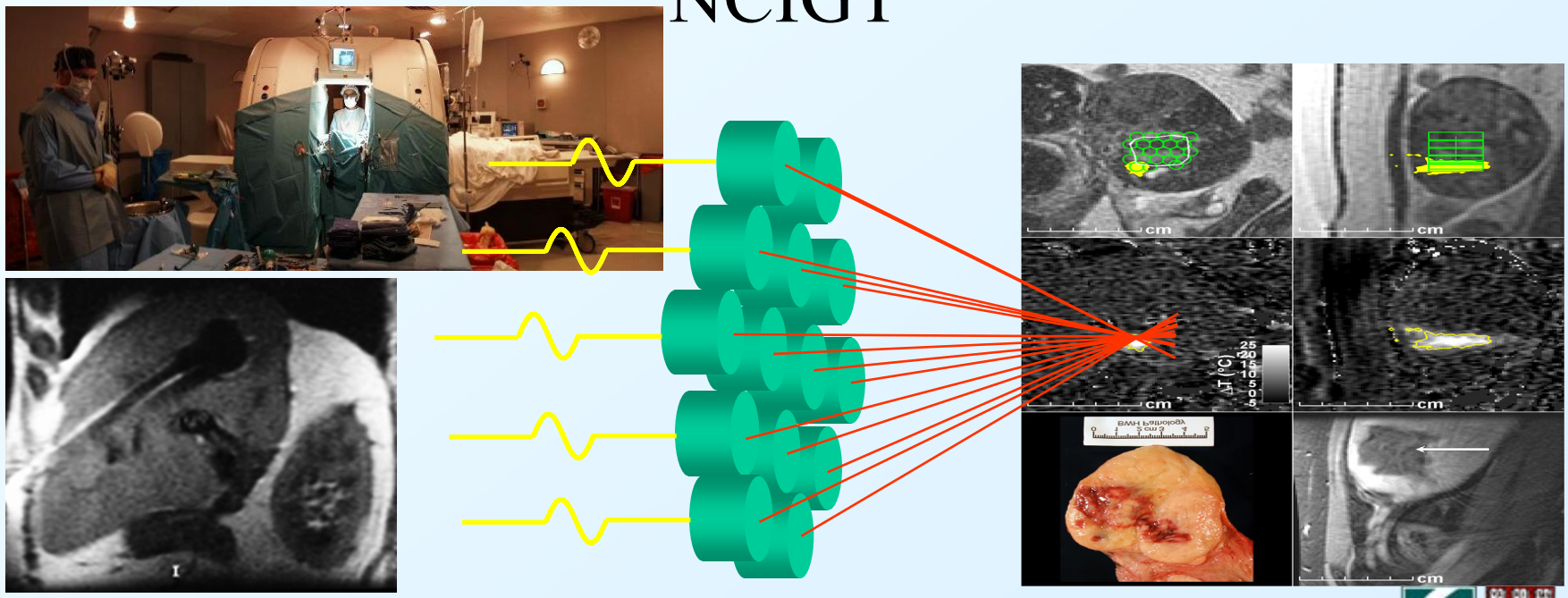
MR intervention for Dummies

Clare Tempany MD

Brigham & Women's Hospital

NCIGT



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Disclosures

- Research grant support
  - Elbit Medical imaging Ltd (InSightec-Image guided treatment)
  - NIH
    - National Center for Image guided therapy
  - GEHC
- Consultant
  - Elbit Medical imaging Ltd (InSightec-Image guided treatment)

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Learning Objectives

- Understand Interventional MR
  - Devices, Equipment, Safety & Infrastructure
- Applications
  - MR Thermometry
- Current/Future imaging and theraputic techniques
- MR guided prostate Bx
- MRgFUS-uterine fibroids
- URL:

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Acknowledgments

- Ferenc Jolesz, Tina Kapur, Anthony D'Amico, Ron Kikinis, Jerry Richie, Stuart Silverman, Kemal Tuncali, Paul Morrison, Noby Hata, Simon DiMaio, Steve Haker, Robert Cormack, Dan Kacher, Gabor Fichtinger, Christos Davatizkos, Greg Fischer, Axel Krieger, Clif Burdette, Jack Blevins, Bob Mulkern, Nathan Mc Dannold, Kullervo Hynenen, Elizabeth Stewart, Fiona Fennessy, Alisa Suzuki, Agneskia Szot-Barnes, Joseph Roebuck, Sandy Wells, Simon Warfield, Kelly Zou, Junichi Tokuda, Masanori Hirose, Kiyo Chinzei, Andy Tsai, Aditya Bharatha, Ian Chan, Minna So, Michelle Albert,, Mark Hurwitz, Dan George, Robert Ross, William Oh, Warren Su, George Toupolos , Harry Kadir, Bob McKie
- ***Special Thanks to Angela Roddy-Kanan RN, and Janice Farihurst RT for help and slides***

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Current trends in healthcare

- "Aging boomers" More elderly patients
  - 17%- 25% > 65 yrs by 2030
- Reduced hospitalization time
  - Personalized medicine
  - Surgery changing: From invasive to minimally invasive to noninvasive
    - Out patient facilities smaller sites/ less overhead
  - Decrease length of stay (LOS)
  - Increased off site care: Telemedicine/telemonitoring
- Increasing role of imaging
  - Biomarker/surrogate markers
  - Personalized medicine
  - More image-guided interventions
- US increase in self pay/self coverage
  - Est to increase to 50%
  - Increase patient choice and control in care givers

OLDER ,
LESS TIME,
MORE IMAGES
MORE PERSONALIZED

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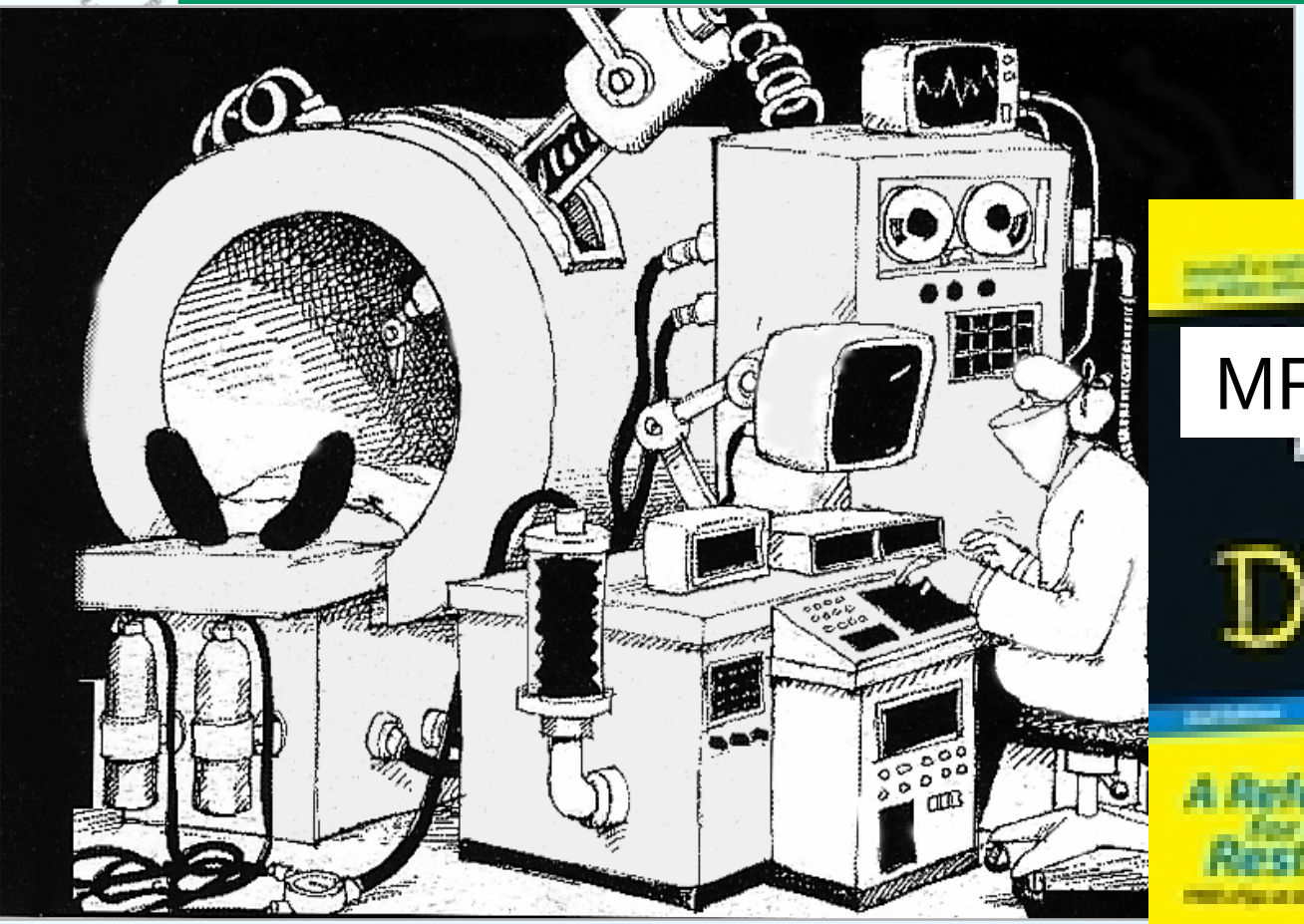
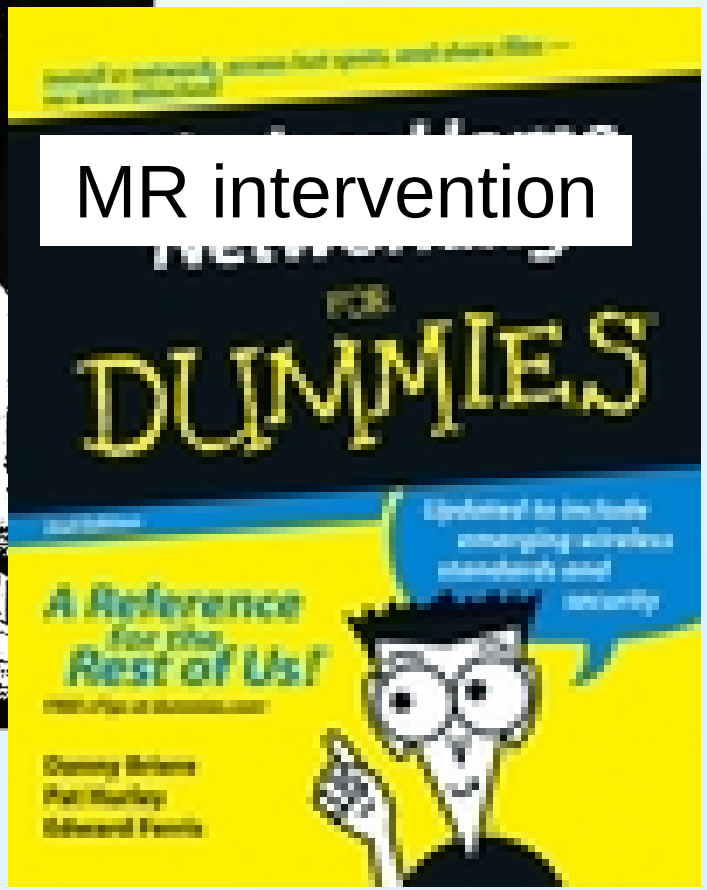
The Vision





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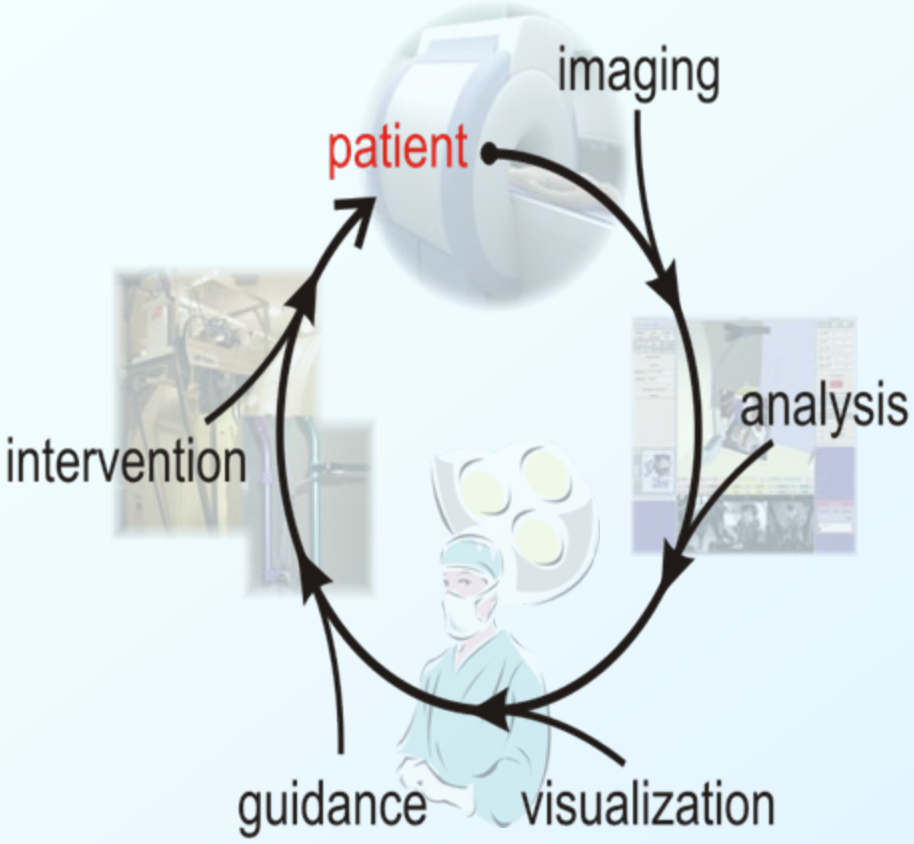
http://www.dummies.com/WileyCDA/

The IGT Vision



- Replace the eye with multimodality imaging
- Replace the hand with image controlled devices
- Integrate therapy with intraoperative imaging
- Develop image-guided therapy delivery systems for multiple clinical applications
- Change invasive procedures to minimally invasive or non-invasive ones

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Blueprint for Imaging in Biomedical Research[1]

The Challenge……

- "Imaging has become essential not only for the detection and monitoring of disease but also for intervention. Methods of acquiring, analyzing, and displaying this information in real time during the intervention must be improved."

