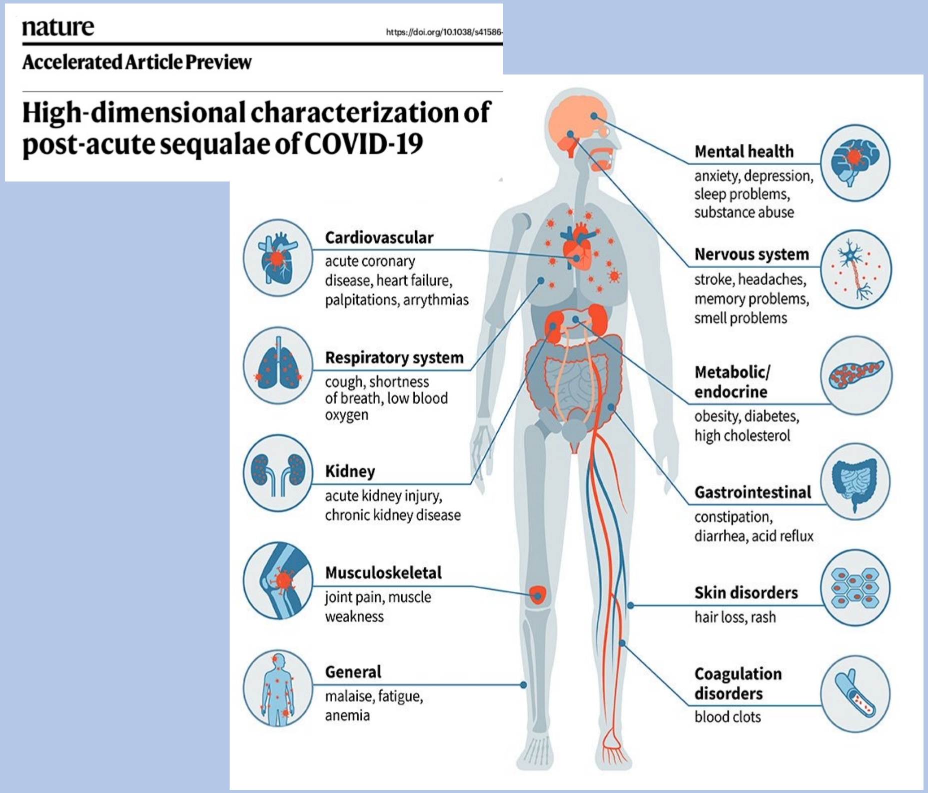


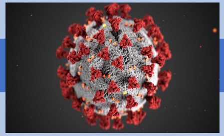
Acute COVID

AI / ML

- Identify infection
- Diagnose disease
- Assess extent
- Monitor therapy
- Detect complications
- Predict outcome / PASC

