MR in the OR: The growth and Application of MRI for interventional radiology and surgery

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@

2015 Meeting of the AAPM

MRgRTMini-track #4 : Joint Imaging-Therapy Science Symposium

STANFORD UNIVERSITY

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Disclosures

- Sponsored Research Project funding from Siemens AX, unpaid Advisory Board member
- Subcontract on NIH grant to Triple Ring Inc.
- NIH Industry-Academia Partnership R01 with Varian (Ginzton Technology Center)
- Founder, Tibaray Inc.
- Moving to Siemens (Head of Innovations, AX) September 2015

Image Guidance during Minimally Invasive Procedures

- MR-Compatible Linear Accelerator (NIH & U. Sydney)
- XMR : a hybrid x-ray/MR guidance platform (Pelc & Fahrig @ Stanford, 1999-2013)
- MV-kV imaging for metal artifact reduction with high-efficiency MV detector (NIH & Varian)
- Tomosynthesis-guided transbronchial needle biopsy using the ‘inverse geometry’ SBDX system (NIH & Triple Ring)
- Image guidance for next generation radiation therapy : PHASER (SLAC, Rad Onc)
- Weight-bearing C-arm CT imaging (Siemens AX, NIH)

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Other Contributors to this Presentation

- Graham Wright,
  Sunnybrook Health Sciences
  Center and University of Toronto
- Steve Hetts, Dept. of Radiology, UCSF
- John Pauly and MRSRL team, EE,
  Stanford University
- Kim Butts Pauly and Peiji Ganouni, RSL,
  Stanford University

Interventional MR : Why Bother?

Evolution of Interventional MR : an Intersection of Advances

Open/short-bore magnets for access to patients
Reduced Pt. anxiety

Improved MRA techniques; Gd-based blood pool agents

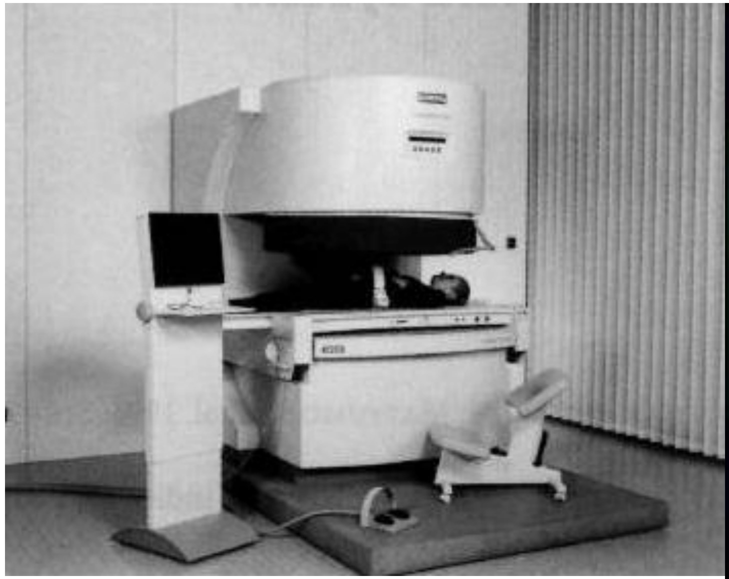
Interventional MR

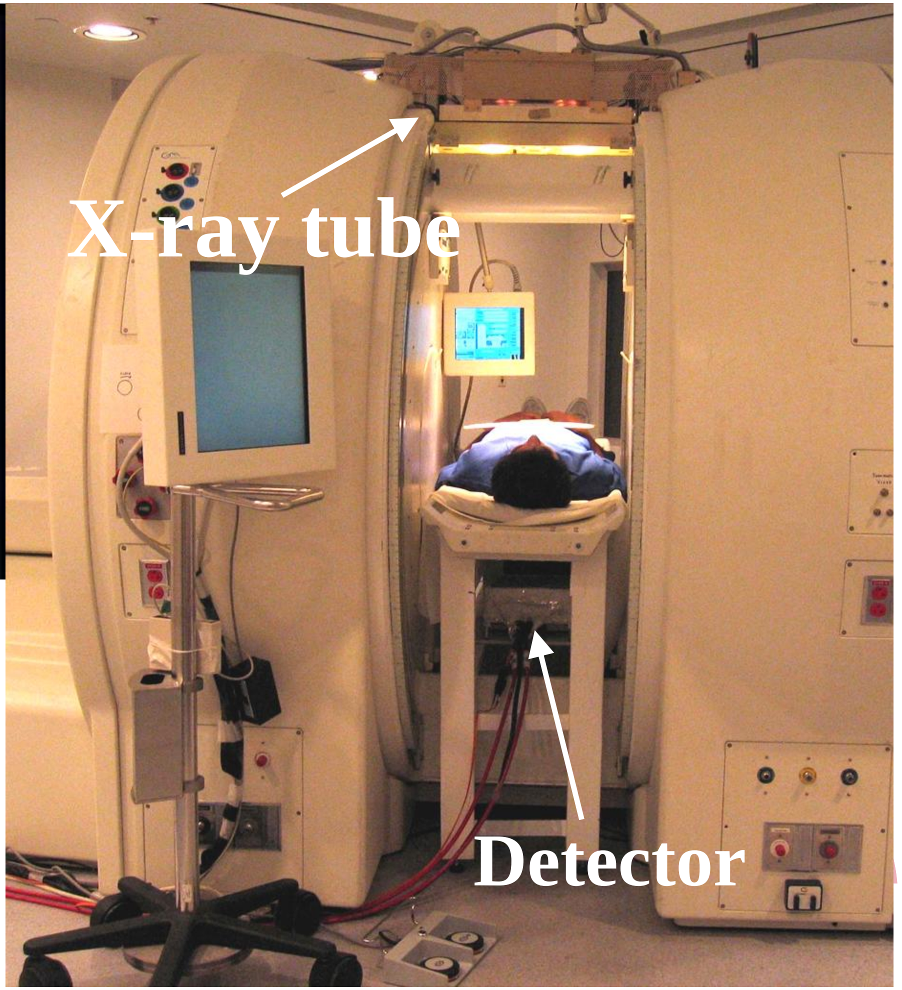
Real-time anatomic and **physiologic** assessment

- *flow rates*
- *organ perfusion, diffusion*
- *metabolism*
- *spectroscopy*
- *temperature*

Rapid MR imaging sequences

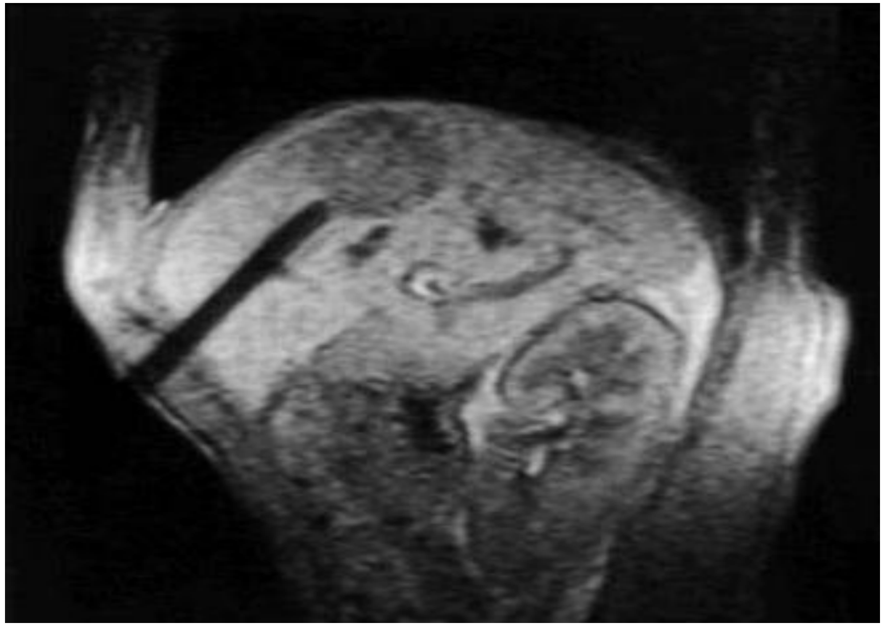
Configurations : Open Magnets

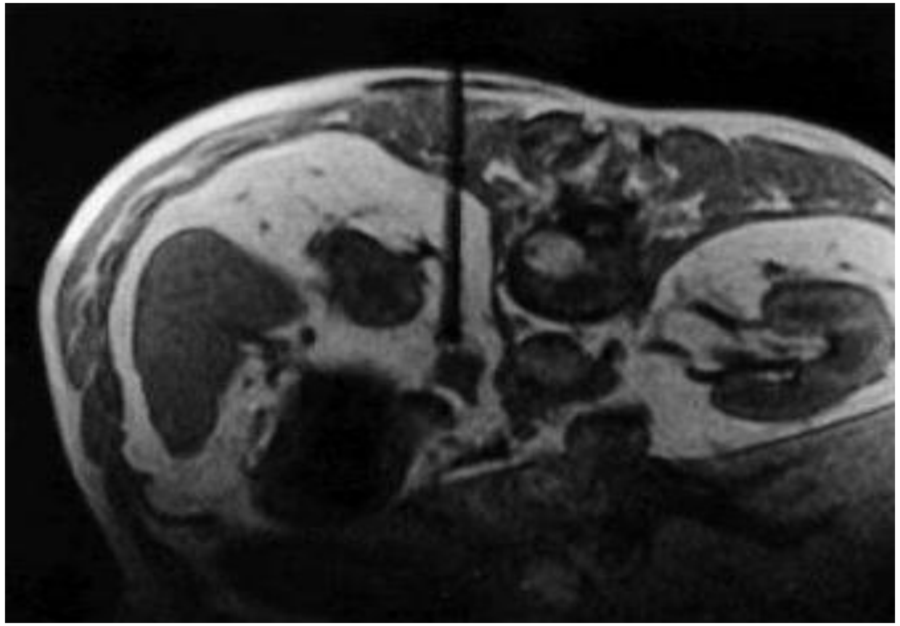




- Direct patient access
- Low field strength (0.2T-1.5T)