Richard L. Ehman, MD, William R. Hendee, PhD, Michael J. Welch, MD, N. Reed Dunnick, MD, Linda B. Bresolin, PhD, Ronald L. Arenson, MD, Stanley Baum, MD, Hedvig Hricak, MD, PhD, and James H. Thrall, MD

(*Radiology* 2007, 10.1148/radiol.2441070058)

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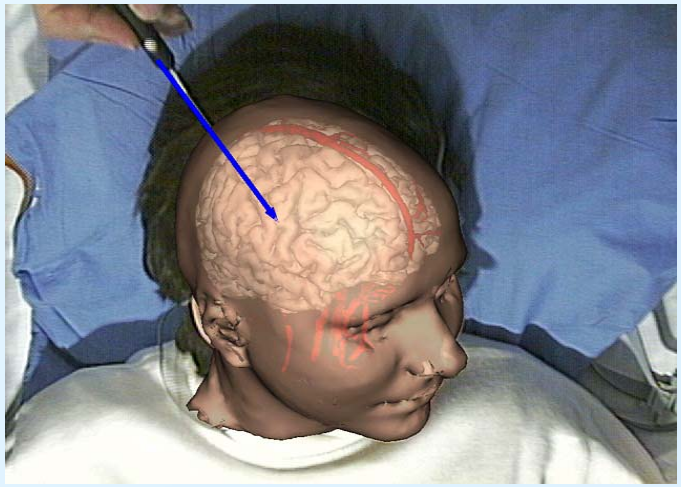
What is surgery ?

Hand – eye coordination



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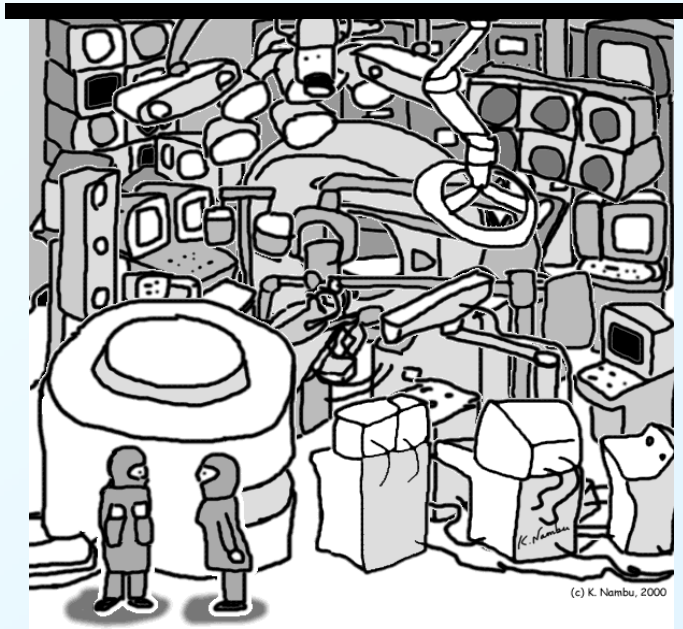
Key Enablers

EYE

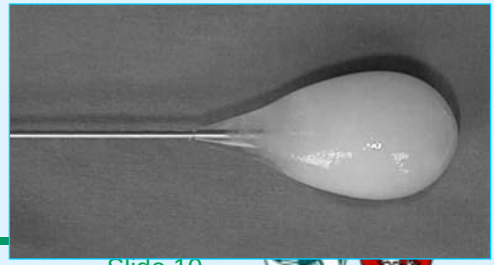


No, Doctor. I don't know where's today's patient.

IMAGING

HAND

TECHNOLGY



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IGT-Changing the face of Surgery

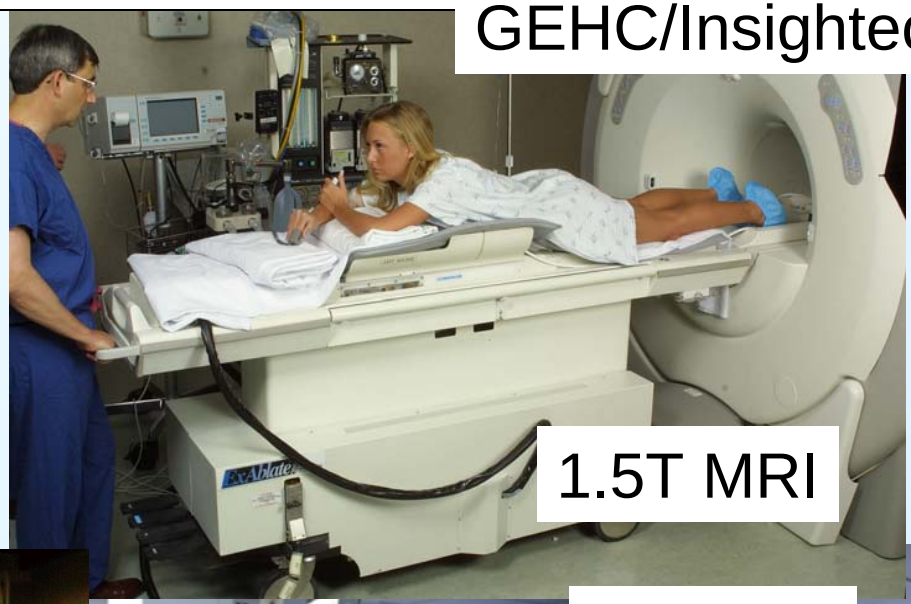
Integration of advanced imaging technology into the Operating Room

THERAPY DELIVERY SYSTEMS

GEHC

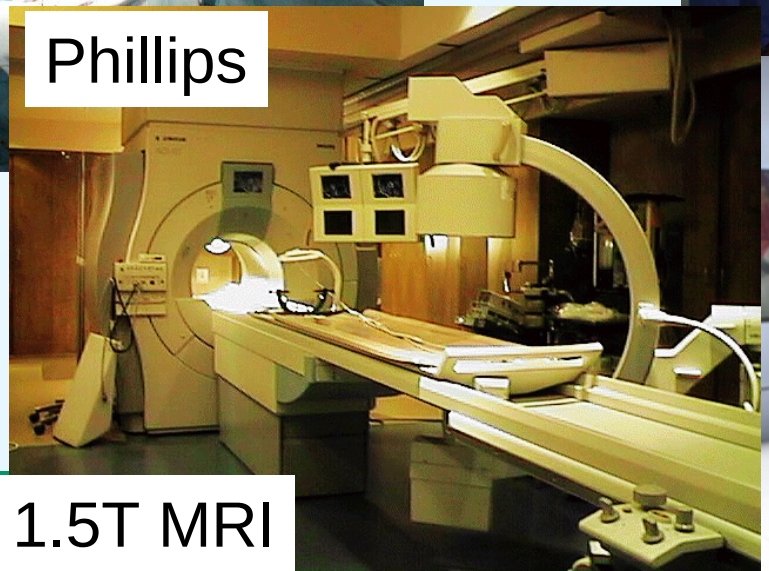
0.5TMRI

GEHC/Insightec



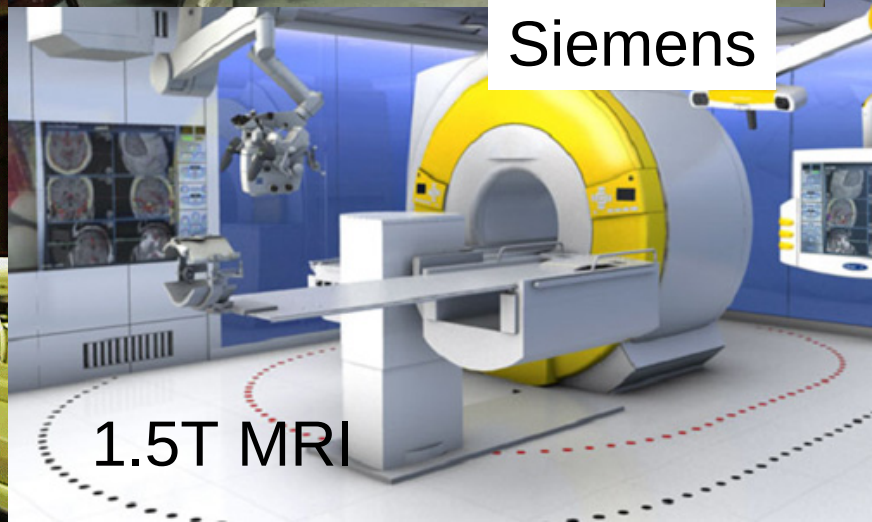
1.5T MRI

Phillips



1.5T MRI

Siemens



1.5T MRI

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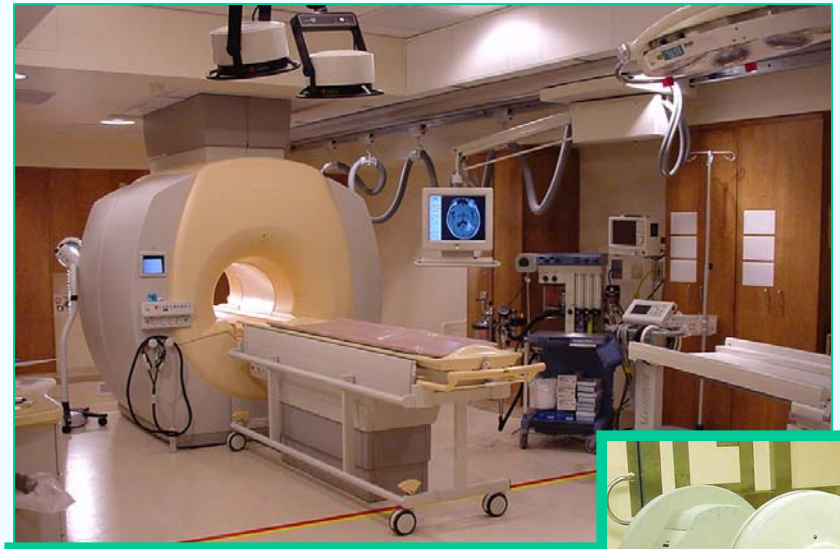
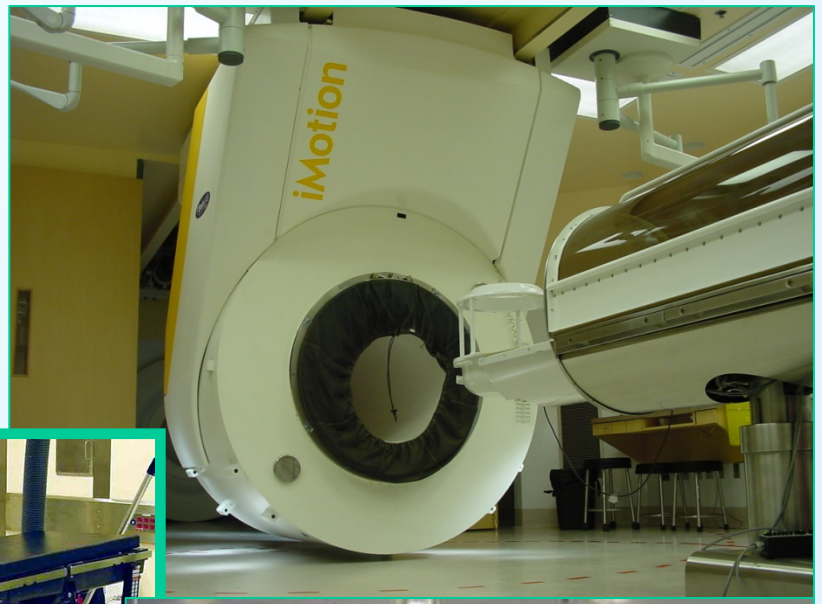
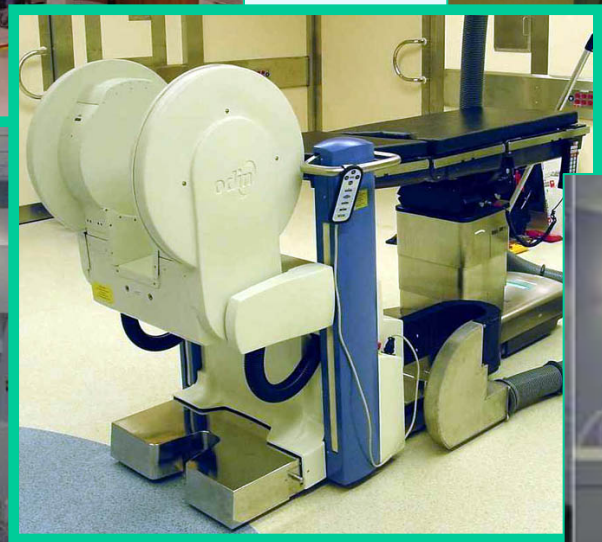
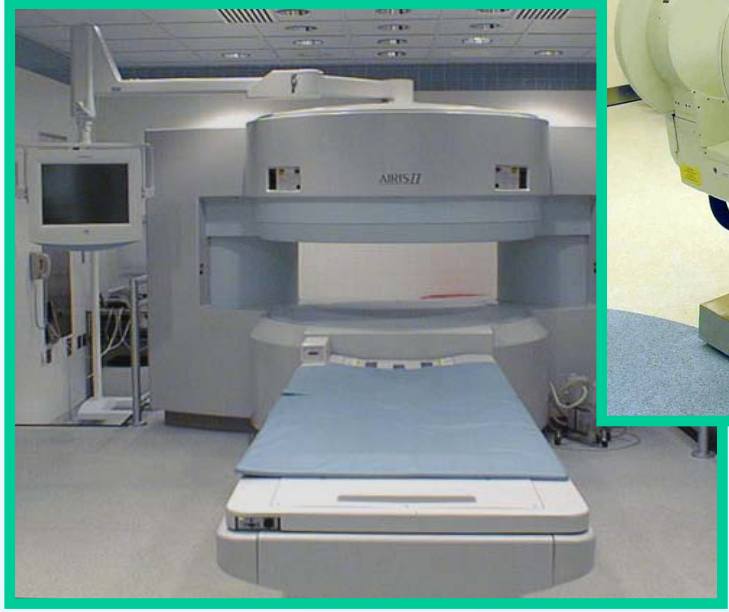
Types of Procedures May Dictate Magnet Type









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MR Surgical Suite

MRI and X-ray Compatibility

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Provided by Jolesz et al.