Long COVID



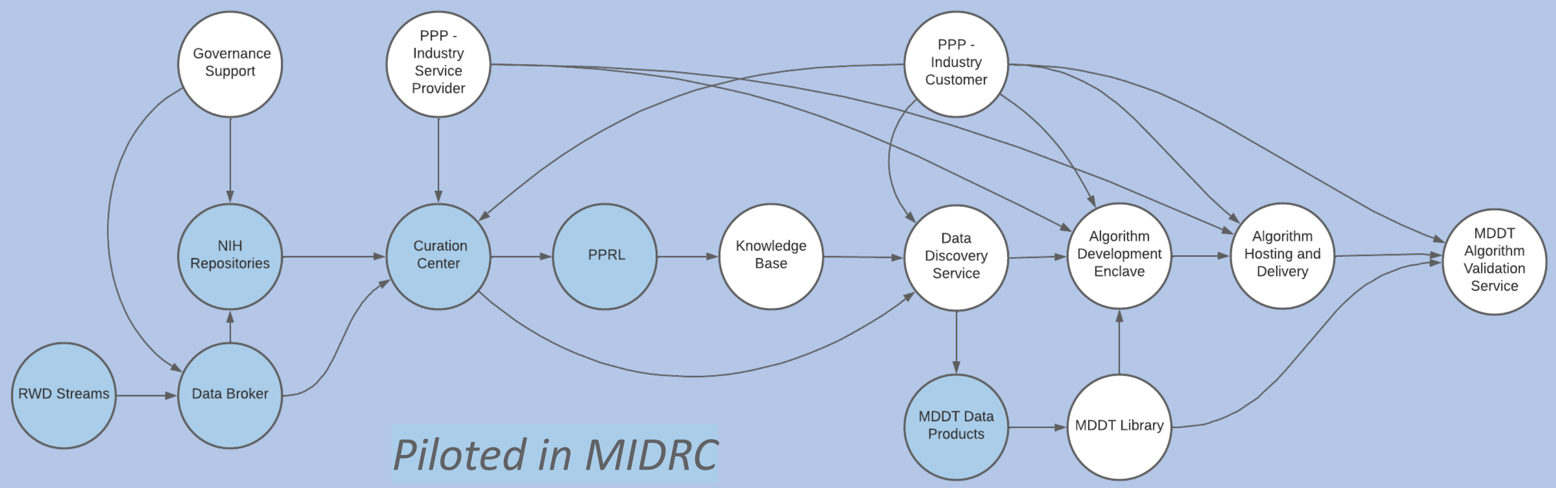


2020

Early 2020

2023+

Currently building a Business Model for an expanded, sustainable, disease agnostic resource to include all imaging modalities!



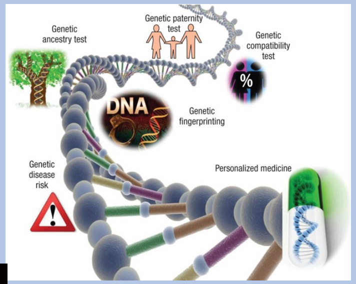
Connecting and Scaling Resources to Scale AI / ML Adoption
Collaborating with the FDA

National Institute of Biomedical Imaging and Bioengineering
Creating Biomedical Technologies to Improve Health

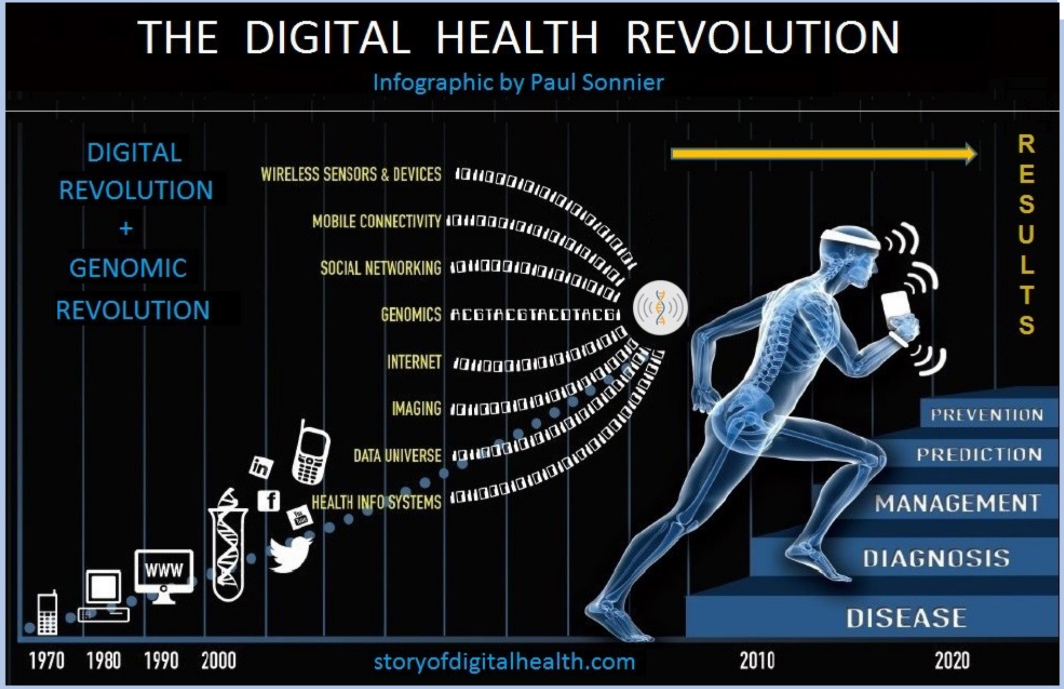
MIDRC
MEDICAL IMAGING AND DATA RESOURCE CENTER.