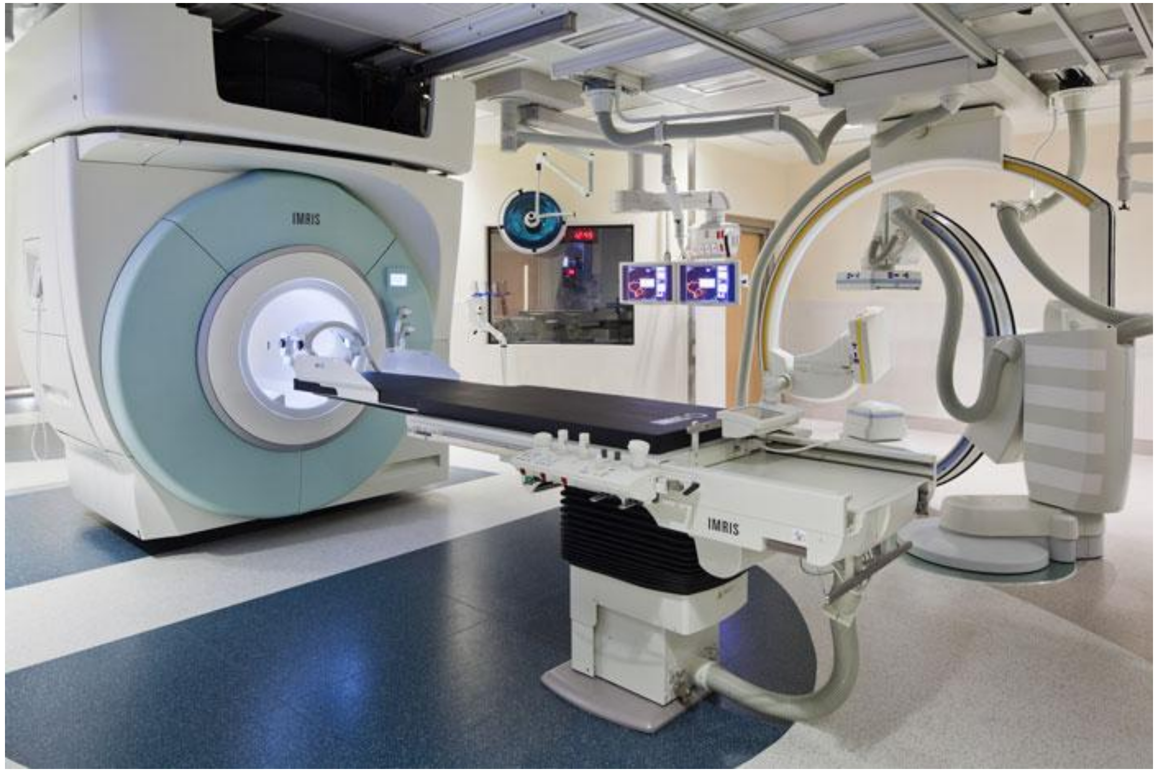
Configurations : Open Magnet



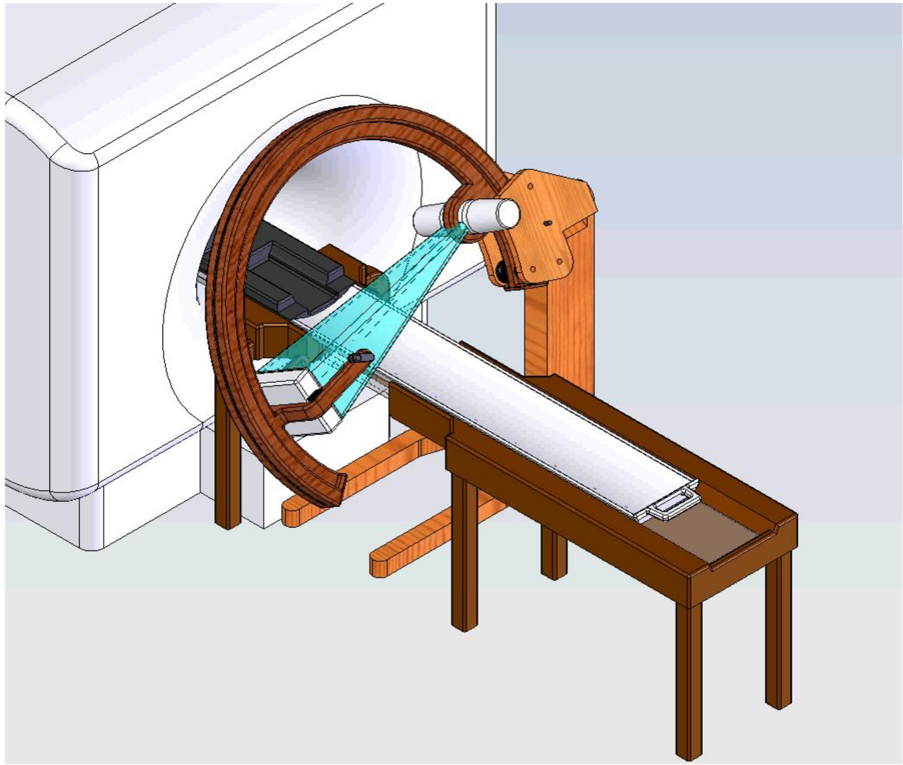


Applications: Percutaneous > Endovascular

Configurations : Hybrid Imaging Systems

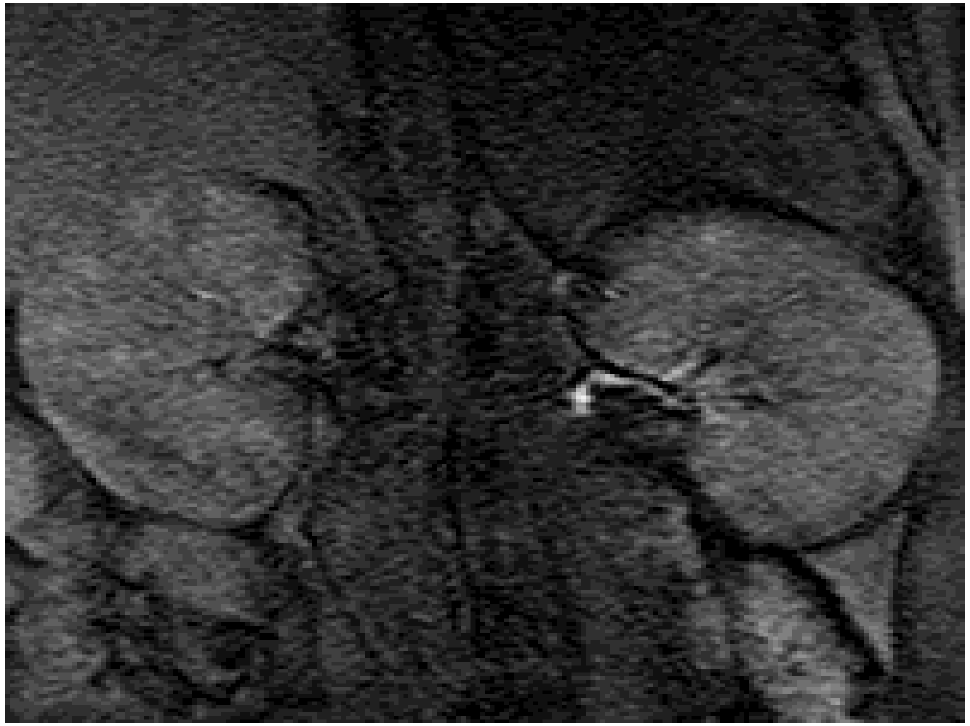


Yale VISIUS MRI-DSA
31 worldwide installations and firm commitments (IMRIS website)



Stanford XMR concept

MR-guided microsphere delivery



DELIVERY SYSTEM: Gadolinium-impregnated Embospheres

IN VIVO MODEL: Canine kidney

PROCEDURE: Catheterization under fluoroscopy

Injection under real-time MR

Multimodality Imaging Interventional Suites

- Take advantage of best features of each type of imaging
- Minimize impact of patient movement
- Reduce reinterventions
- Enhance patient safety

Challenges

- Device safety
  - heating
  - artifact
- Device control
- Device visualization
  - MR imaging sequence and resulting artifacts
  - Real-time system interface and control

Device Safety : Labelling

- MR Safe
  - an item that poses no known hazards in all MRI environments
- MR Conditional
  - an item that has been demonstrated to pose no known hazards in a specified MRI environment with specified conditions of use
- MR Unsafe
  - An item that is known to pose hazards in all MRI environments

MR Conditional : the details

- Field conditions that define the MRI environment
  - Static magnetic field strength
  - Spatial gradient
  - dB/dT
  - RF fields
  - Specific absorption rate (SAR)

Device Safety

- Risk of RF heating due to inductive and/or capacitive coupling with transmitted B_1 field
  - Change geometry (e.g. coiled vs. linear)
  - Distributed RF traps along the length of the wire
  - Flexible transformers
  - ‘safety index’

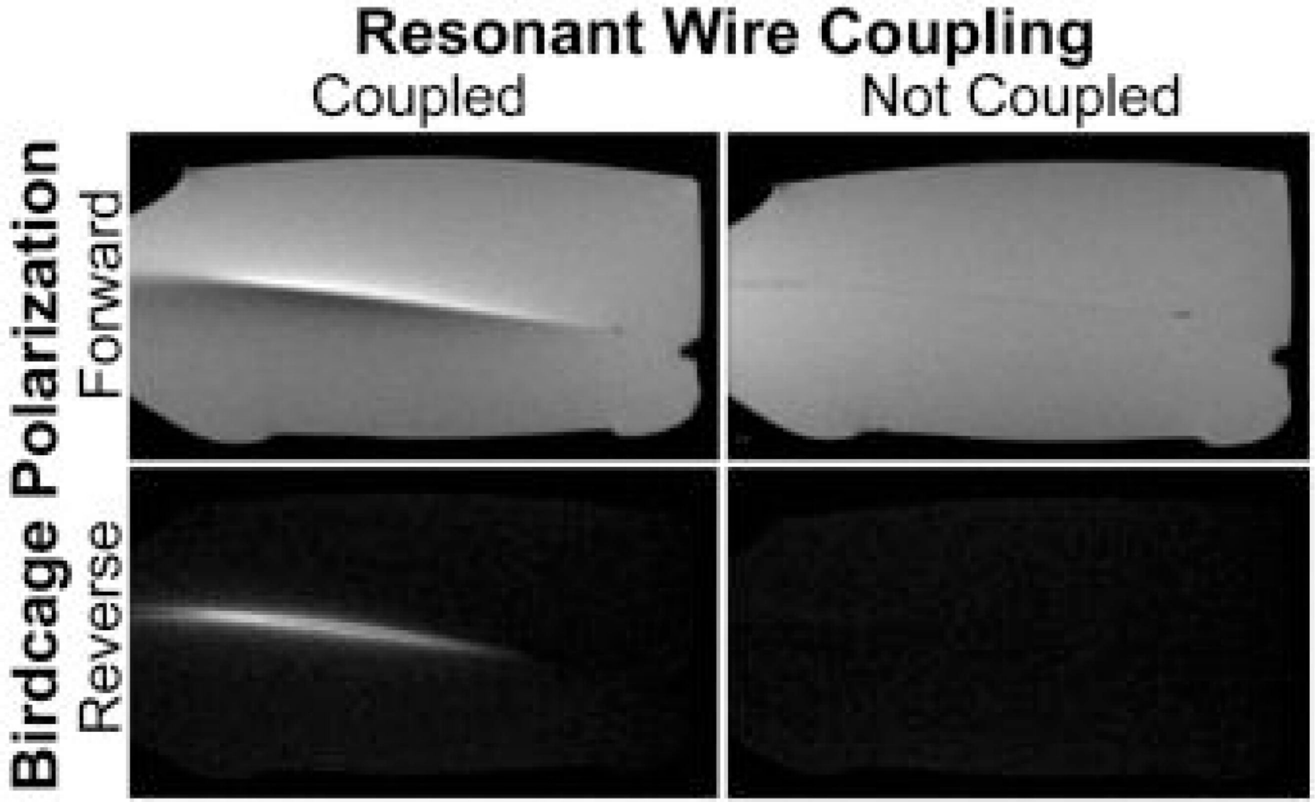
Device Safety : Monitoring

- If transmit and receive RF fields have reverse polarization, then no hydrogen spins are excited, and no signal from tissue is detected (use e.g. birdcage coils)
- BUT a conductive object loading the coil can result in RF eddy currents
- homogeneous circular polarization of the birdcage is disturbed and polarization errors are generated

MRSRL *Overall et al.*, Magn Reson Med . 2010 September ; 64(3): 823–833.

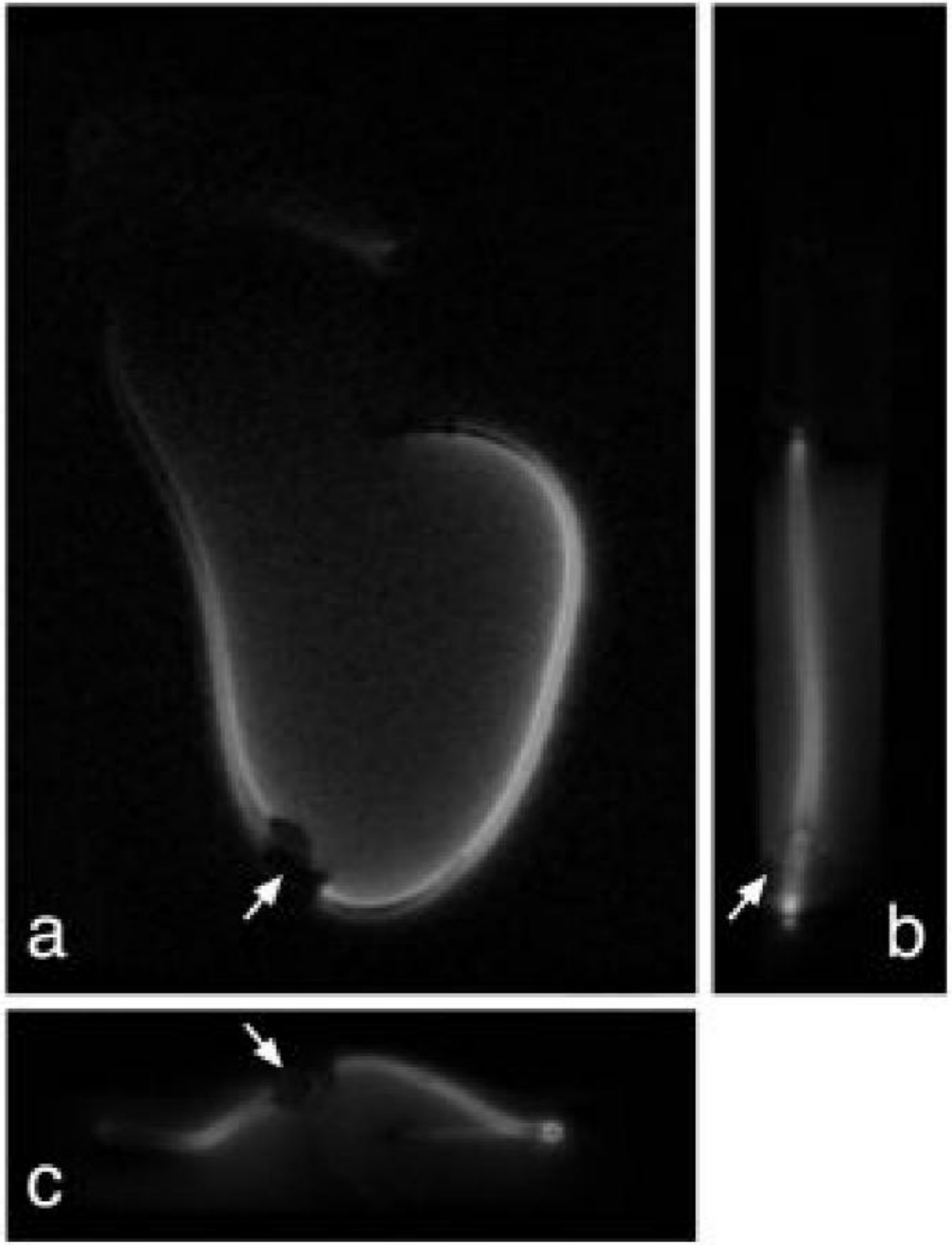
Result of Reverse Polarization

- Suppression of background
- Remaining signal arises from RF current alone
- Get estimate of local wire current, that is wire-geometry dependent