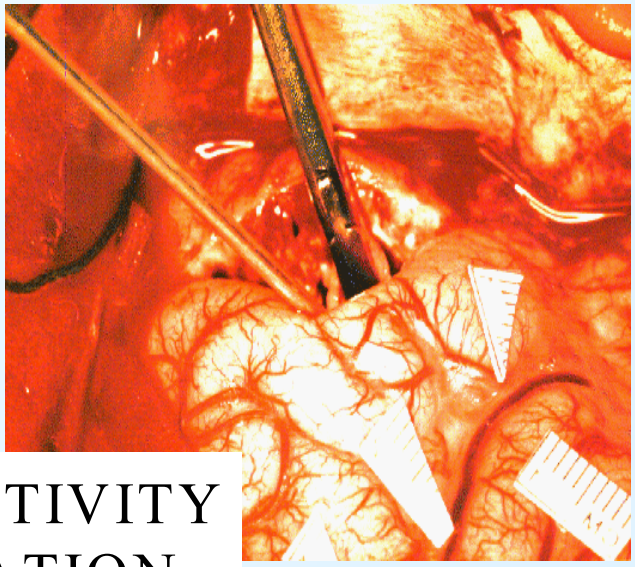
The Goal of Image-guidance

To maximize therapy to target with no loco-regional effects

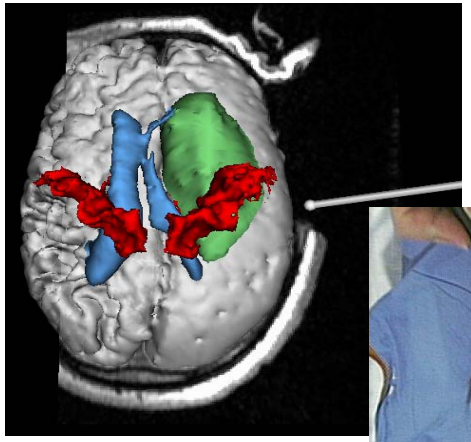
Allows physician to see beyond the Surface

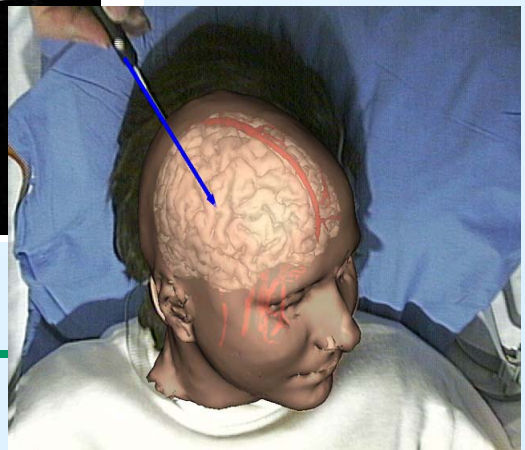
Define Targets/ Control Interventions

- Define Target-Imaging
- Direct therapy-Imaging
- Deliver & Control therapy
- Disease-eradicated, controlled, relieved, palliated



INTERACTIVITY
NAVIGATION





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Role of imaging

- Localization
- Targeting
- Navigation
- Monitoring
- Control

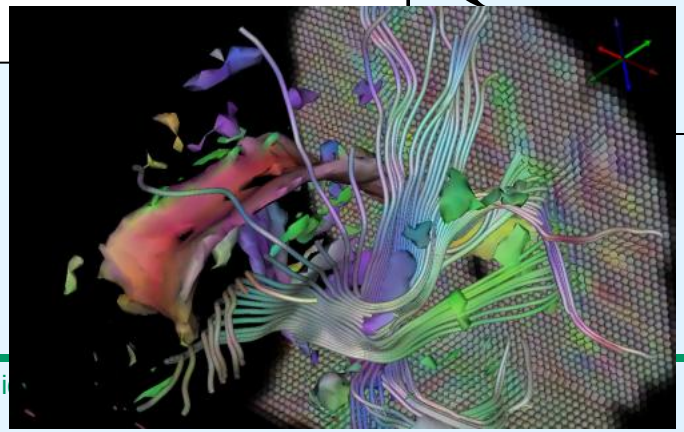
Diagnostic Imaging

Surgical Planning

Interactive Imaging

Dynamic Imaging

Quantitative Imaging



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IGT : BWH OVERVIEW

- Milestones
  - 1993, 1994, 2005, 2006
- Multidisciplinary approach
  - Computer science, Image processing, Bioengineering, Robotics
  - Radiology, Surgery, Rad Onc, Ob/Gyn, Anesthesia
- Multimodality approach
  - MRI, PET, CT, US
- Multiple vendors and industries
  - Equipment
    - Anesthesia devices
    - Visualization,tools,IT
- Multiple funding sources
  - NIH, Industry
- Training tracks
  - NIH grant-R25 fellows in IGT

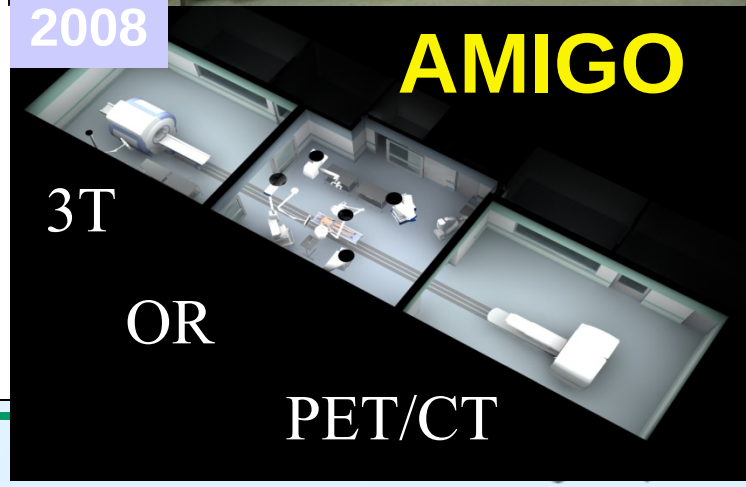
1993

MRT

1994

MRgFUS

2008



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MRT The first decade1996-2006

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Nursing, Safety & Equipment Challenges

- MR safety
- Location of IMRI
- Equipment and Imaging
- Codes
- Draping patient/magnet
- Positioning patients

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MR Safety

- Develop P & P & Assign “safety officer
  - has the responsibility of making sure that the MR safety policies are updated and adhered to and that staff working in the MR area have received safety training.
- Magnetic field is always present
- Design your suite to allow careful planning of “Zones”
  - Zone 1 - hallway outside suite
  - *Key card access ONLY*
    - *Zone 2 - waiting room within suite*
    - *Zone 3 - areas adjacent to magnet room*
    - *Zone 4 - room that houses magnet*
- Screening /training of staff & Screening of patients
- Hazards
  - Projectiles of ferrous objects
  - Heating of ferrous implants

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MR Safety Signage

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Staff Training/Screening & Patient Screening

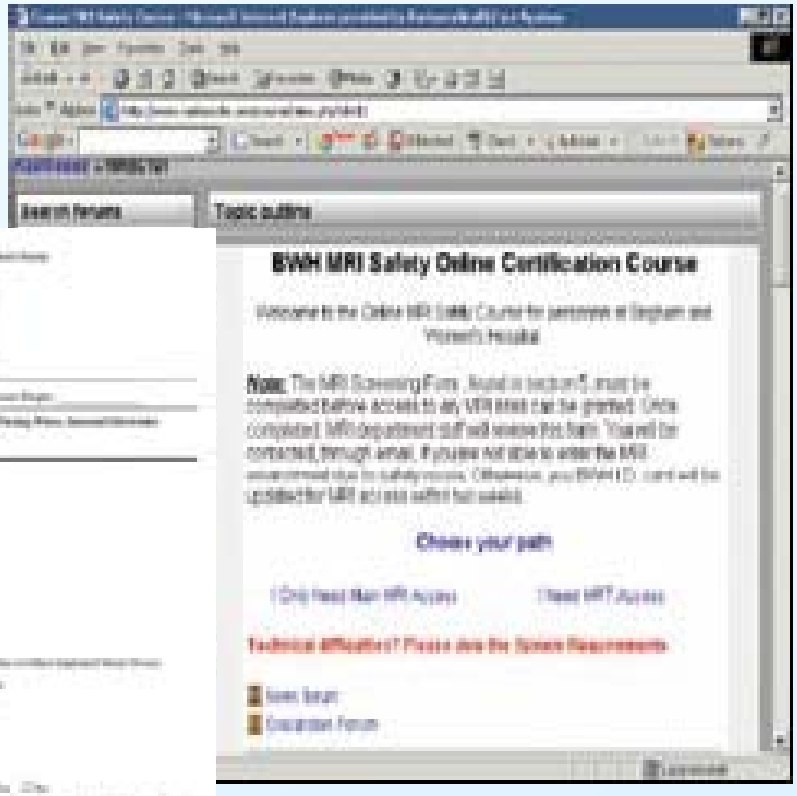
On Line Training

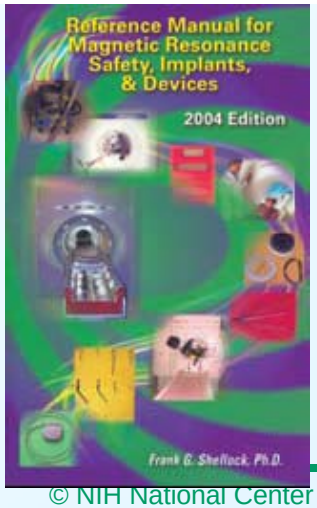
Non Patient Screening


BRIGHAM AND WOMEN'S HOSPITAL

MAGNETIC RESONANCE (MR) ENVIRONMENT SCREENING FOR NON-PATIENTS

IMPORTANT INSTRUCTIONS





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Instrument Challenges

- MR Instrument language
  - MR safe
  - MR compatible
  - MR conditional
- Availability of MR safe instruments
- Controlling ferrous instruments
- Color coding

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Instrument/Equipment Testing

Test with hand held magnet
Color code appropriately: Green – GO-Safe
Image if necessary
    Skull pins, biopsy needles, retractors, head clamp

- Red is not safe (stop)
- Green is safe (go)

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Anesthesia

- Anesthesia machine
- Patient monitor
- IV poles
- Different equipment
  - Extra time for preparation
- Safety issues
  - Can't monitor ischemia
  - No mesh ET tubes
  - No crossing of EKG wires
  - No internal temp measurement

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MR Technologist is the Watch Dog

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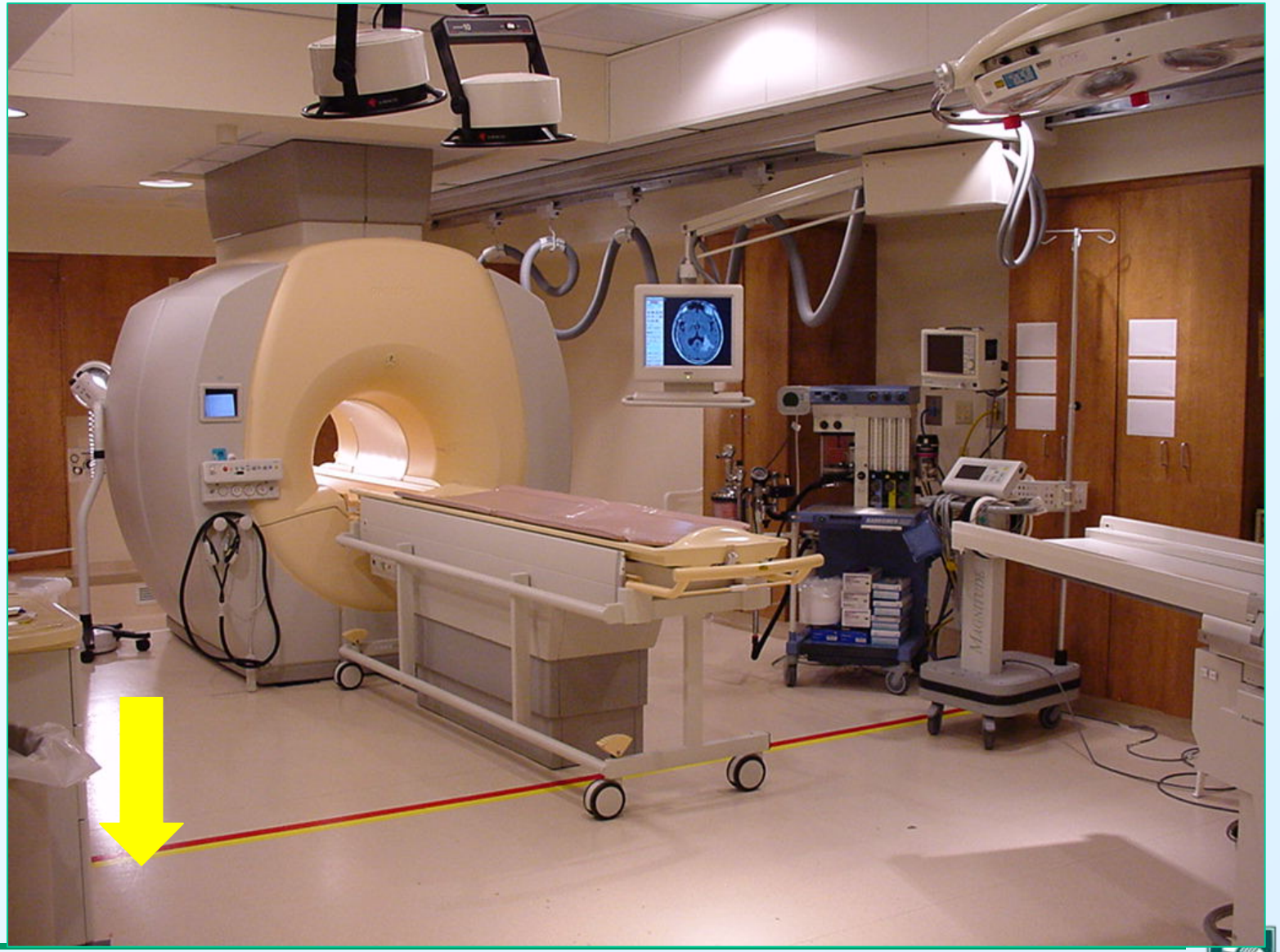
Gauss Lines



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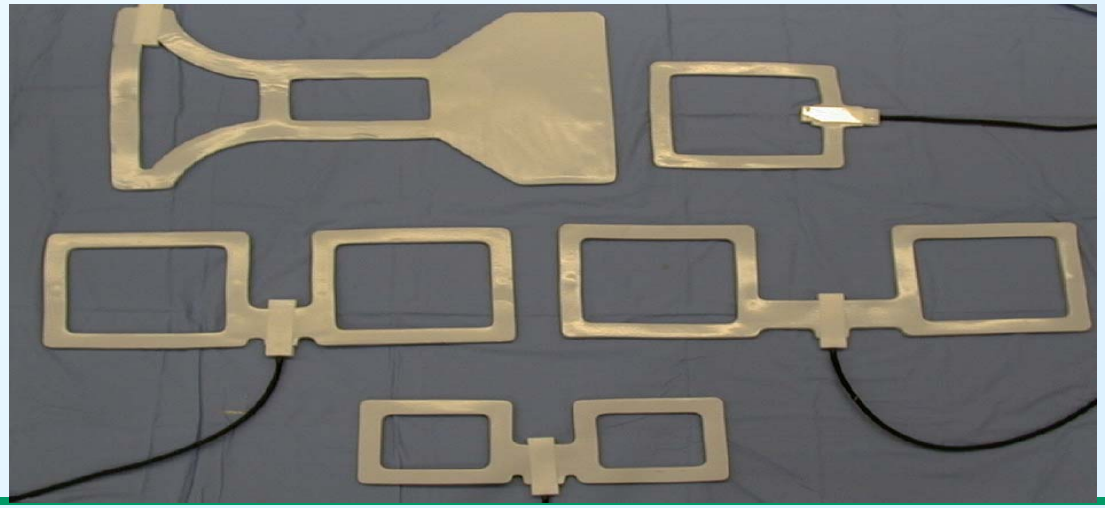
Fairview University Medical Center, Minnesota