DEPARTMENT OF HEALTH & HUMAN SERVICES · USA

Vision for NIBIB: *Future of Health*



CONTINUOUS MONITORING & ANALYSIS OF VARIOUS SOURCES OF HEALTH DATA



MULTISCALE
MULTI-MODALITY
TEMPORALLY CONTINUOUS

Time

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Improving precision patient care through Medical Imaging

- Advancing medical image quality
- Enhancing information content in medical images
  - ➢ Extracting tissue characteristics & physical properties
- Re-thinking image acquisition/display strategies
- Enhancing image-guided therapy & surgical skills
- Integrating various sources of health data
- Preparing for the dawn of Artificial Intelligence applications to medical imaging and healthcare.

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FUTURE TRENDS BY MODALITY

Medical Ultrasound: developed many decades ago, but recent advancements are making this imaging modality more useful than ever before. These include:

- Artificial Intelligence: beamforming, speckle reduction and disease identification
- Quantitative ultrasound: sub-resolution imaging using tissue speed of sound, acoustic attenuation, & backscatter coefficients
- Tissue harmonic imaging: using non-linear propagation of ultrasound through the body tissues
- Flexible and wearable arrays: Allows continuous, non-invasive monitoring to provide comprehensive, real-time cardiac information.

These advancements are leading to higher quality, less expensive, more accessible (POC settings) imaging, while decreasing the need for human interaction while performing US examinations.

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FUTURE TRENDS BY MODALITY

Optical Imaging: Improved precision measurement in OI & spectroscopy, e.g., using quantum enabled imaging and sensing. OI tools for rapid non-invasive diagnosis in both in-person and remote clinical settings, focus on wearable and handheld devices.

Nuclear Medicine: With the introduction of targeted radiotherapy (TRT) agents, SPECT imaging these alpha-emitting isotopes (and their daughters) to aid therapy planning and dosimetry for cancers, while minimizing the dose to surrounding healthy tissues/organs. Given the energy of TRT's gamma emissions, collimator-less SPECT appears to show good promise.

Molecular Imaging: Is evolving in several directions, notably personalized medicine and health monitoring & sensing in everyday settings. Of particular interest are the further development of *theranostics* and multiplexed imaging techniques.

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FUTURE TRENDS BY MODALITY

Computed (XRAY) Tomography: Photon Counting has already introduced an innovation for CT imaging that promises to use tissue composition to aid in radiological diagnosis.

Phase-Contrast & Dark Field X-ray Imaging: offer improved resolution and material discrimination, promising wider clinical applications (e.g., emphysema).

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FUTURE TRENDS BY MODALITY

Magnetic Resonance Imagers: More cost-effective:

- *Lower-field strength* MRI enabled by *machine-learning-based SNR improvement*,
- *Reducing helium consumption* of 1.5 or 3T) and
- *Operational Simplicity* (e.g., reducing site requirements, *'one-button operation'* like CT),
- *More Ergonomic* (minimizing gradient *noise*, reducing *claustrophobia* with open-bore design with higher SNR comparable to conventional cylindrical design
- *Integration with therapeutic procedures* (image-guided therapy or surgery, tracking for cell- or gene-therapy).

MRI Protocols:

- Efficient simultaneous *multi-'contrast' acquisitions*: independent acquisition (e.g., fMRI, DTI, MRS) on the *same device*
- *Automated imaging protocols & analysis*: streamlining acquisition (advanced pulse sequences) and reconstruction protocols (*reducing scan time & personnel costs*);
- Fusion Imaging to enrich *information on structure and function*
- Improved quantification & quality through *greater use of AI/ML.*
- High field 7T MRI: *Brain to Body* – e.g., MSK.

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FUTURE TRENDS BY MODALITY

Bioelectric Technologies:

- Electroencephalography (EEG) remains *dominant but less precise* due to the attenuation of electric field by the body.
- Magnetometers are better for sensing *signals inside the body* but more expensive. Magnetometers are expected to become more affordable, especially in ambulatory applications.
- New sensor hardware and low-cost image-guided reconstruction (by low-field MRI?) could be helpful.

THANK YOU!