MRSRL

- Reverse-polarization projection images still clearly show the pacemaker leads
- Controlled prescan procedure designed to limit unsafe heating (local tissue heating cannot exceed 2 degrees over the trunk)



To define an interventional device as 'MR Conditional' all of the following are considered except:

3%	1.	Static magnetic field strength
7%	2.	Spatial Gradient
9%	3.	Specific absorption rate (SAR)
8%	4.	Radiofrequency (RF) fields
72%	5.	MR image quality

Answer

- 5. MR image quality
- Reference: American Society for Testing and Materials (ASTM) International, Designation : F2503-05. Standard Practive for Marking Medical Devices and Other Items for Safety in the Magnetic Resonance Environment. ASTM International, West Conshohocken, PA, 2005

Device Visualization

- RF ablation for LV tachycardia
  - Map area of infarct
  - Visualize lesion size
- Cross total chronic occlusions in the coronary arteries
- Extend to RF ablation for atrial fibrillation
  - Imaging of lesions still very challenging in the LA

Etezadi-Amoli et al., Magnetic Resonance in Medicine 73:1315–1327 (2015)

Active Imaging

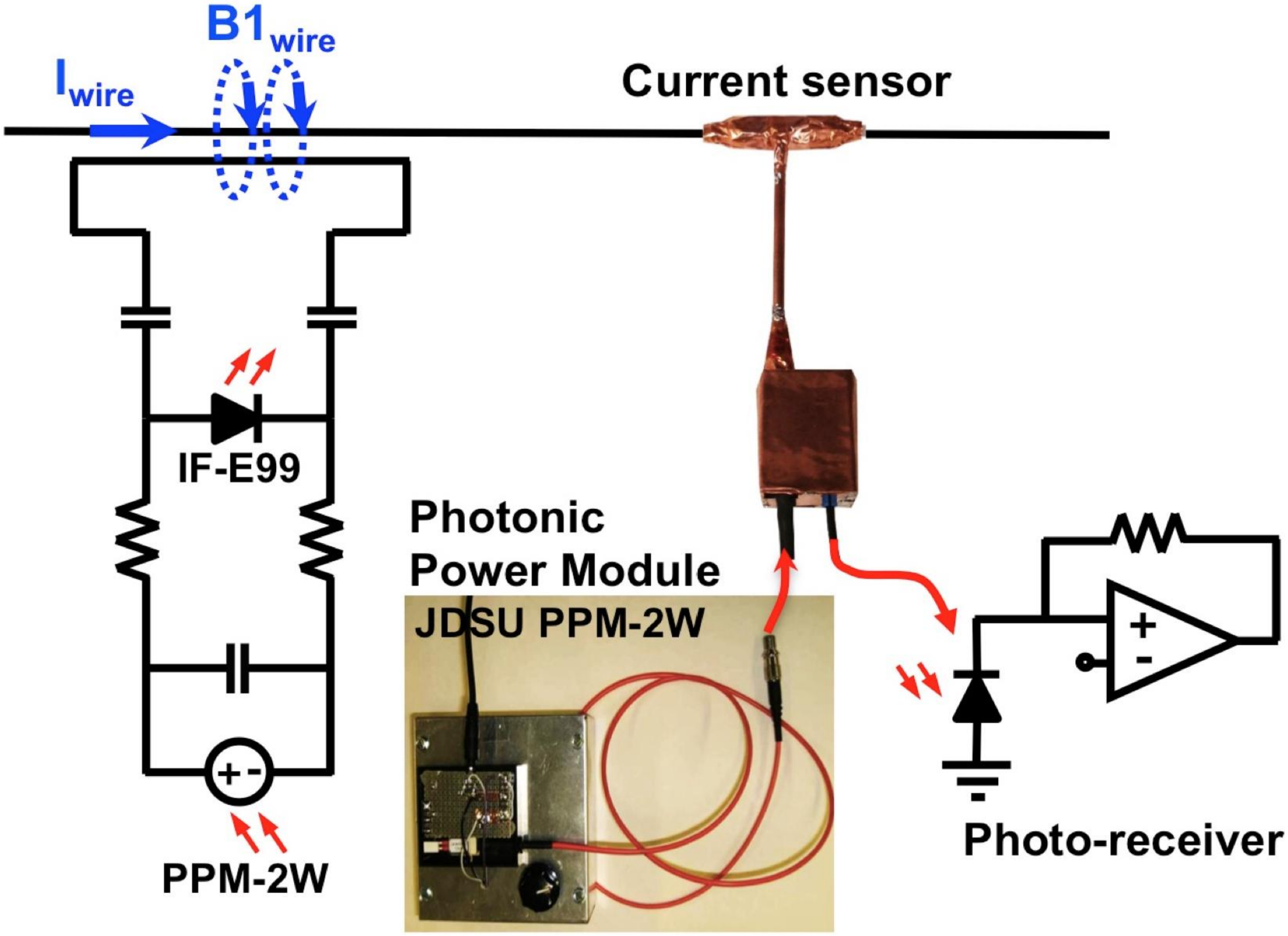
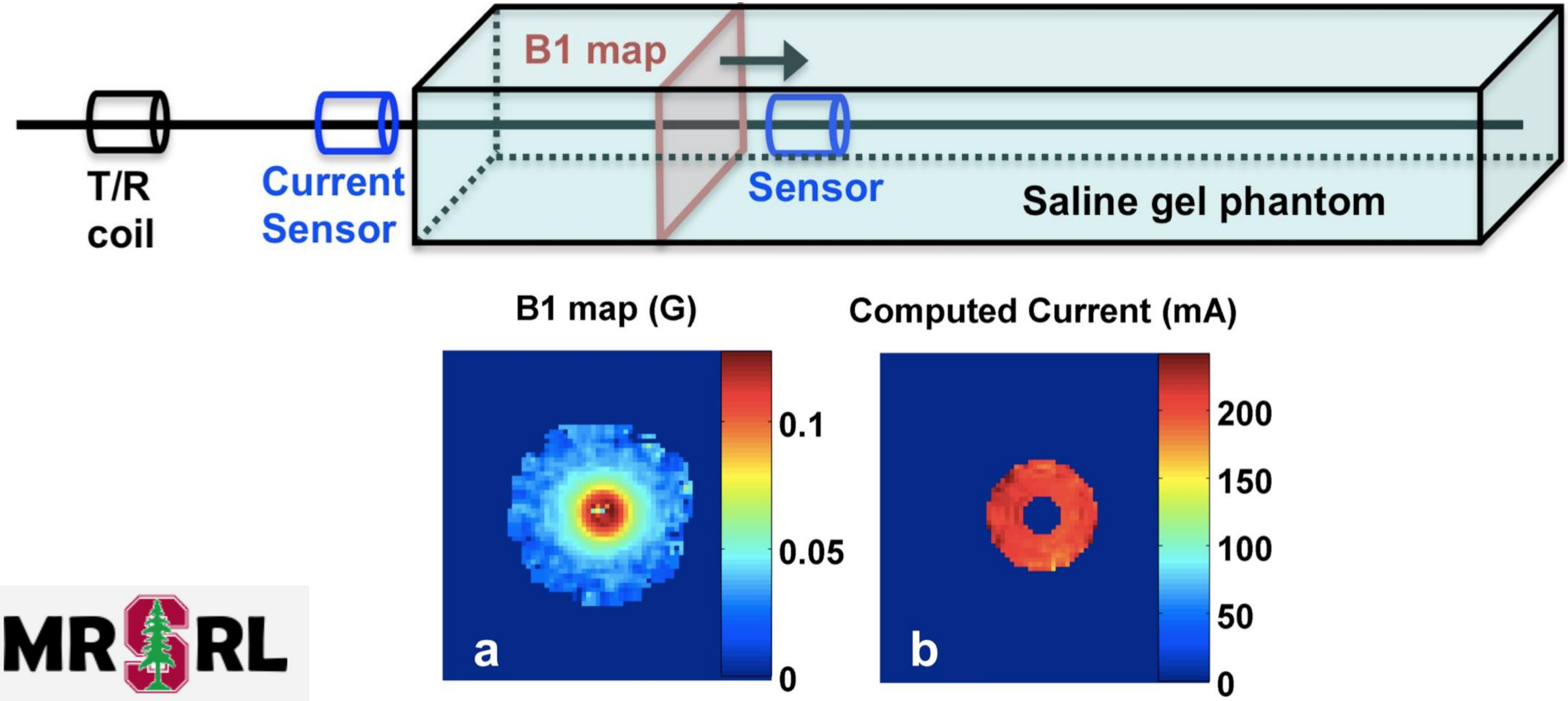
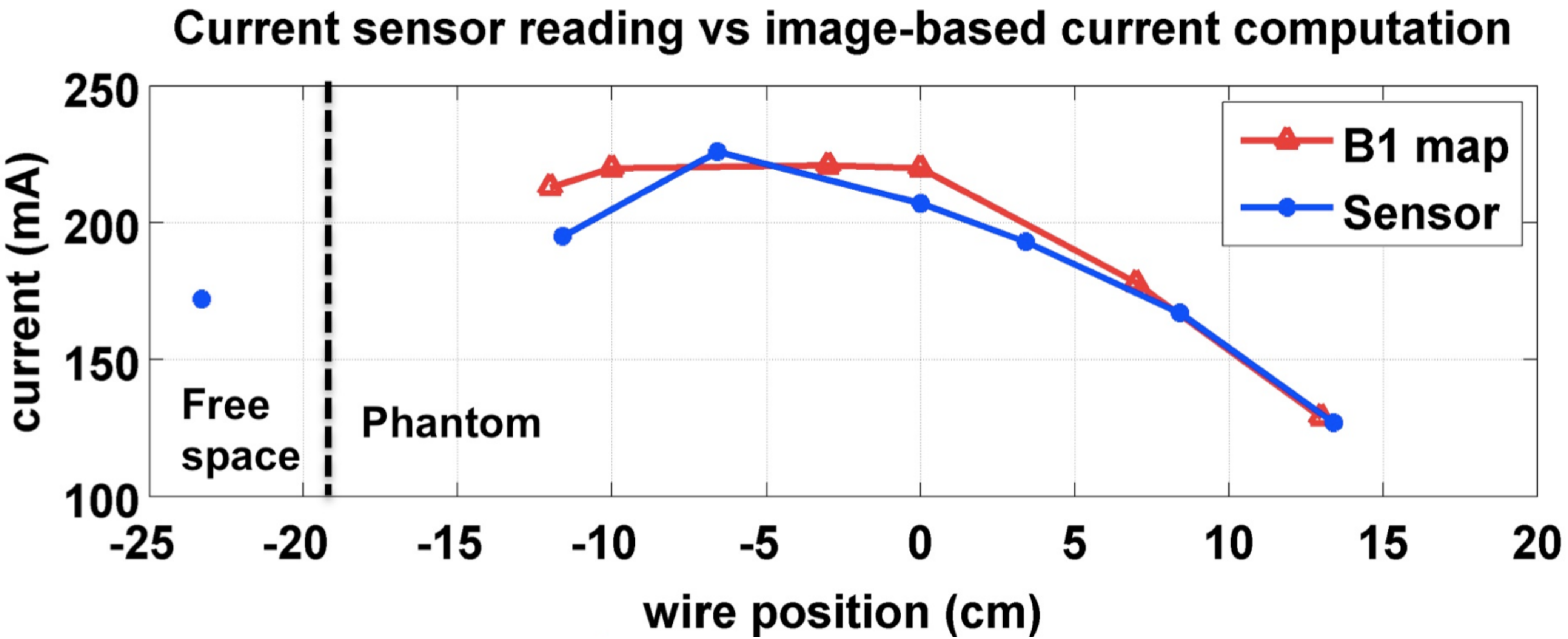