Coils, Draping and Imaging

- RF coil placed around area of interest
- Can be placed before (unsterile) or after (sterile) draping
- Coil gets plugged into side of magnet



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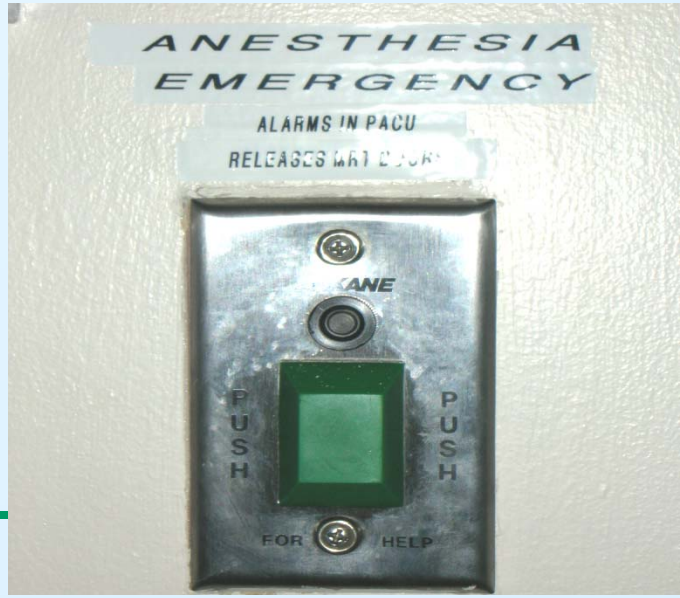
Medical Emergencies

- Bring pt out of room
- Have designated code area
- Push button to release locked doors
- Quench magnet only if needed

Area with code cart, defibrillator oxygen, pt monitor etc

Anesthesia Emergency Button
Located in magnet room
Alarms in main recovery room
Releases locked doors to suite for 1 hour



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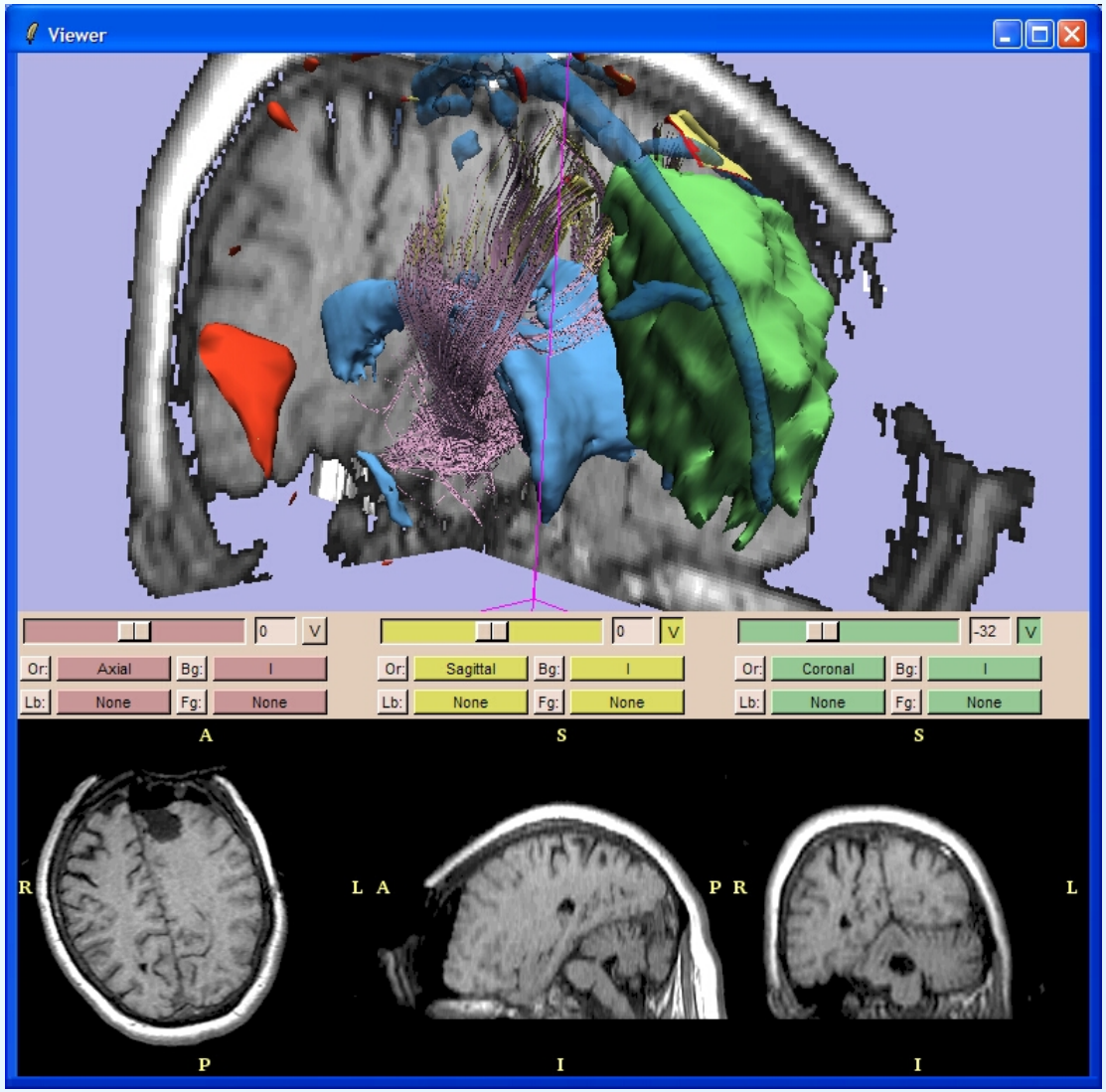
3D Slicer Surgical simulation software



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Provided by Pieper et al.

MRT BWH program highlight 8/25/06

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Neurosurgery Milestone

Font Size A A A Send

BWH completes 1,000th Intraoperative MR-guided Craniotomy

In August 1996, neurosurgeons at Brigham and Women's Hospital (BWH) performed the world's first intraoperative MR-guided brain tumor craniotomy, successfully removing a tumor using the most advanced imaging techniques available.

As BWH marks the 10th anniversary of this landmark procedure, Neurosurgery, Neuroradiology and Magnetic Resonance Therapy (MRT) teams last month combined to perform the hospital's 1,000th intraoperative MR-guided craniotomy.

"This milestone is testament to how effective this

Teams from Neurosurgery, Neuroradiology, and Magnetic Resonance Therapy (MRT) worked together to perform the hospital's 1,000th intraoperative MR-guided craniotomy.

http://www.brighamandwomens.org/ofcurrentinterest/craniotomy.aspx

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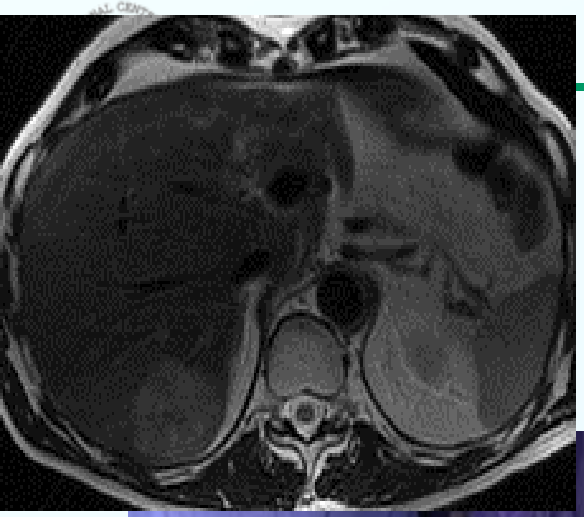
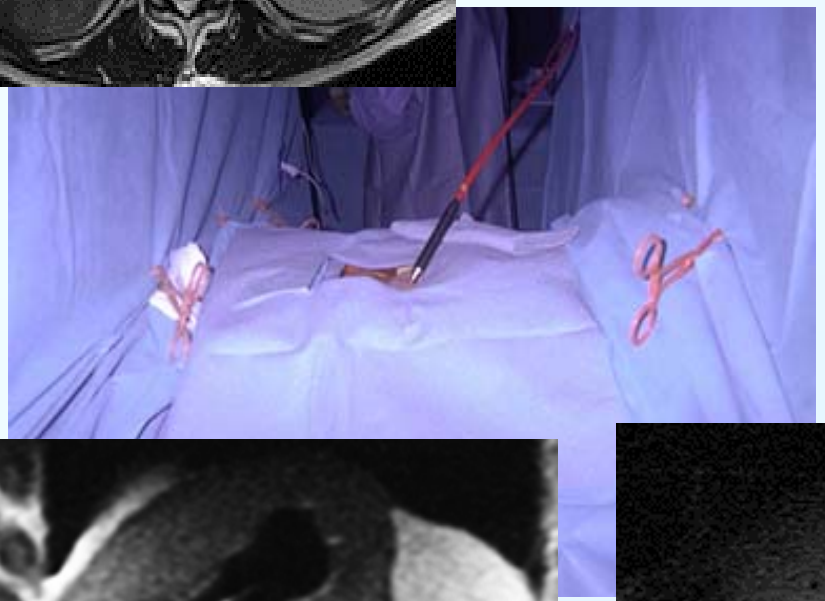
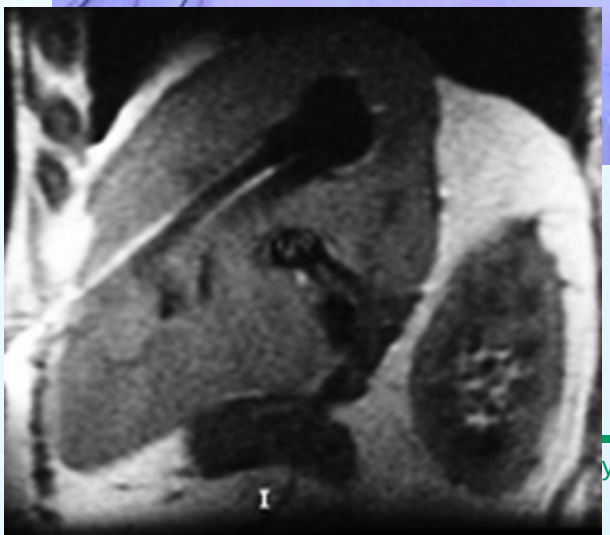
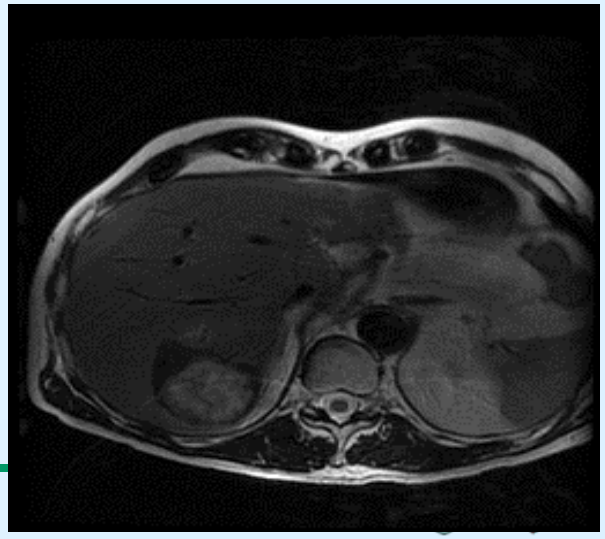
MR guided Cryotherapy





- MRI of iceball compared with
  - 24 h contrast enhanced MRI
- Estimate of cryonecrosis:
- Volume and location of signal void iceballs
- Volume and location of decreased enhancement cryoablative area





3D Slicer

- Image Processing
  - Segmentation
  - Registration
- Model Building
- Scene Graphs
- Also Supported by NAC P41, NAMIC U54
- Open Source