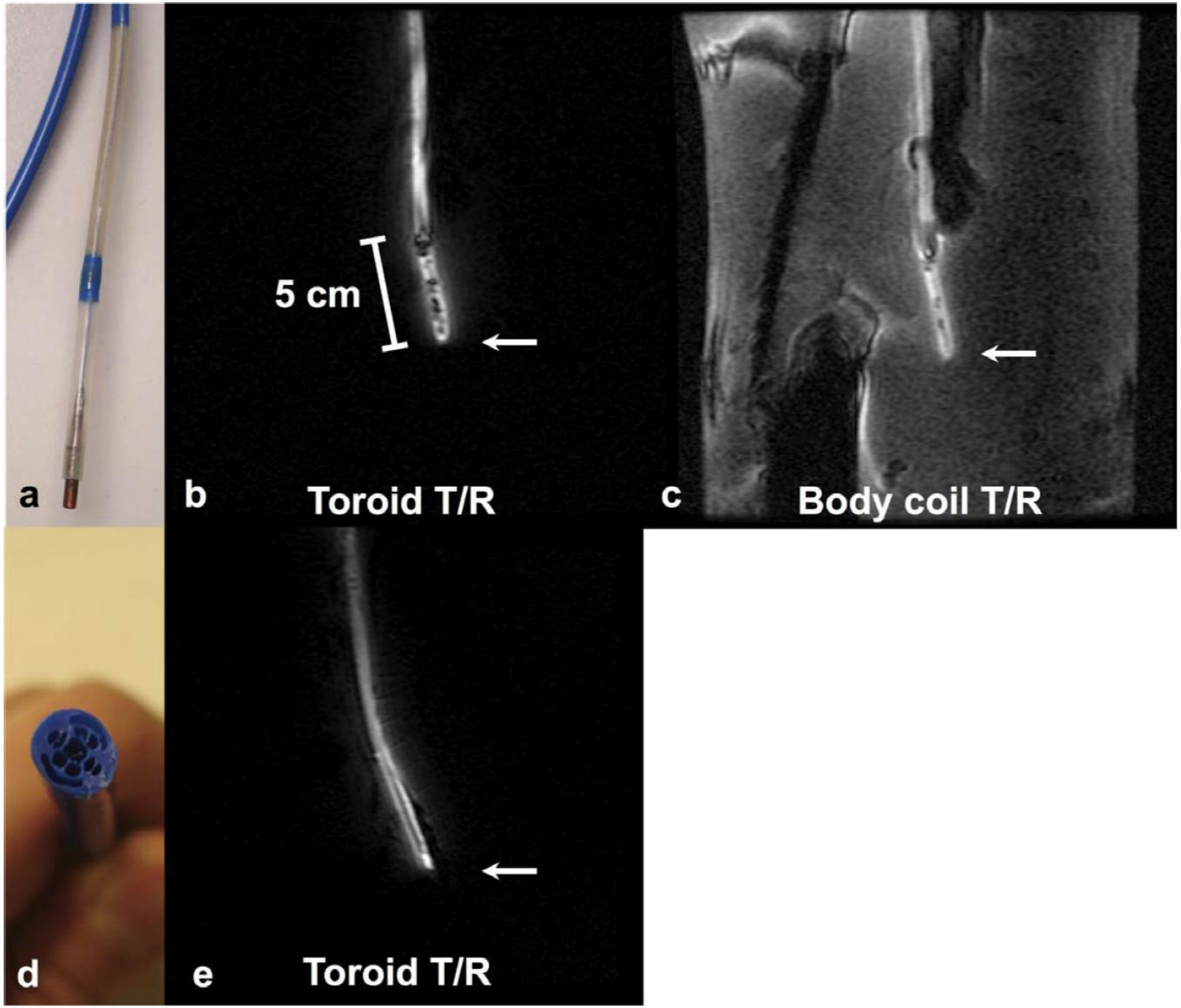
Image-based current sensing



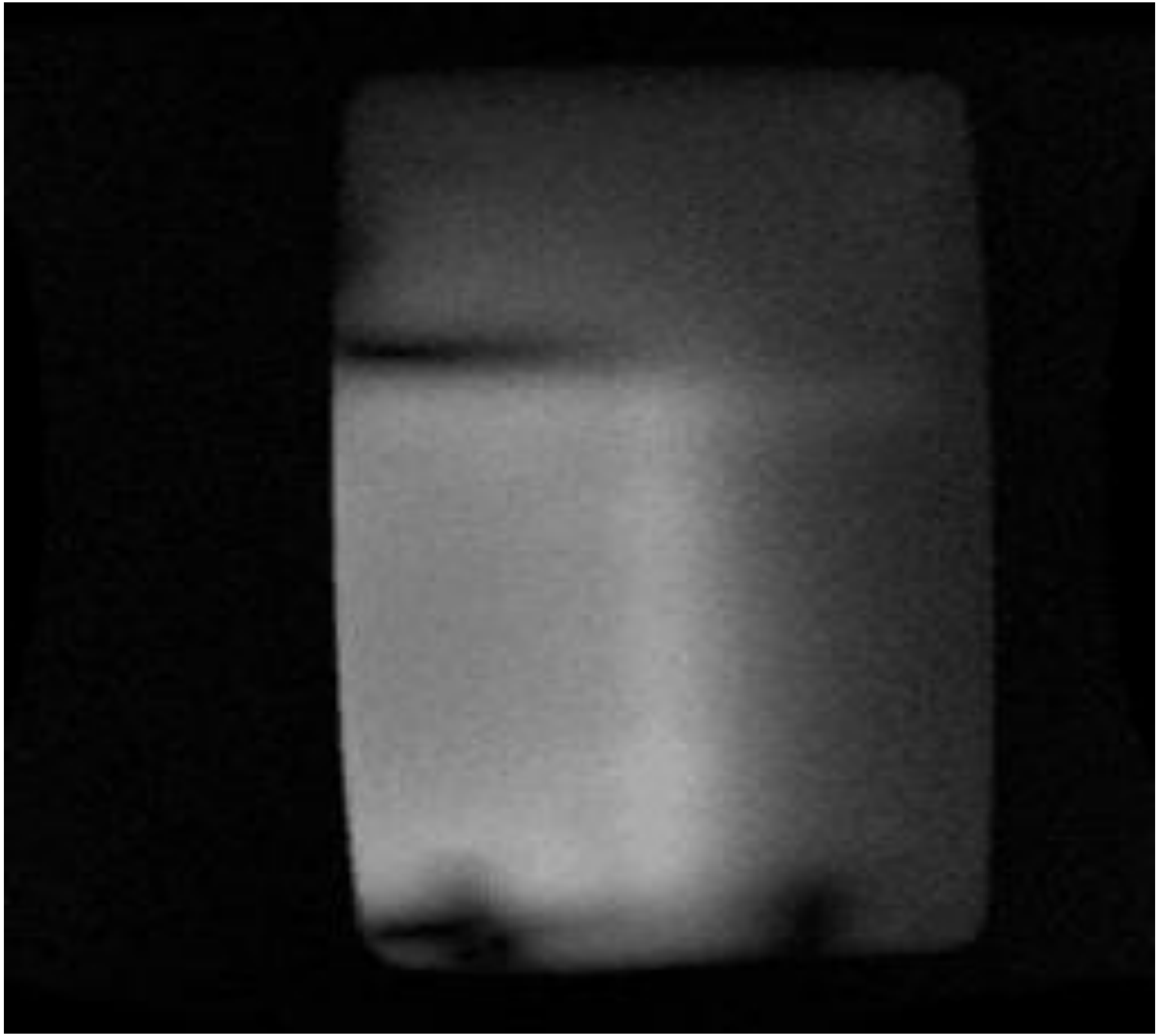
MRSRL


Current sensor reading vs image-based current computation
current (mA)
250
200
150
100
-25
-20
-15
-10
-5
0
5
10
15
20
wire position (cm)
B1 map
Sensor
Free space
Phantom

MRSRL

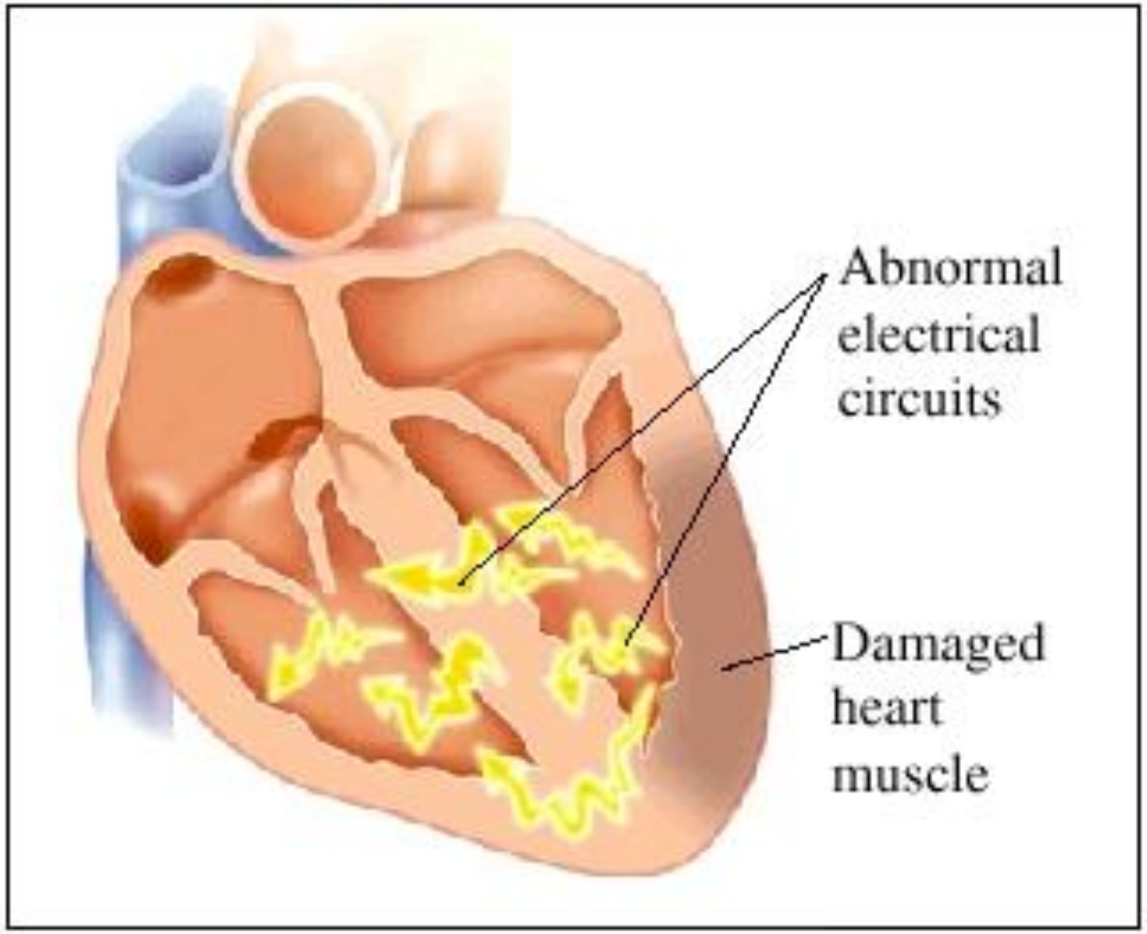


a
b
5 cm
Toroid T/R
c
Body coil T/R
d
e
Toroid T/R



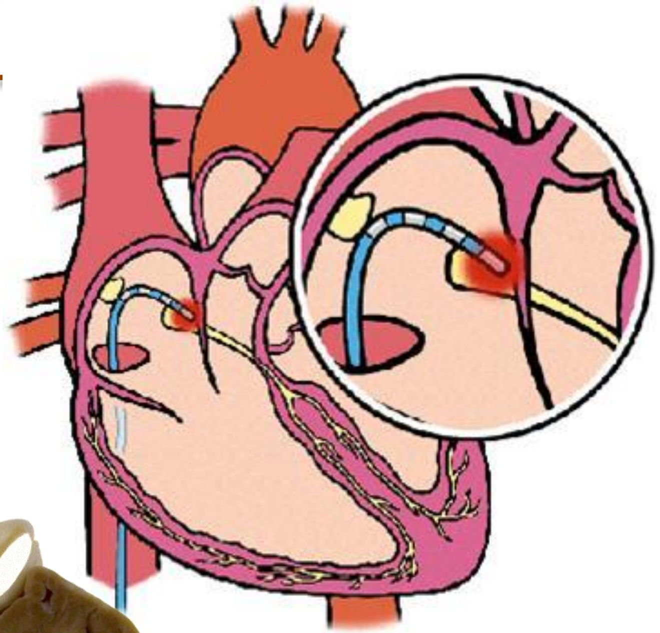
Cardiac arrhythmia

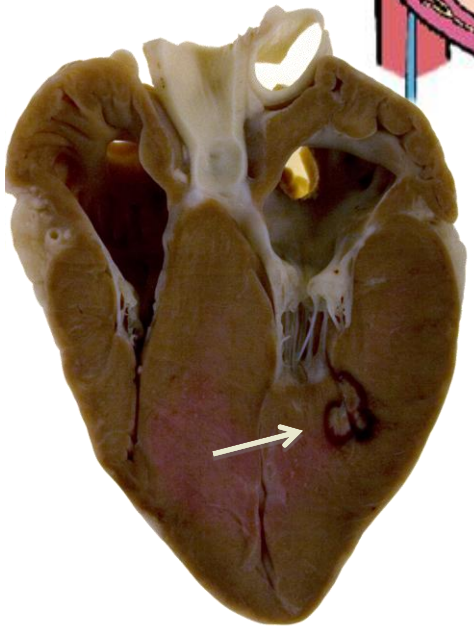
- Caused by unwanted electrical foci
- Risks associated with arrhythmia:
  - Atrial Fibrillation (AF) : 15% of all strokes (~70,000)
  - Ventricular Tachycardia (VT) : high risk of sudden cardiac death



Motivation - RF ablation for arrhythmia

- Current treatments
  - medication (~50% successful)
  - implantable cardioverter-defibrillator
  - catheter ablation
- Radiofrequency ablation (RFA)
  - Often a first-line therapy
  - Radiofrequency (RF) energy
  - Burn undesirable electrical foci





The Vision-MR™ Ablation Catheter looks, feels, and functions like a conventional ablation catheter, but our patented technology makes it uniquely MR-enabled.

An MR-enabled ablation catheter is not enough to make ablation procedures safe and effective in the MRI environment. The EP recording system and cardiac stimulator must also be MR-enabled to avoid dangerous electromagnetic interactions with the MRI scanner and to provide clear intra-cardiac electrograms and interference-free MR images.