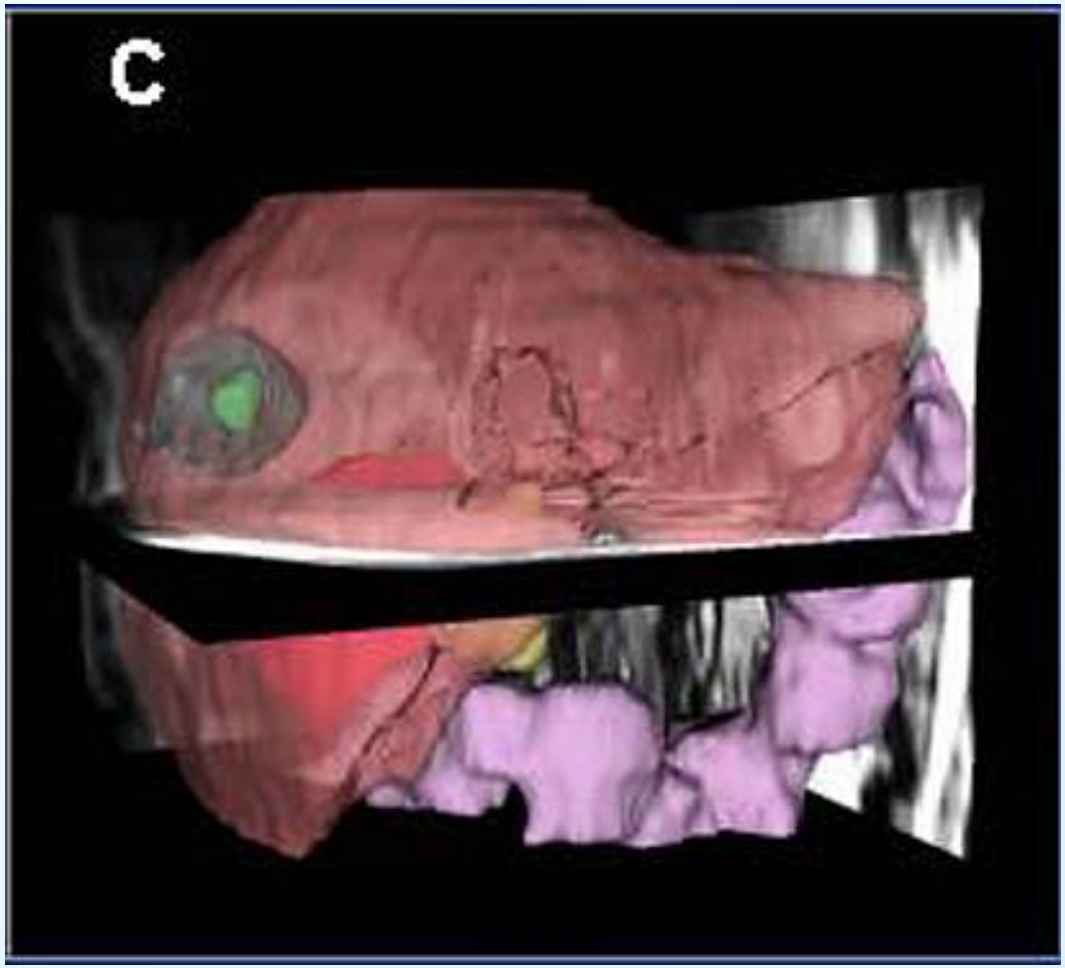


image provided by Dr. Silverman

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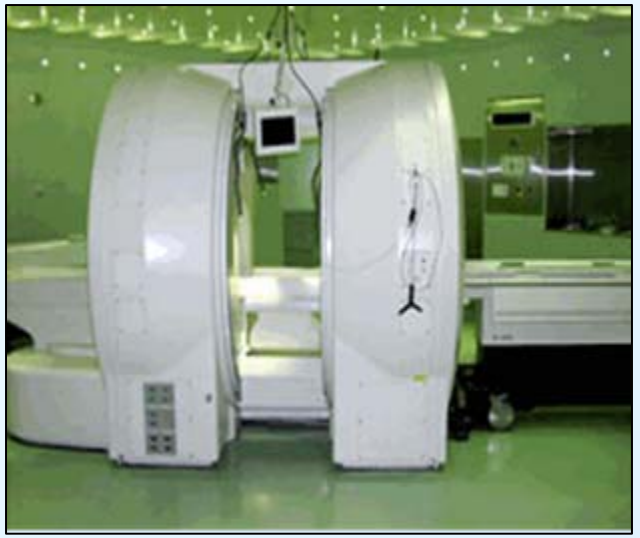
Overview of BWH Prostate IGT program

- 1997-Est D'Amico & Tempany
  - MRg Brachytherapy (1-2/wk):
    - 472 men treated (9/29/06)
  - MRg Biopsy (1-2/month): 68 men
- Use MR images to plan, guide and monitor intervention
  - Pre-procedure 1.5T/3T multi-paramteric data
  - Procedure 0.5T Non-rigid registration
- Open interventional magnet
  - GE Signa SP 0.5T system
  - Allows transperineal access



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Prostate Cancer: Some facts

- 1.5 million biopsies/year
- 25 million men have at least one negative biopsy
- 230,000 new cases diagnosed in 2005
- Est. 450,000 new cases in 2015
- Approx 4-8% disease specific mortality rate

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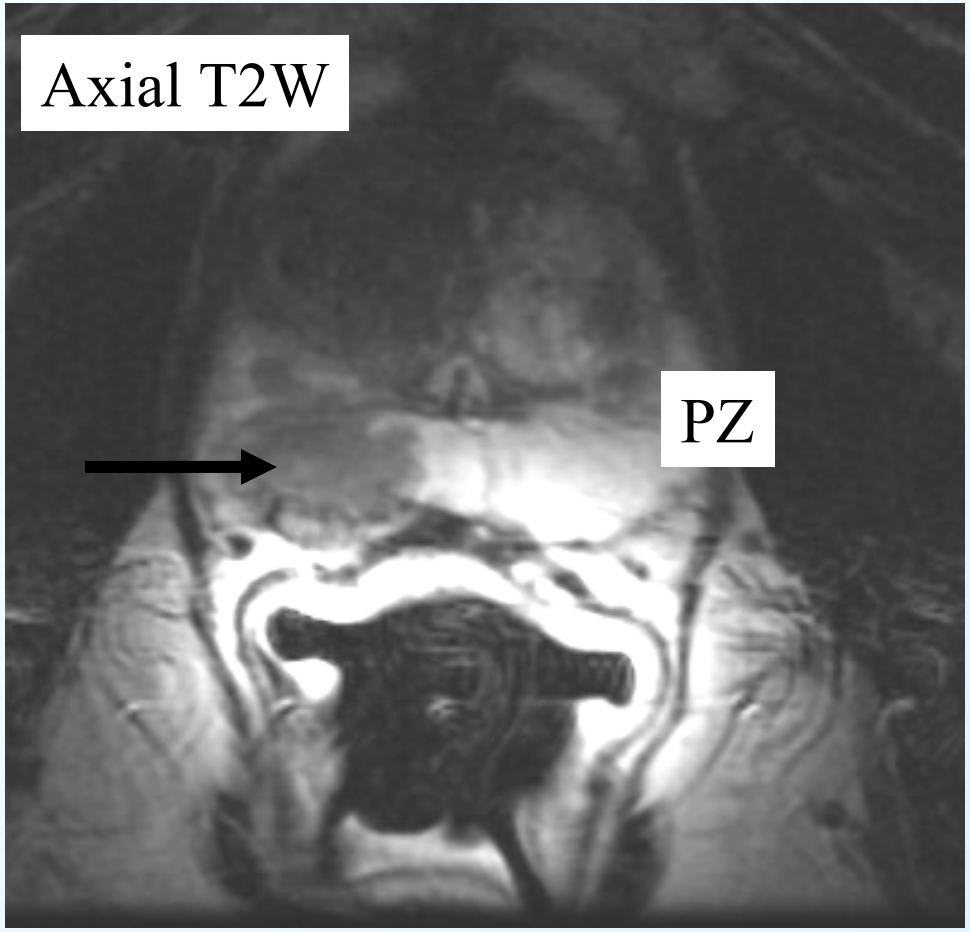
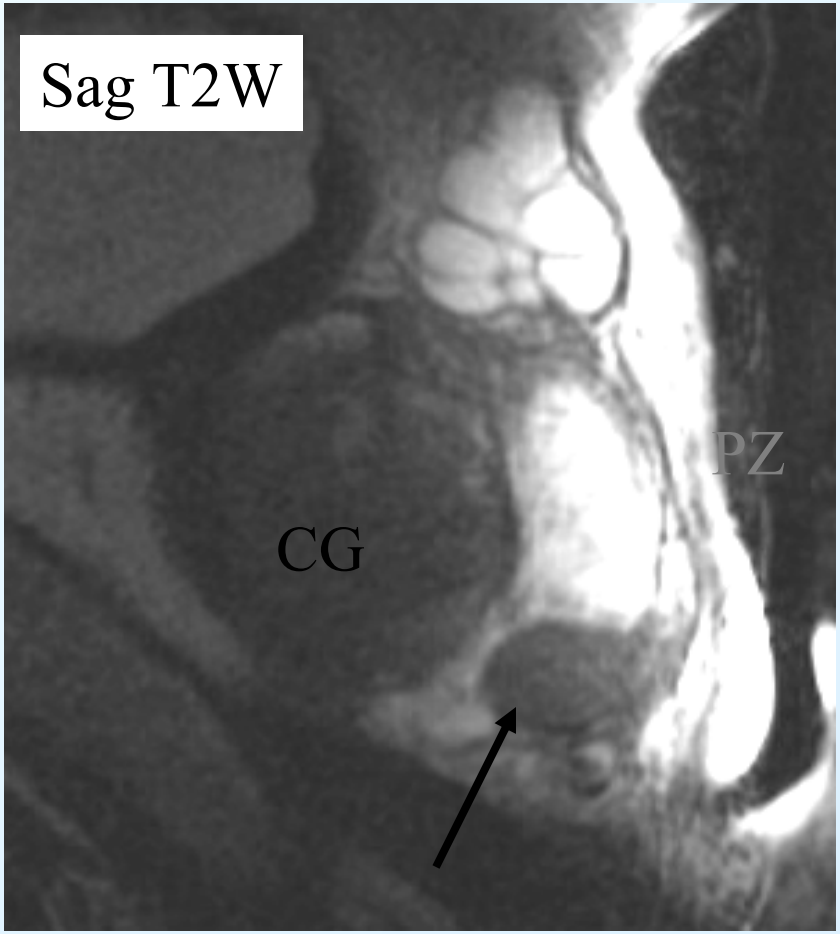
Focal right sided tumor with ECP





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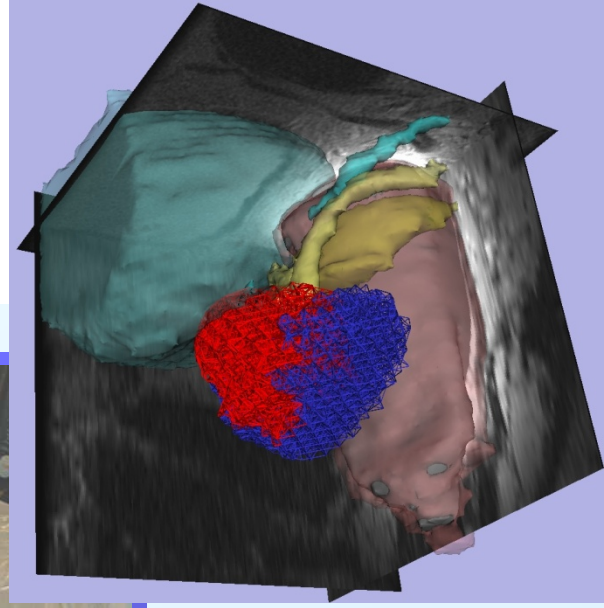
Prostate cancer
Image guided therapy



Prostate Imaging

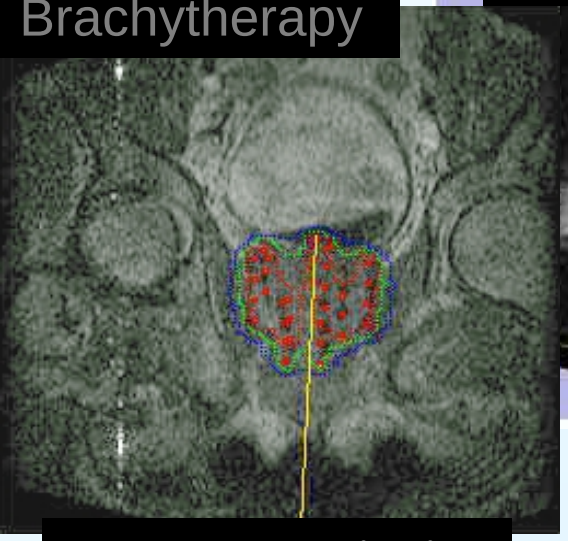
Detection

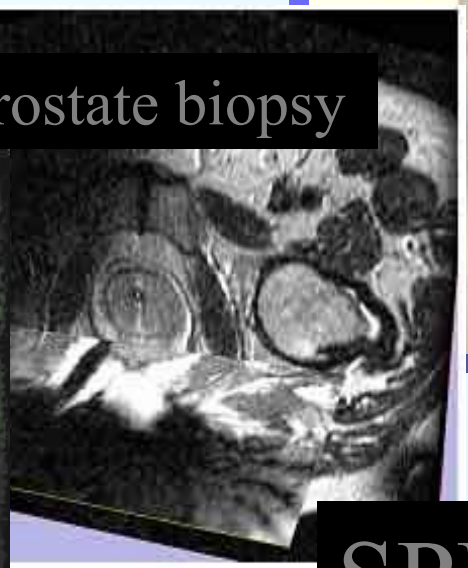
Staging

Prostate biopsy

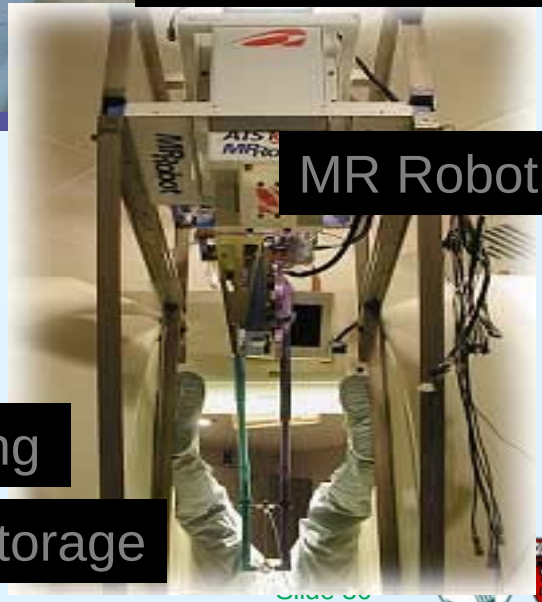
FEM Based Deformation

Brachytherapy





Mutual Information



MR Robotics

SPL

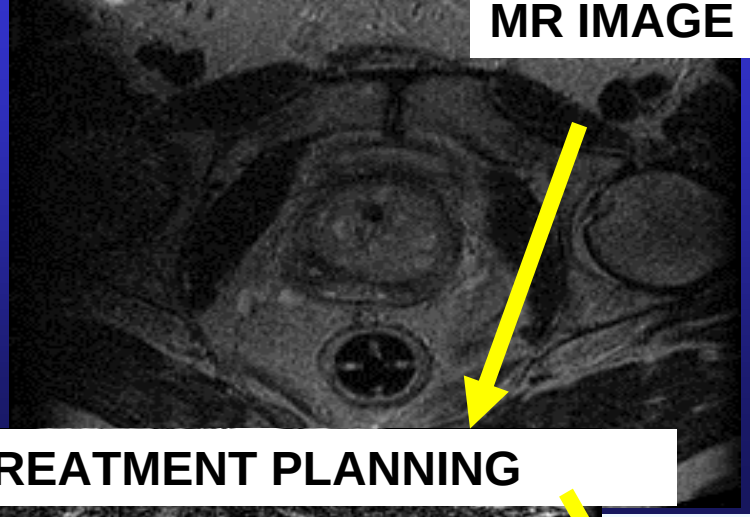
High Performance Computing

Treatment monitoring
CALGB/Novartis-
STI571

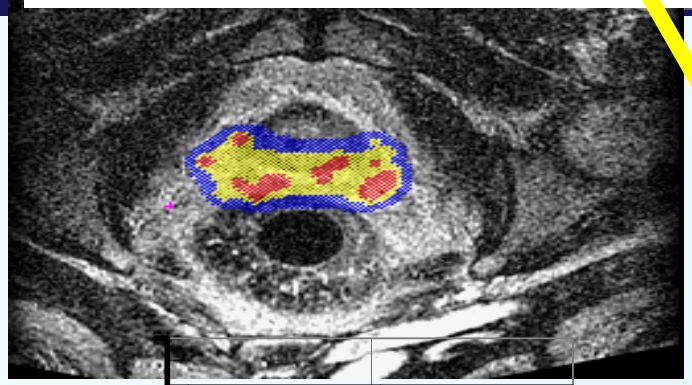
Gigabit network

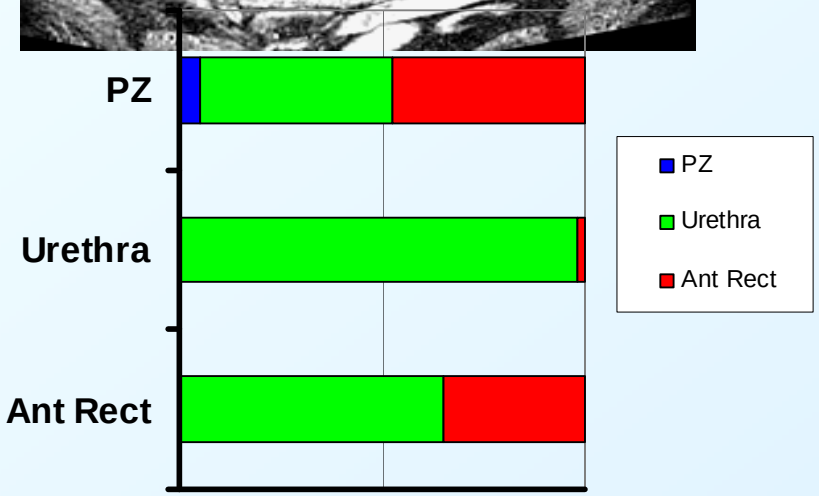
Terabyte storage

Prostate cancer imaging and Brachytherapy program-Today

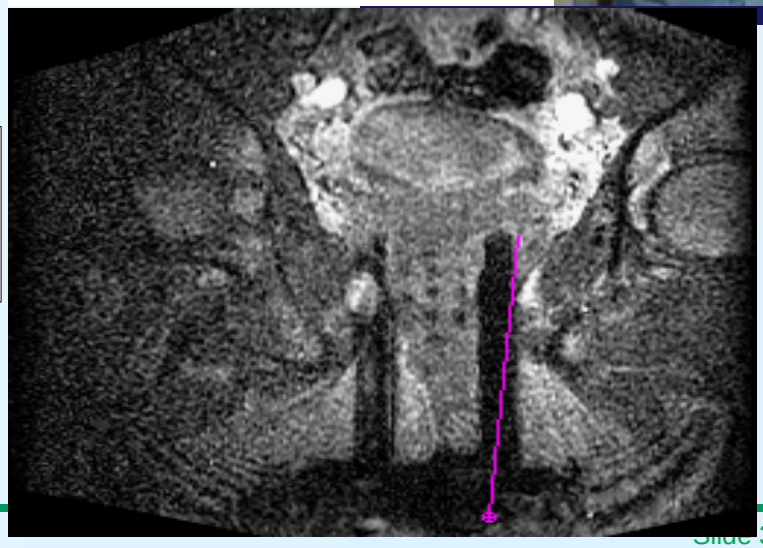


TREATMENT PLANNING





NEEDLE PLACEMENT



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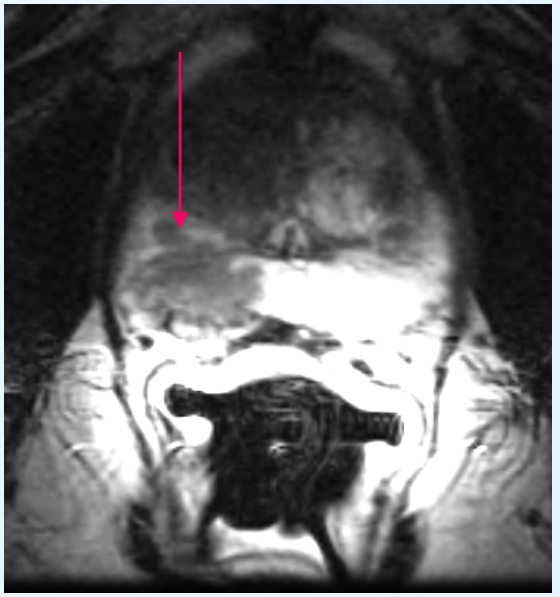
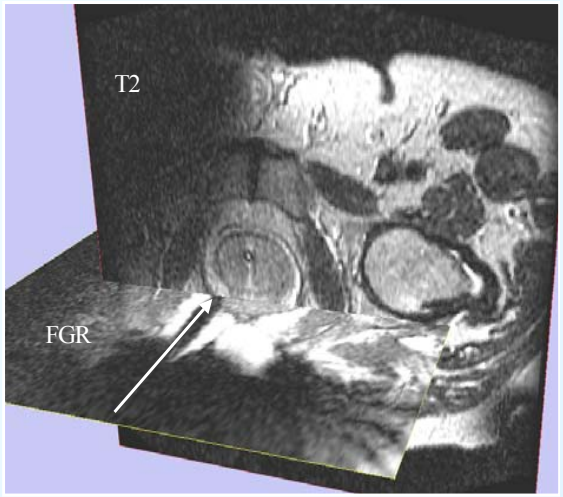
MR-guided prostate biopsy clinical research program

- Clinical need
  - TRUS high false negative
  - MR Bx *Target +Sextant/octant*
- Need target validation method
- Need 'free-hand' or Robot assisted approach

MR TARGET





3D-Slicer* adapted for prostate procedures and target definition, trajectory planning and guidance

* http://www.slicer.org/

Slicer prostate biopsy module

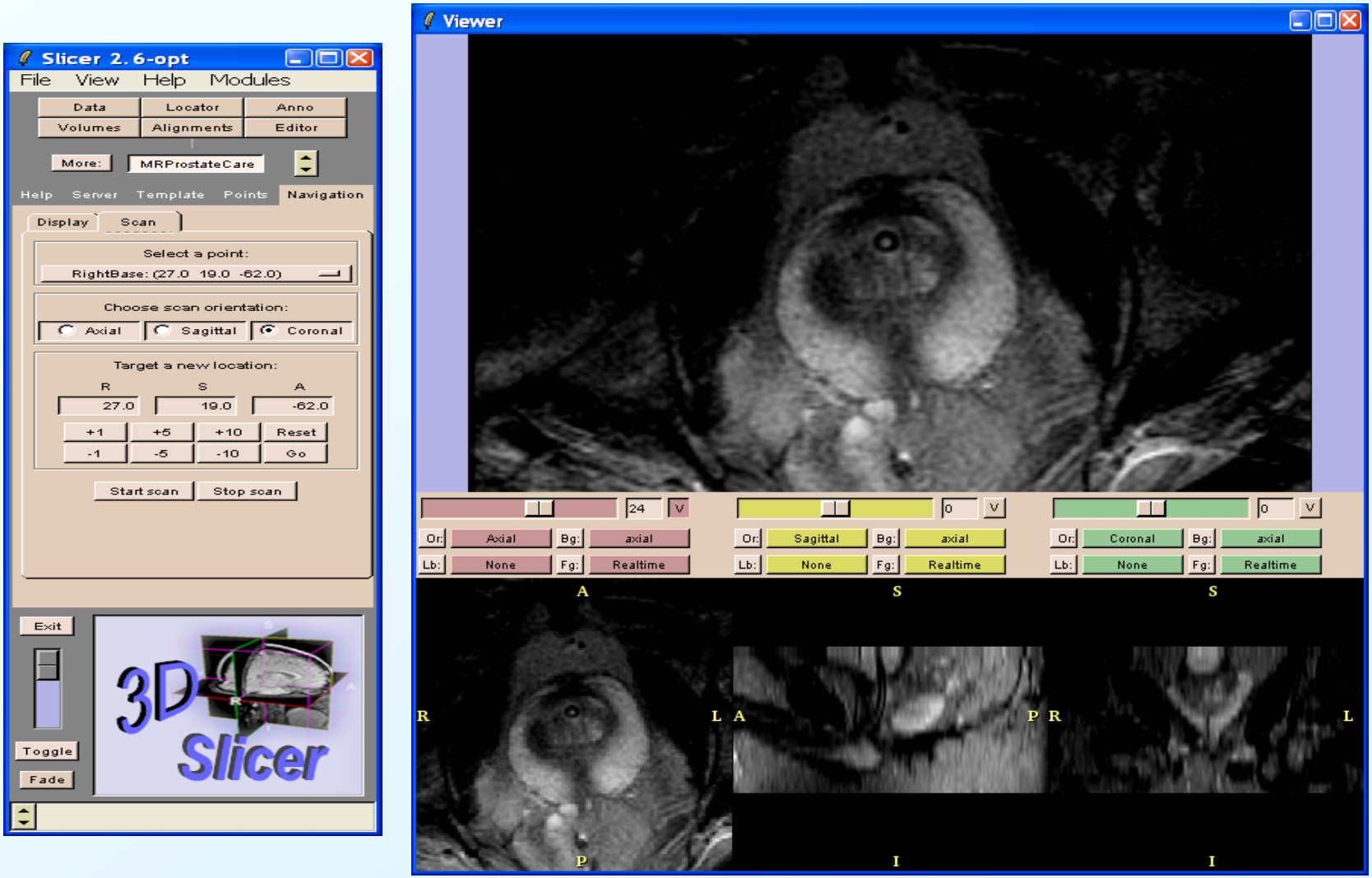


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Image Fusion and Visualization

Real time intra-operative images and registered pre-operative image can be fused to aid in needle guidance. Images not otherwise available in the operating room can be utilized.

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Case history

- 61yo Male Chemical plant manager
  - PSA history (4 prior biopsies)

• Feb 2000	12.5	Biopsy negative
• Dec 2000	14.7	Biopsy Negative
• Feb 2001	13.9	
• April 2001	15	Biopsy negative
• Sept 2001	14.7	
• Sept 2002	21.7	Biopsy(15 cores); Negative

- MR exam
  - Feb 2003- 2cm lesion left side
- MR guided targeted prostate biopsy
  - 8/13/03 (PSA 18.8)
    - Prostate Adenocarcinoma: GG 4+7 in 4/7 (2 target cores)
- 11/03 radical prostatectomy
  - *3.5 cm bilateral tumor confined to prostate*

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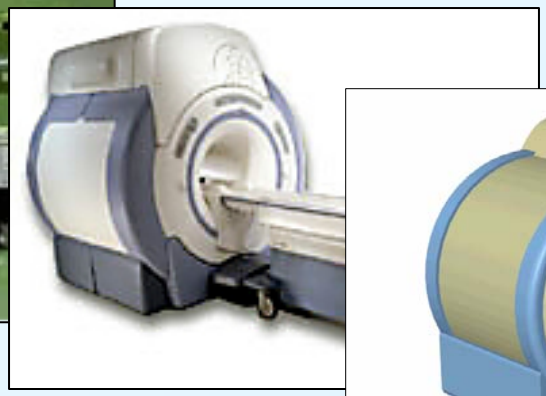
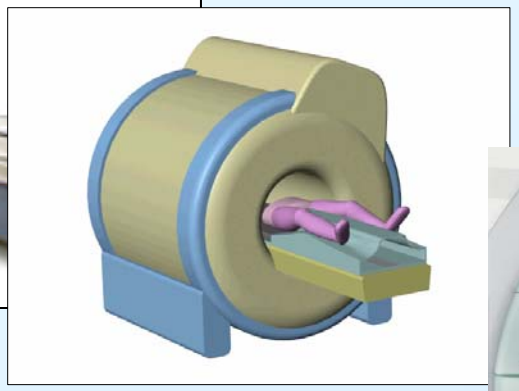
Current challenges

- Prostate diagnosis and therapy in high-field, closed-bore scanner (3T)
  - High-quality imaging,
  - More prevalent in clinics and hospitals.

Mechanical guide to accurately reach lesion under image guidance is necessary.





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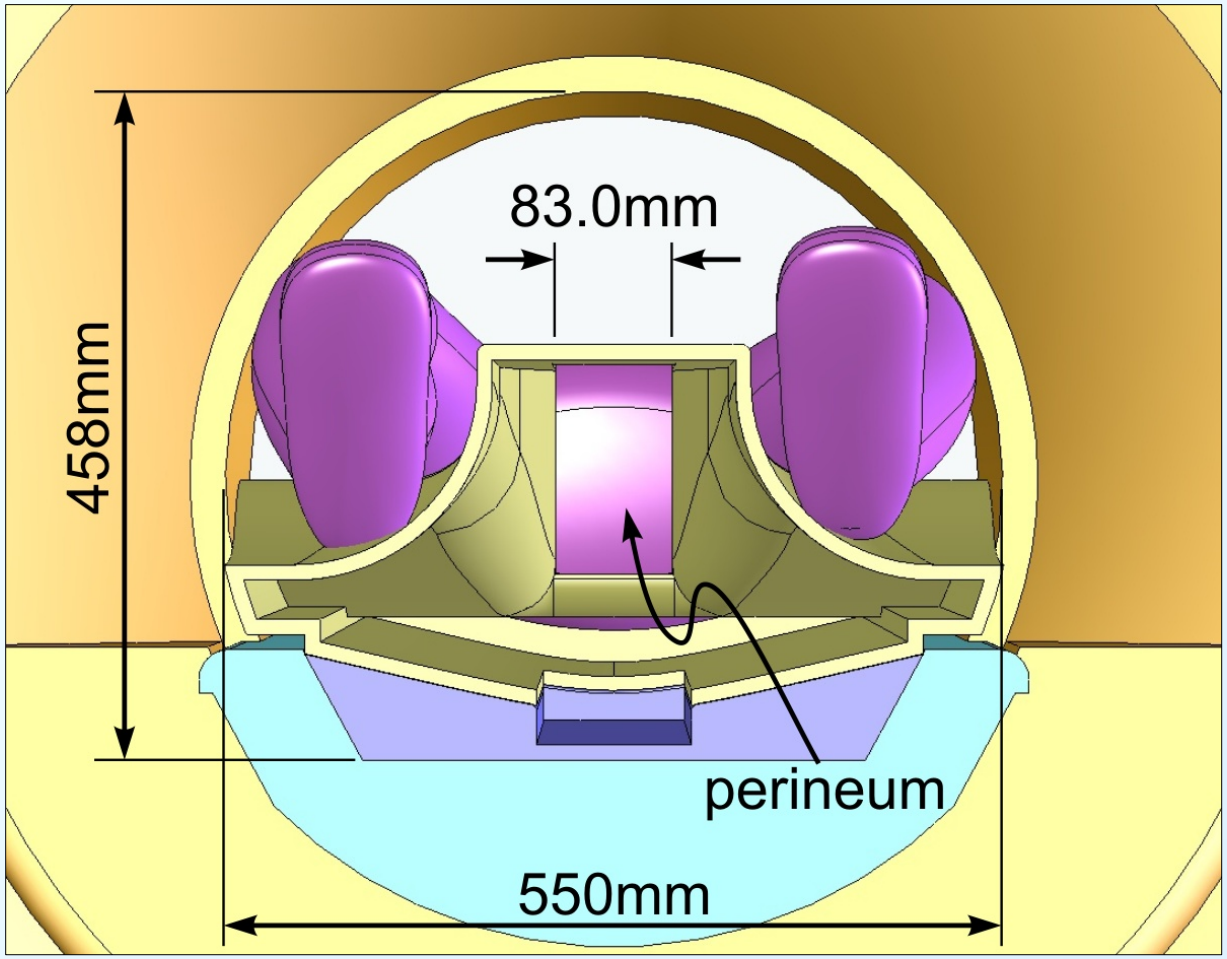
Challenge: Workspace