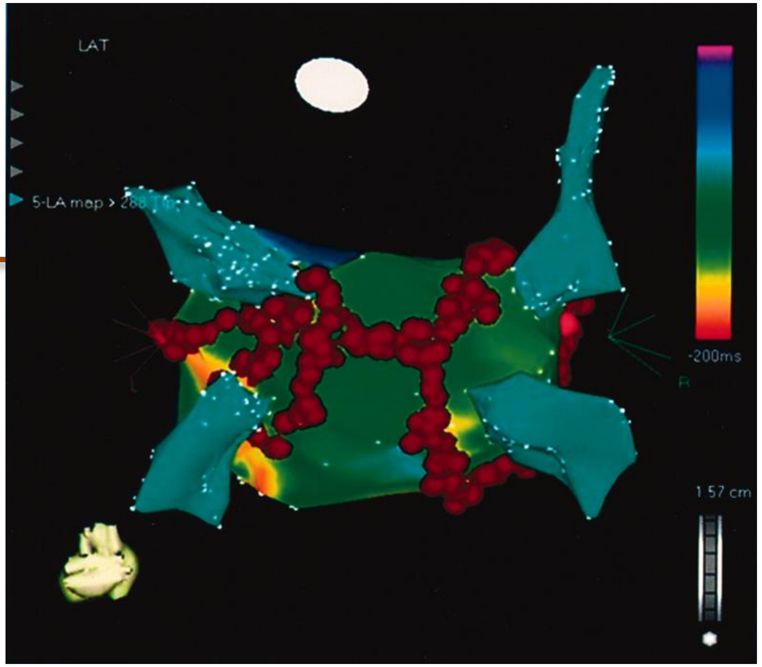
The Advantage-MR™ EP Recorder/Stimulator System delivers the needed MR-enabled recording and pacing functions.

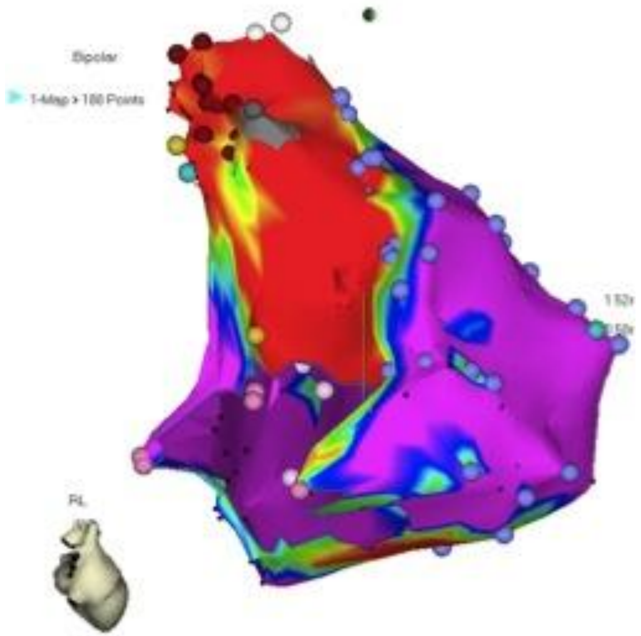
"Imagine, now, that you can see these things, and you are there to treat them."

Christopher Piorkowski M.D., Ph.D.
Head of the Department of Electrophysiology, University of Dresden Heart Center

Motivation - RF ablation

- Currently indirect measurements of lesion formation:
  - RF energy delivered
  - temperature at catheter tip
  - mapping/catheter tracking



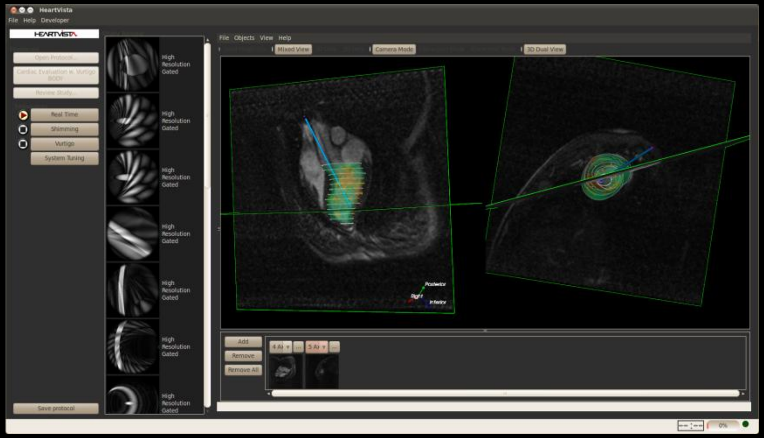


Crandall M A et al. Mayo Clin Proc. 2009;84:643-662

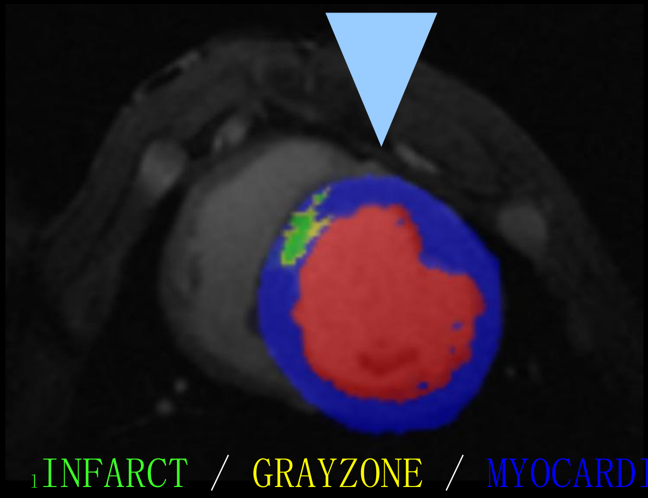
Systems Integration for Electrophysiology

GE MR Scanner

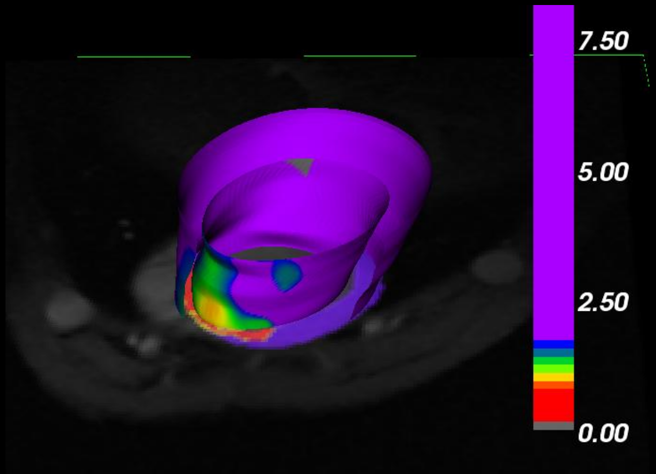
Imricor catheters



Catheter tracking with RTHawk (HeartVista) and Vurtigo visualization (Sunnybrook)



Automated segmentation

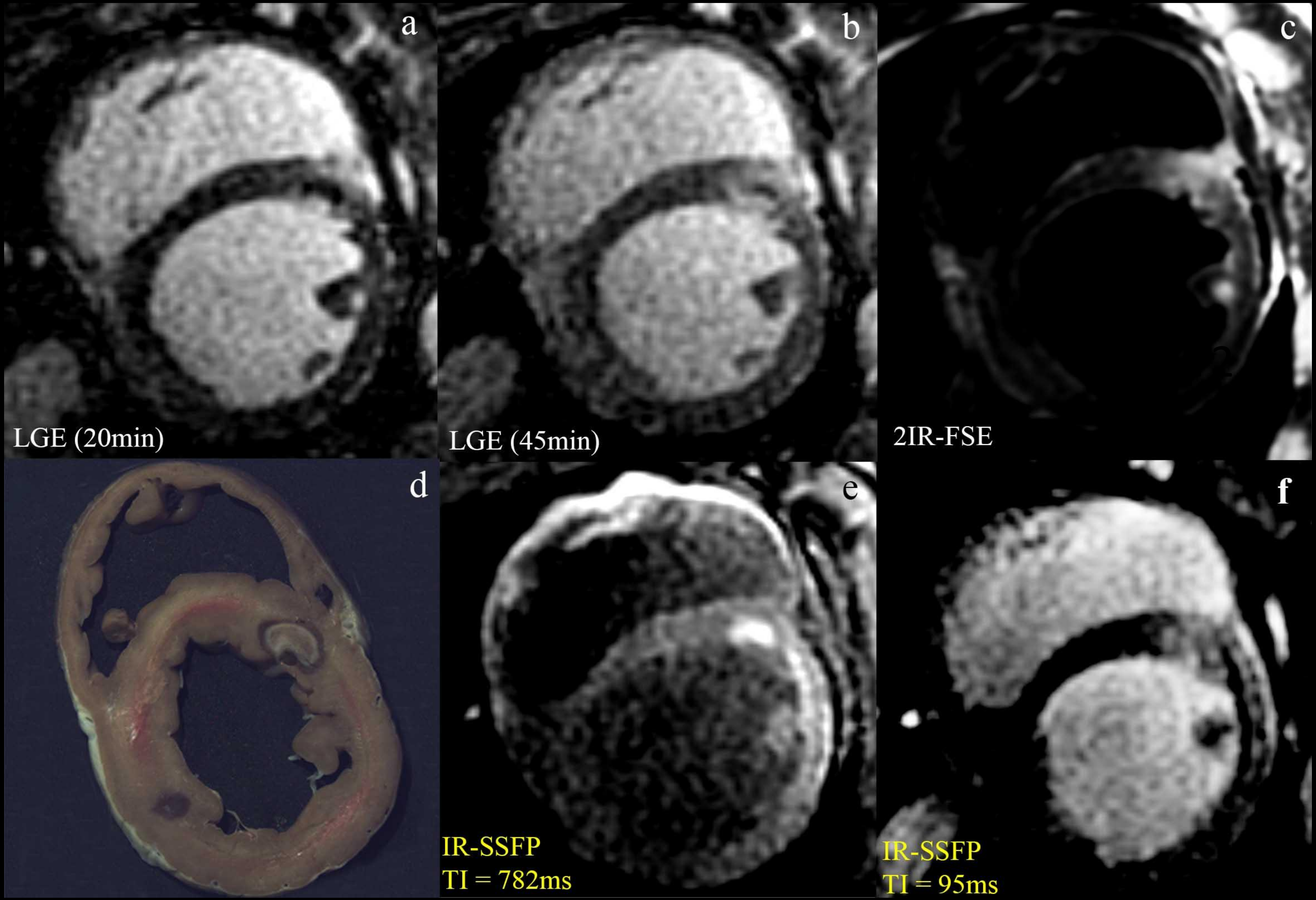


Voltage mapping overlays fused in Vurtigo

Oduneye S et al., IEEE Trans BME Sept 2013

Oduneye S et al., JCMR Apr 2015

RF Ablation Lesion Characterization



Sunnybrook HEALTH SCIENCES CENTRE

Celik et al, Circ EP 2014

Device Control

- Lack of MRI compatible catheters and guidewires -> difficult to navigate under MRI guidance
- Other techniques
  - Catheter tip ferromagnetic beads
  - Smart material actuators
  - Hydraulic catheter
- Limited functionality

Muller, L., et al. (2012)

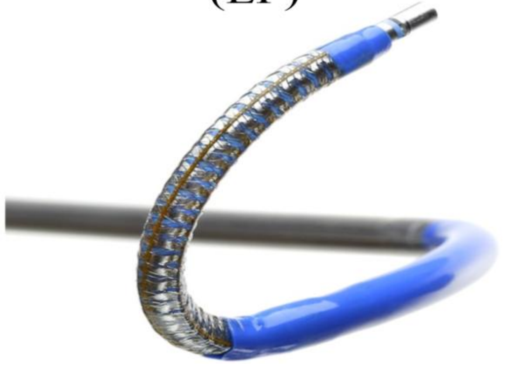
Current Steerable Approaches

- Stereotaxis
  - Two permanent magnet heads with custom guidewires with NdFeB tips
  - Single plane angiography system with modified tube (magnetically shielded) and detector
- Mechanically Steerable
  - Tip deflection via the use of a pull string
  - Not inherently MR-safe
- Other
  - PM beads
  - Shape memory polymers
  - hydraulic

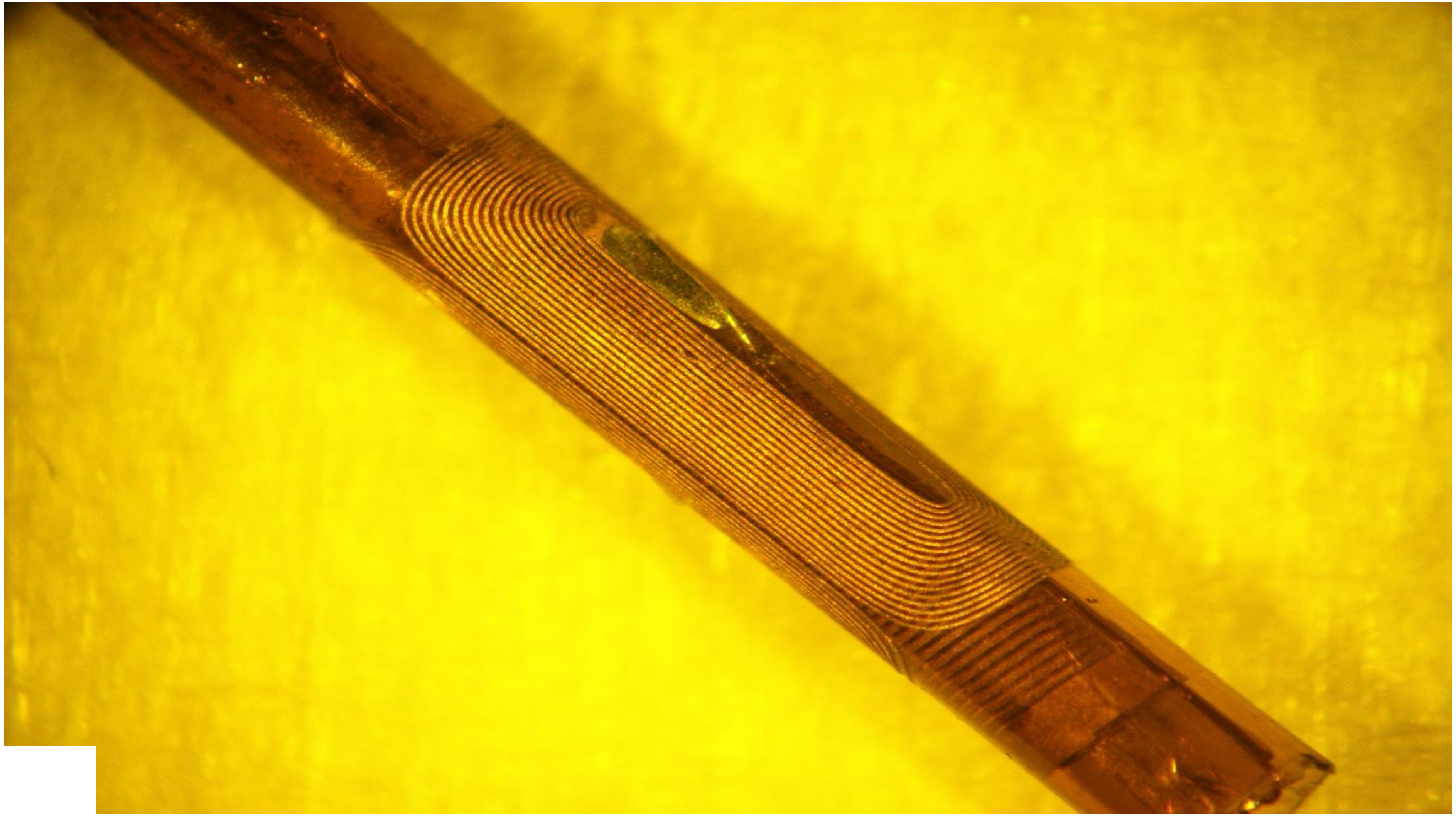
Courtesy: Saint Francis Care, Hartford, CT

Bard Dynamic XT (EP)

Hansen Medical Artisan Extend (EP)

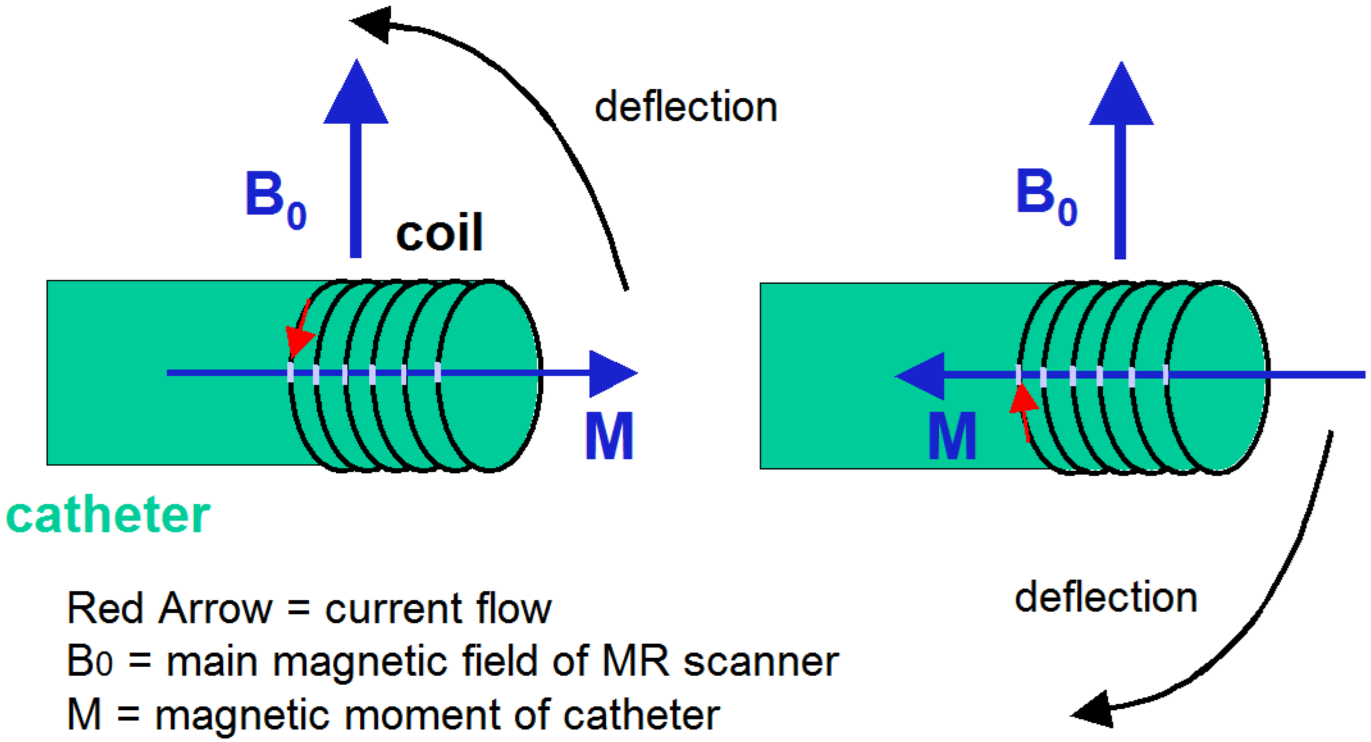


Two-Coil, Double Layer
2.5 French Microcatheter



Wilson et al, *JVIR* 2013

Deflection of Catheter Tip

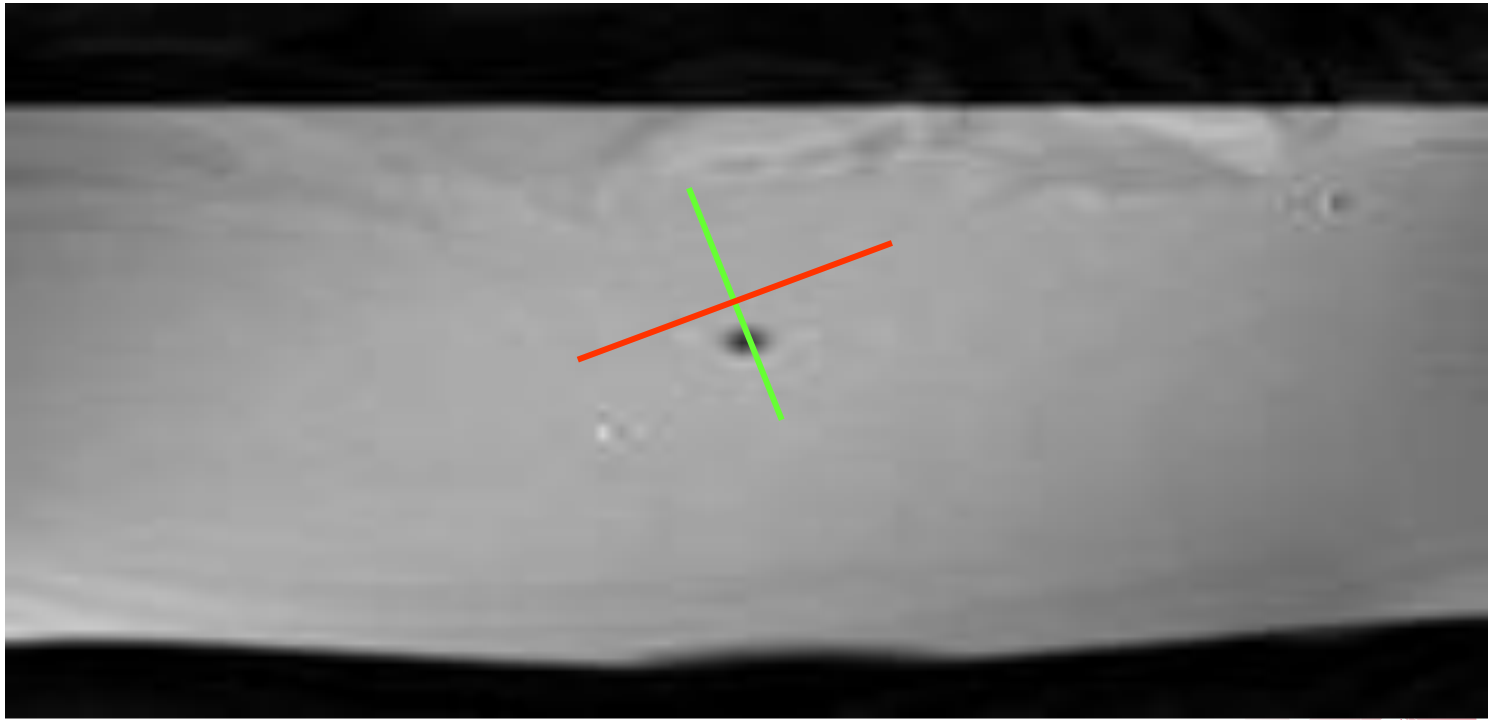


Red Arrow = current flow
B_0 = main magnetic field of MR scanner
M = magnetic moment of catheter
Curved arrows= direction of deflection

Settecase, F., M. S. Sussman, et al. (2007); Roberts, T. P., W. V. Hassenzahl, et al. (2002); Muller, L., M. Saeed, et al. (2012).

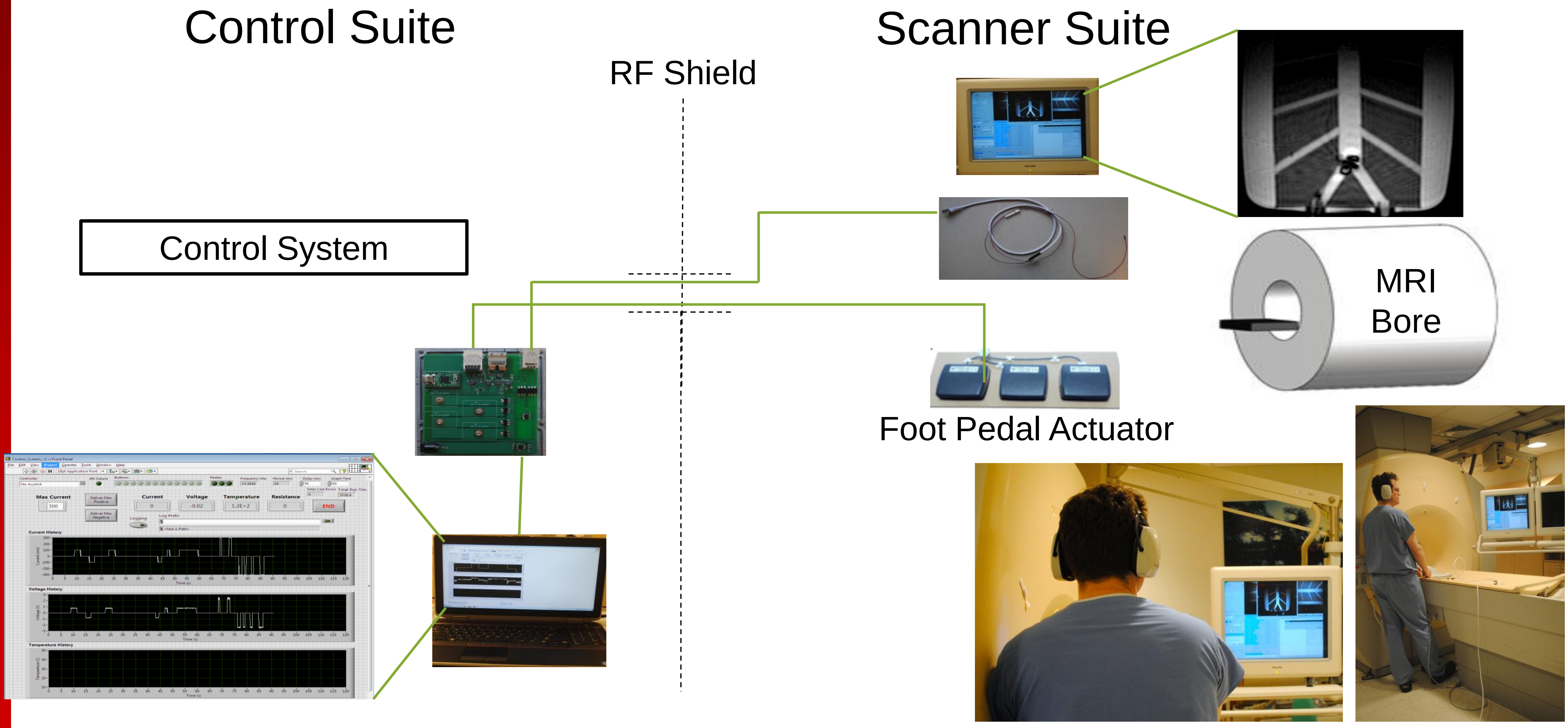
Catheter Deflection

- Double Layer Deflection Catheter (DHC-5)
  - Single layer activation
    - +100 mA inner
    - -100 mA inner
    - +100 mA outer
    - -100 mA outer