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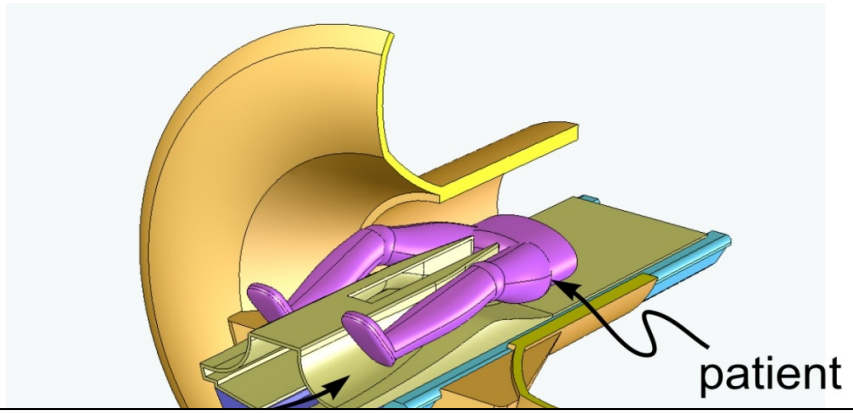
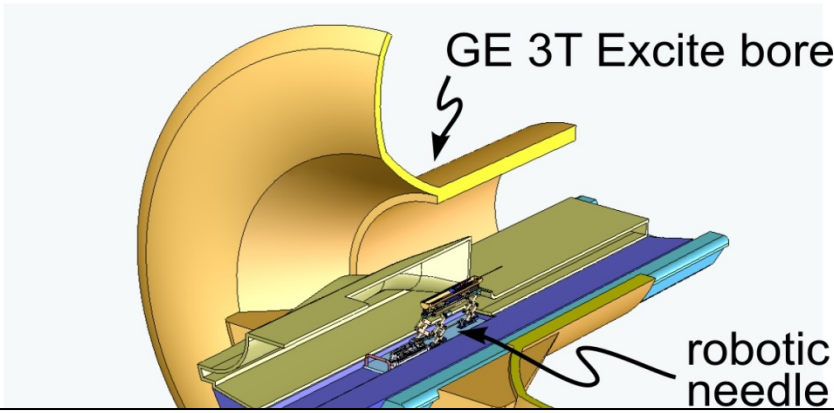
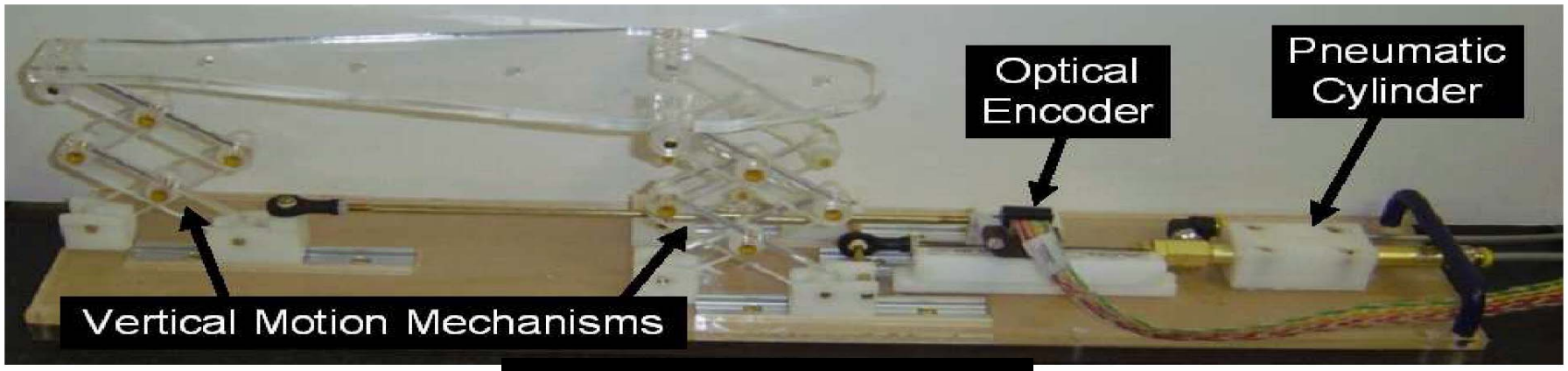
Robot-assisted In-bore Needle Placement







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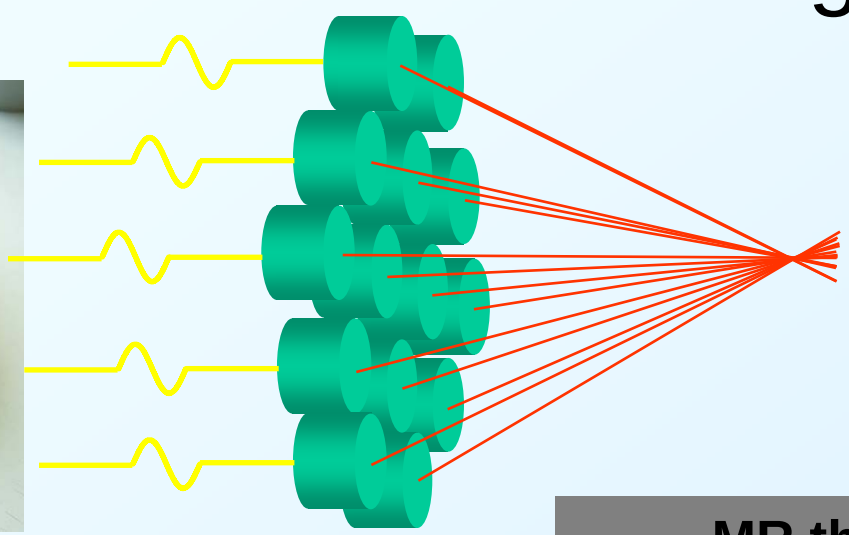
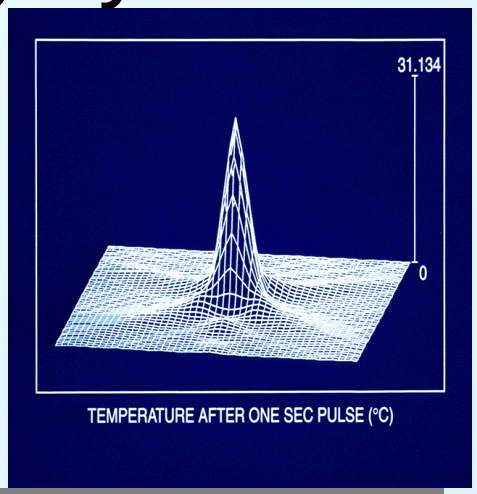
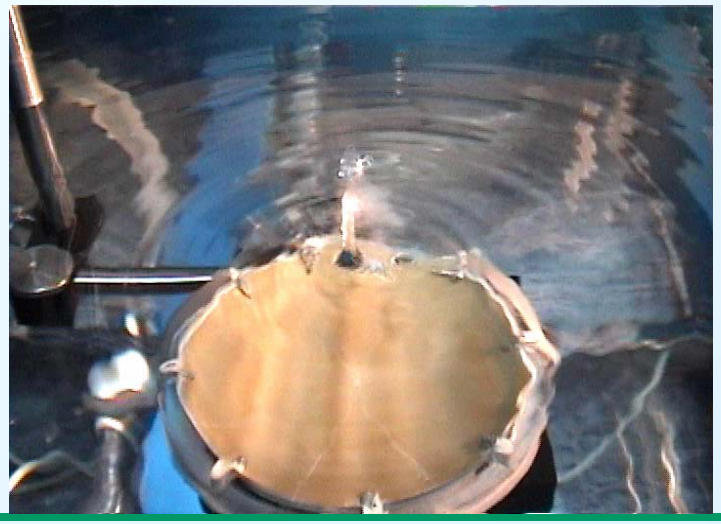
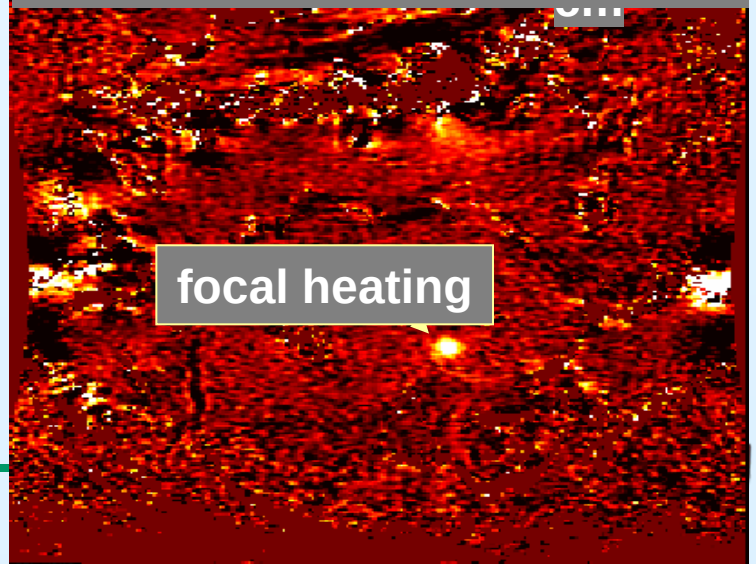
Magnetic Resonance guided Focused Ultrasound surgery







MR thermometry
Real-time feed back



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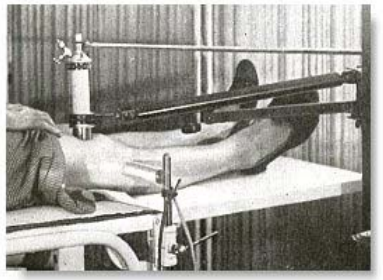
History of FUS

- 1926 Wood & Loomis
  - High Intensity US biological effects on unicellular organism
- 1942 Lynn et al
  - First theraputic use of FUS-Liver
- 1942 Fry et al-Animal brain
- 1950 Fry Brothers
  - Open craniotomy, intraoperative sonications

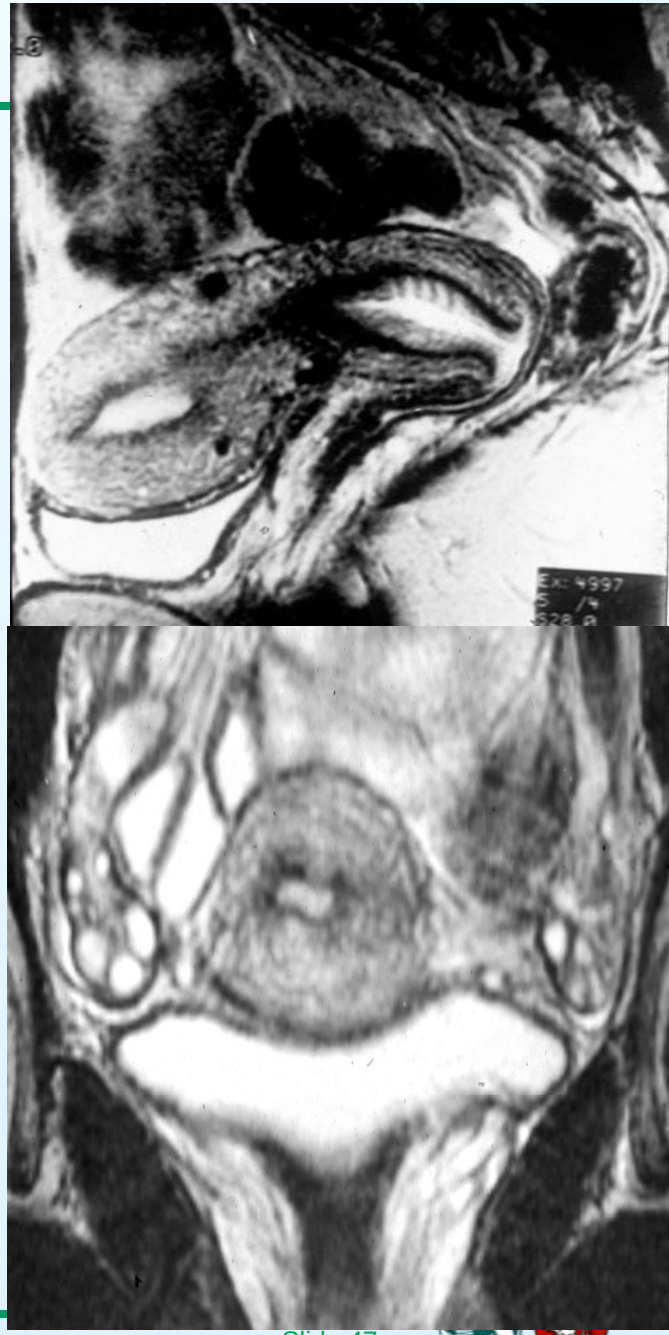
    Parkinson's Disease
- 1975 Lele-"Ideal surgical tool"
- *1993 Hynenen, Cline & Jolesz et al*
  - *MRg FUS & First MRg FUS using single element transducer in tumor of rabbit muscle*



Professor William Fry

MRgFUS: critical features

- MR imaging
  - Anatomic resolution
  - Superior soft tissue differentiation
- Real time MR thermometry
  - Proton resonance frequency shifts, with temp changes
- Immediate MR treatment outcome
  - Post treatment MR with IV Gadolinium