inner coil axis of deflection
outer coil axis of deflection

System Configuration in MRI Suite



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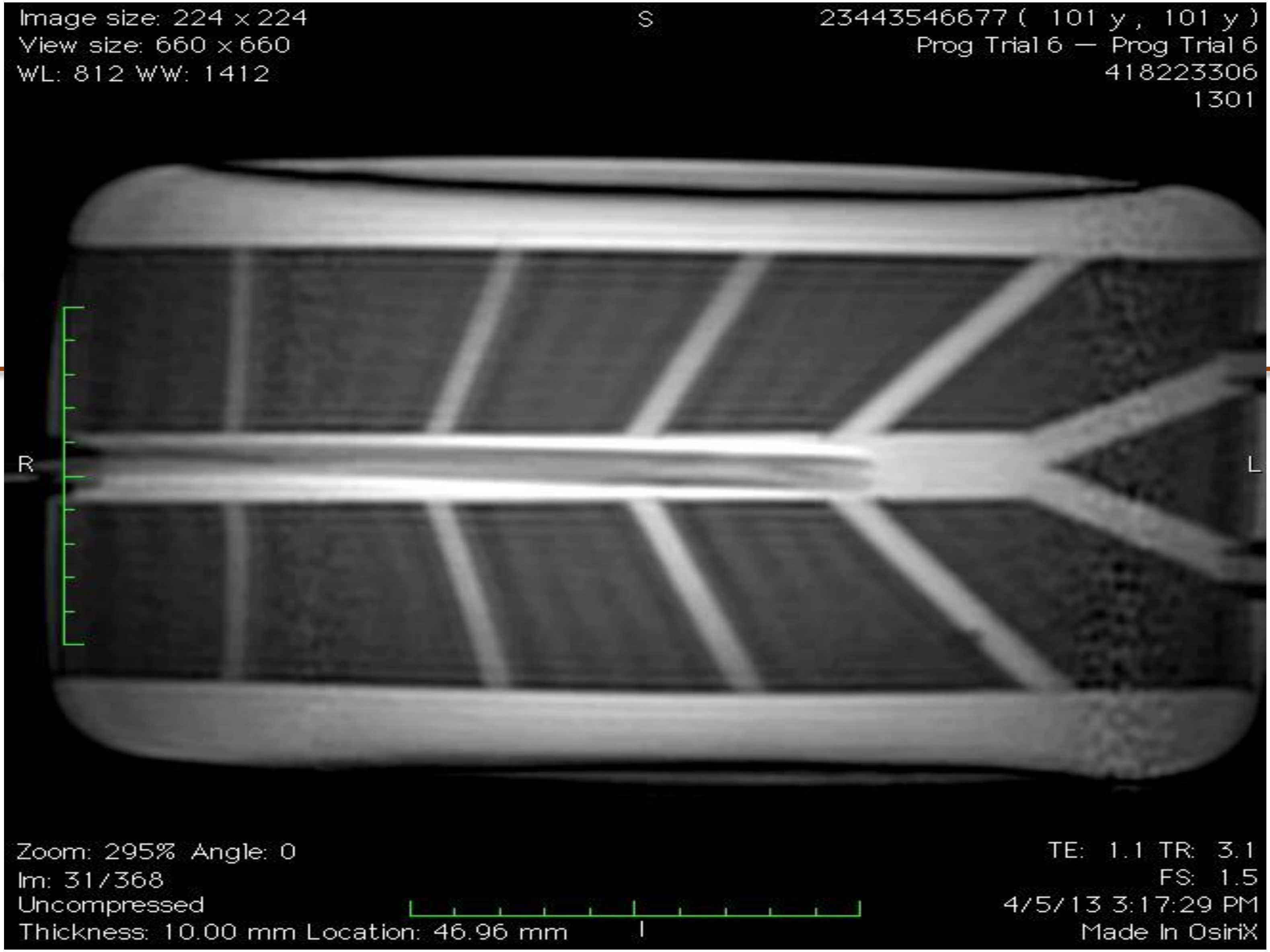
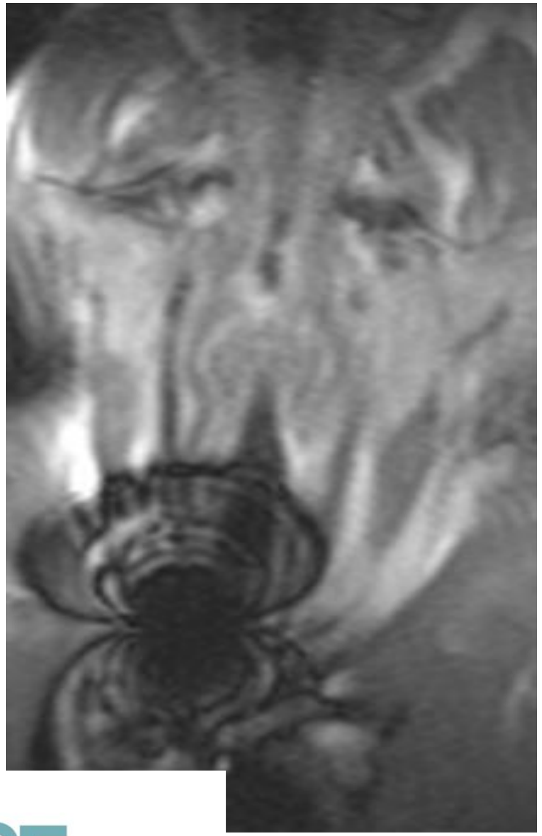


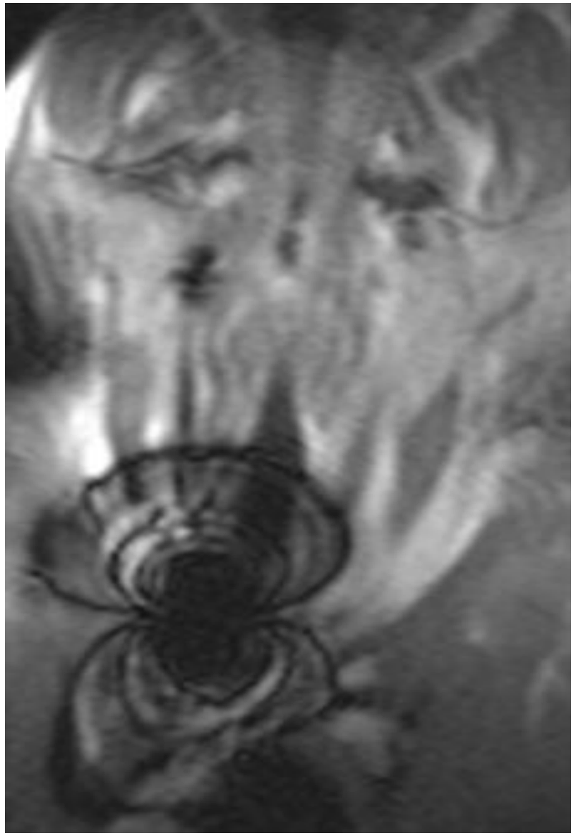
University of California
San Francisco

Swine Carotid Heating Experiment

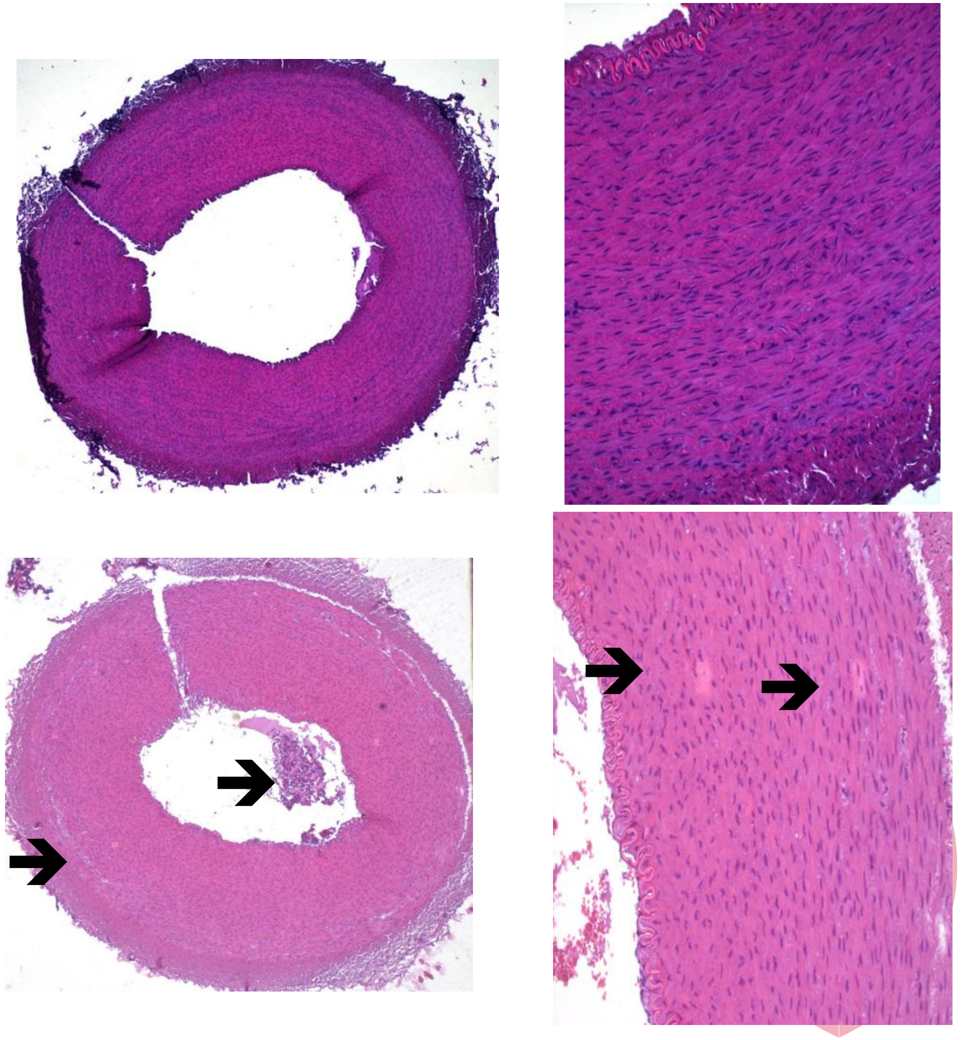
No Cath Tip Current



With Cath Tip Current



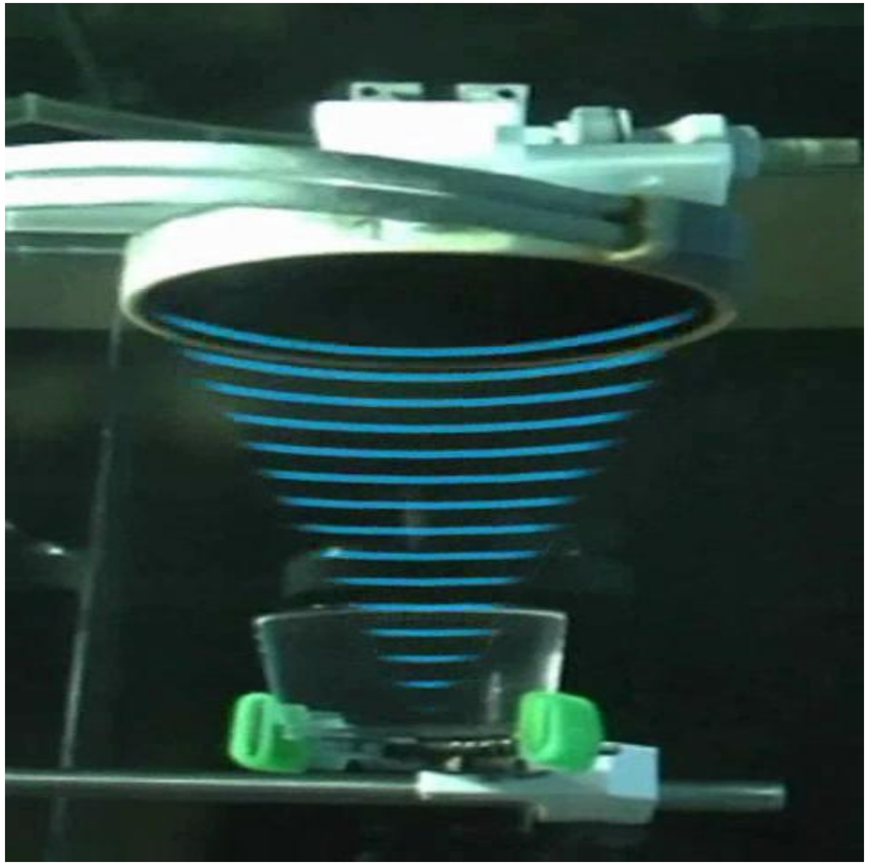
H&E **H&E High Mag**



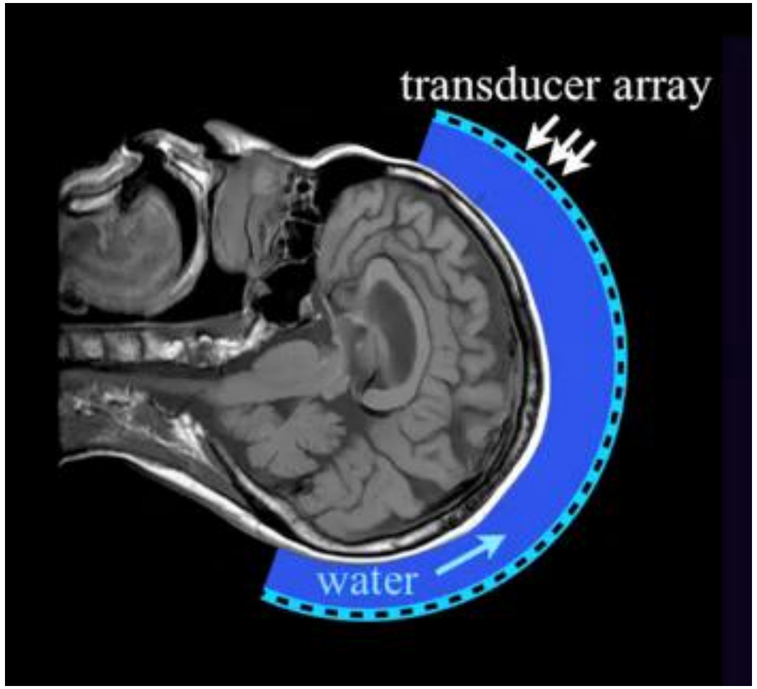
UCSF
University of California
San Francisco

And … Focused Ultrasound

- large area ultrasound transducer array outside the body
- focused geometrically or electronically
- amplification
- significant intensities deep within the body, without damage to intervening tissues



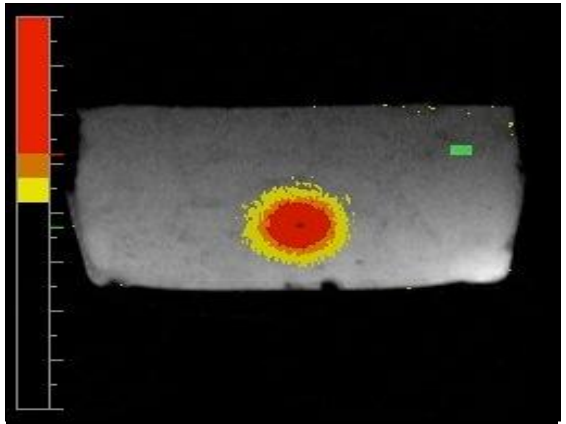
Modern System



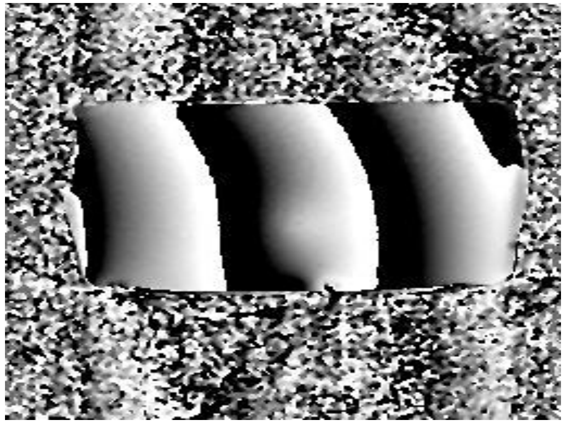
- 1000 elements
- cooled circulating water
- focusing/amplification

Temperature Mapping

- change in hydrogen bonding with temperature
- proton resonant frequency (PRF) shift = -0.0909 ppm/°C.

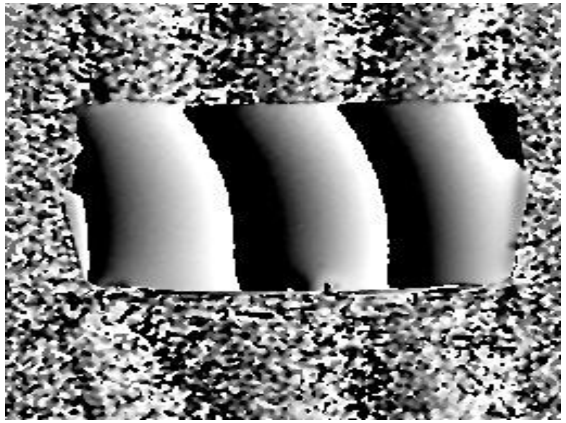


T, Thermal Dose



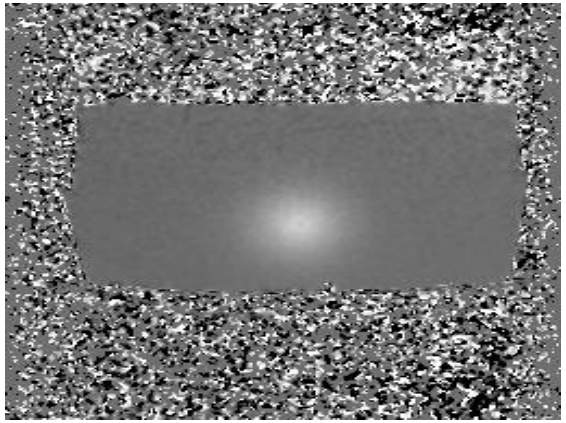
Phase image during heating

−



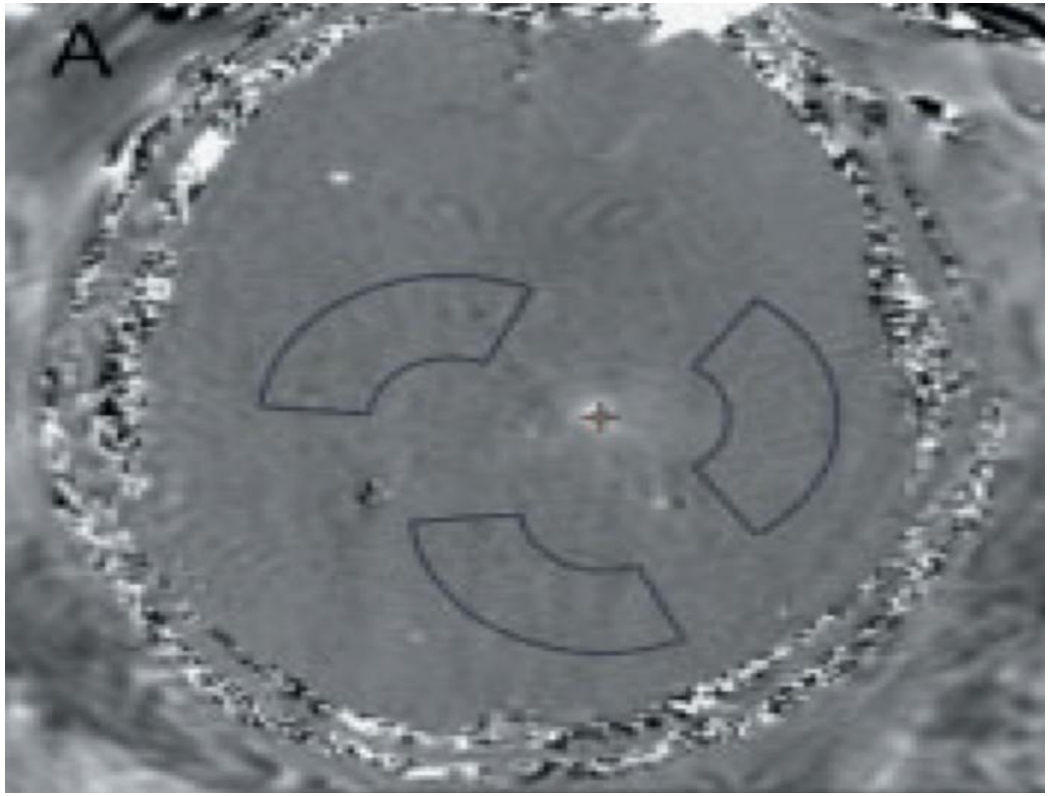
Pre-heat phase image

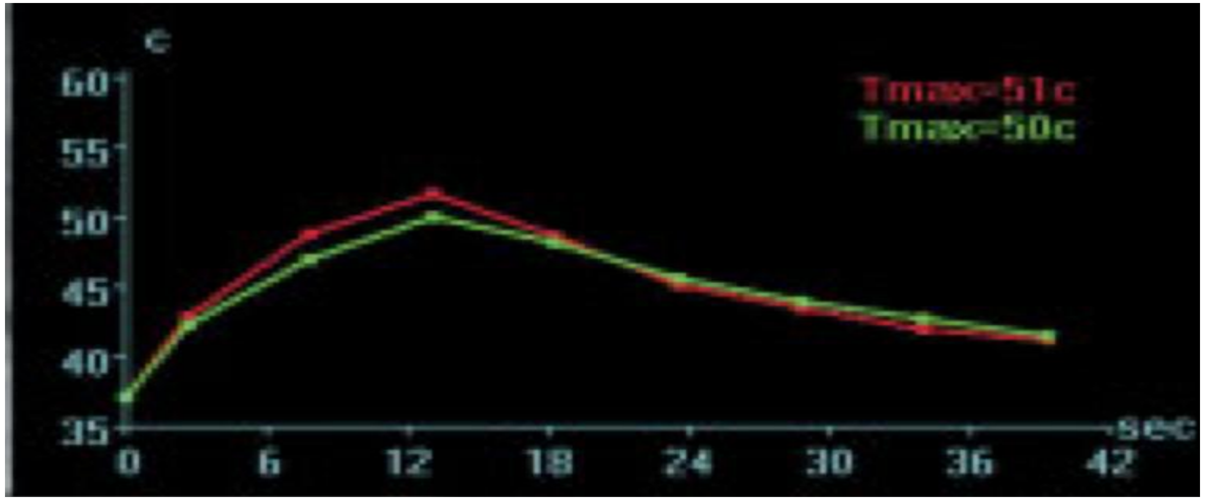
=



Difference

Monitoring: Temperature





Martin, Ann of Neurology, 2009

- Temperature Goal: 58°C for 20 s, 3 times
- Thermal Dose

Courtesy of Jeff Elias, UVA

Essential Tremor

- 10 million Americans or 3% of the population have an essential tremor.

Pretreatment

- immediate symptom relief.
  - *Elias WJ, et al. N Engl J Med. 2013 Aug 15;369(7):640-8*

Posttreatment

Which of the below guidance/feedback techniques is not provided by MRI?

35% 1. Differentiation of living tissue from dead tissue

2% 2. Perfusion

2% 3. Magnetic catheter navigation

45% 4. High-resolution (200 microns) real-time (15 fps) projection images

16% 5. Real-time temperature monitoring

Answer

- 4. MRI does not provide high-resolution projection images at 15 frames per second, and therefore visualization of small guidewires and small vessels is challenging under MR guidance alone.

MRI-guided Interventions

- Visualizes soft tissues and organs for enhanced targeting
- Can provide perfusion and diffusion data
- Provides real-time feedback
  - lesion size
  - temperature monitoring
- No ionizing radiation

MR-guided RT vs. MR-guided Interventions

- Very similar **hardware-related challenges**
- Access to physiological information for **targeting**
- Real-time feedback on **motion**
  BUT
- No immediate tissue response
  - temperature monitoring
  - lesion size

✓ Renal Denervation

"MRI guided renal denervation could provide a verifiable procedural endpoint that is missing today."

Prof. Gerhard Hindricks M.D., Ph.D.
Director of the Department of Electrophysiology Leipzig Heart Center

The World Heath Organization (WHO) estimates that over one billion people worldwide are affected by hypertension[1], a condition of raised blood pressure that contributes to nearly half of all cardiovascular disease[2]. Drug therapy is a popular treatment option for this disease, though some patients develop drug-resistant hypertension or experience adverse effects from long-term pharmaceutical treatment. For these patients, the immerging technology of renal denervation via radiofrequency ablation holds promise for long-term management.

However, major drawbacks of this procedure include difficulty in seeing and selecting the appropriate ablation location and, more importantly, verifying that the desired ablation lesions are formed during the procedure. MRI guided renal denervation has the potential to solve these problems.

Our MR-enabled renal denervation products are being evaluated in preclinical studies.

[1]WHO/DCO/WHD/2013.2.

[2]CDC, Vital Signs: Prevalence, Treatment, and Control of Hypertension – United States; Feb. 4. 2011 60 (014):103-108.

Other Contributors to this Presentation

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- John Pauly and MRSRL team, EE,
  Stanford University
- Kim Butts Pauly and Peiji Ganouni, RSL,
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