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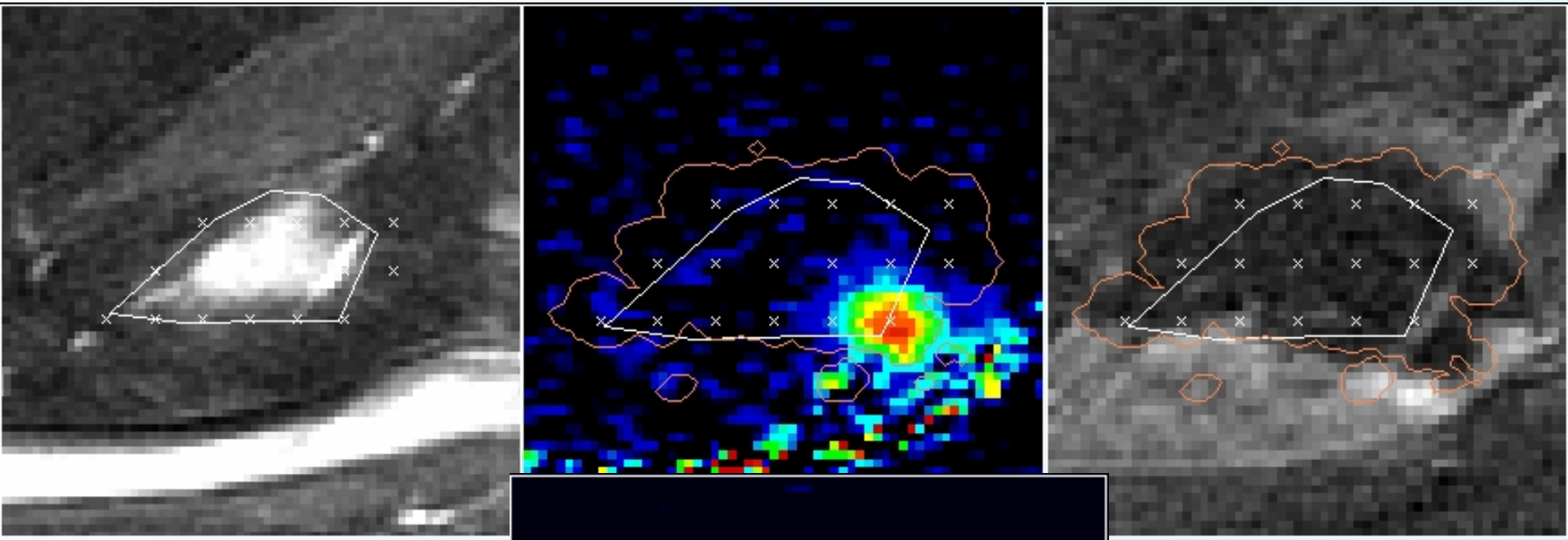
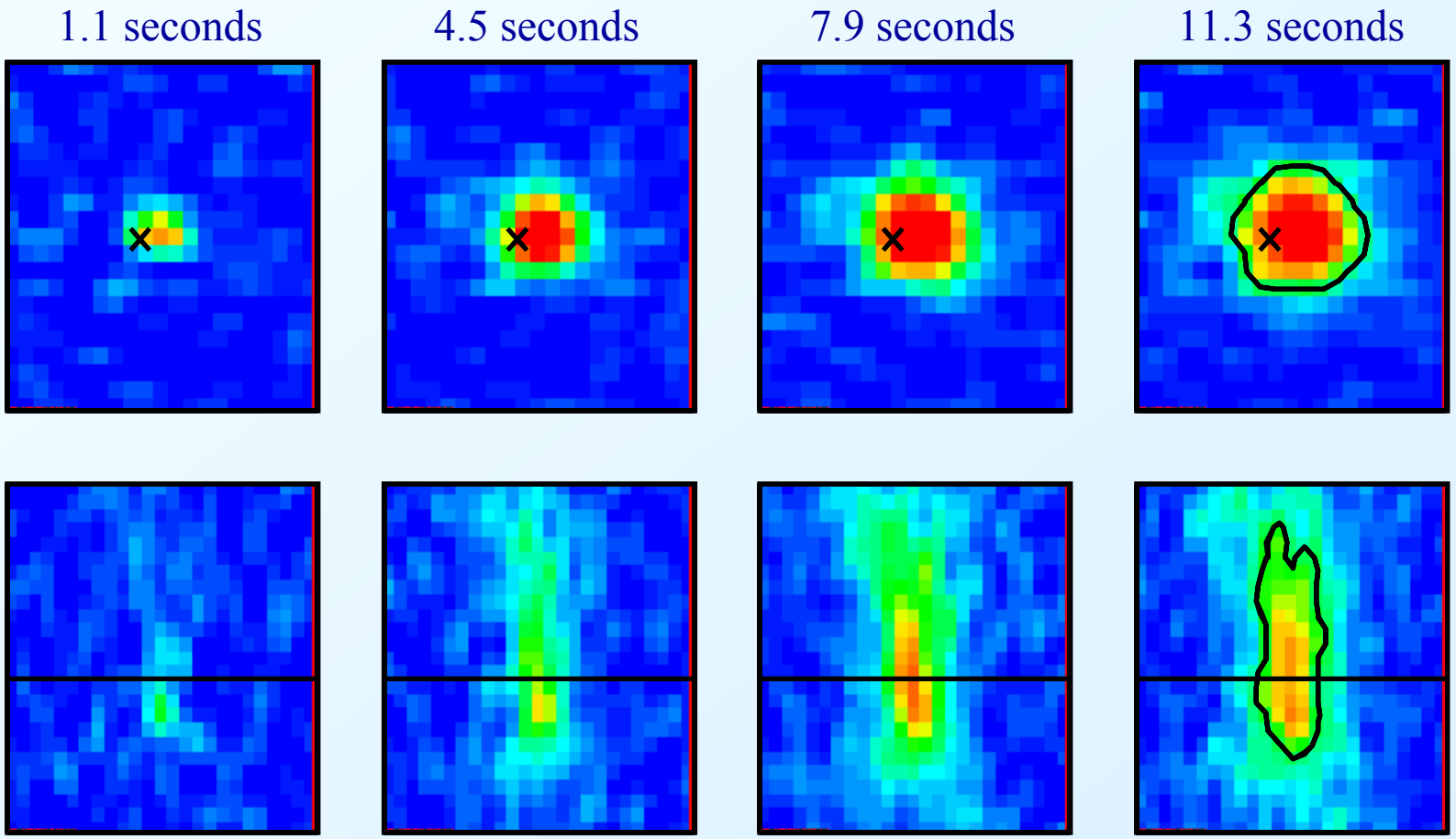
Focused Ultrasound Surgery of Rabbit Tumor



Provided by Hynynen et al.

Thermal Development of a 10 Second Sonication



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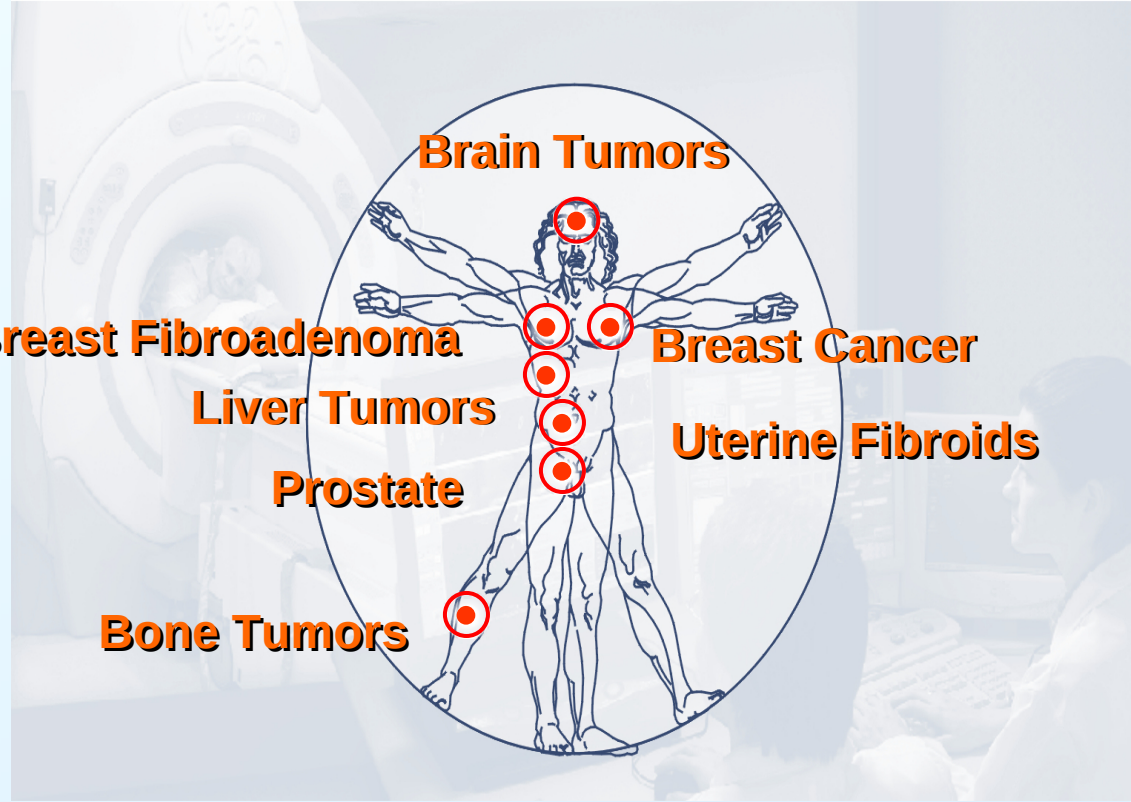
MRgFUS clinical applications

- Breast
  - Fibroadenoma
  - Breast cancer
- Uterine fibroids
- Brain
- Bone
- Liver
- Prostate



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MRgFUS system Components

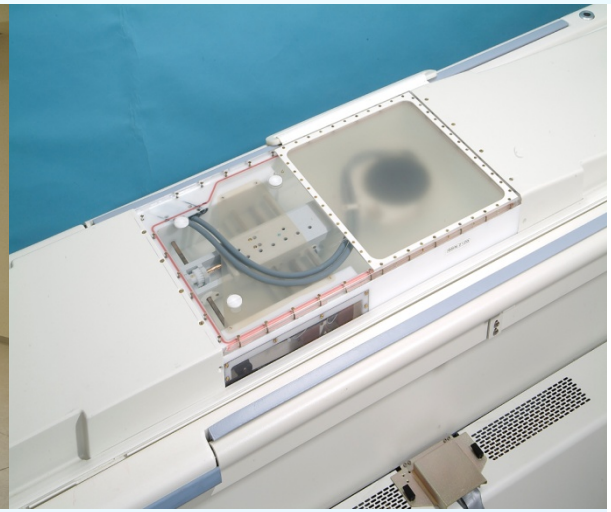
1.5T magnet
General Electric

Pre-procedural-post imaging

Patient Table

ExAblate 2000 *

- **Docks to MR scanner**
- **Consists of electronics and transducer in water bath**



ExAblate 2000 *

Insightec Inc

Phased Array Transducer

- **In sealed water bath on patient table**
- **Connects to positioning system**
- **Moves in X-Y, tilt and roll directions**

ExAblate 2000*

Operator Console

- **Controls all treatment planning and operation**
- **Thermal imaging analysis/display**
- **Sits next to SIGNA MR**

*** Insightec Inc, Haifa, Israel**

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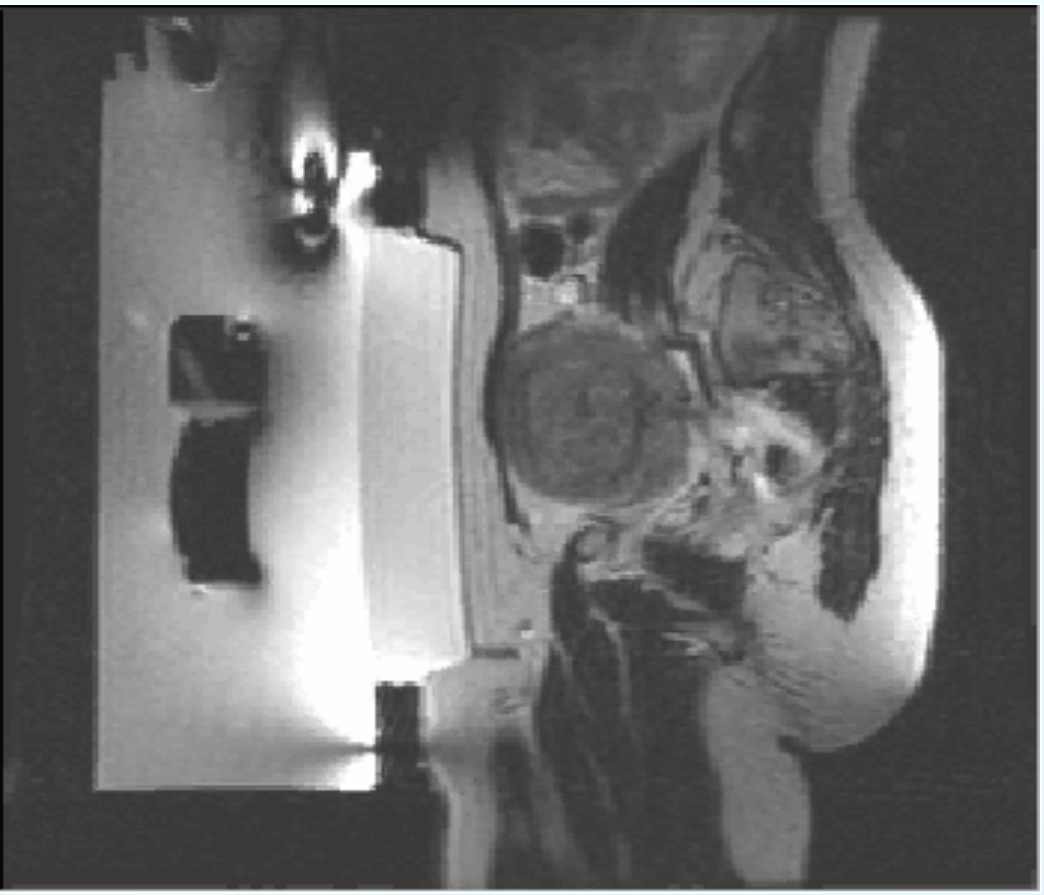
MRg FUS Uterine fibroid Treatment Planning



Clinical trial Protocol

- Planning beam path
  - Avoid bowel
  - Scar
  - 4cm from sacrum
- 100 cc's tissue
- 15mm from outer surface
- 3hrs sonnications
- IVCS
- Start Rx
- Low power build up
- To theraputic power

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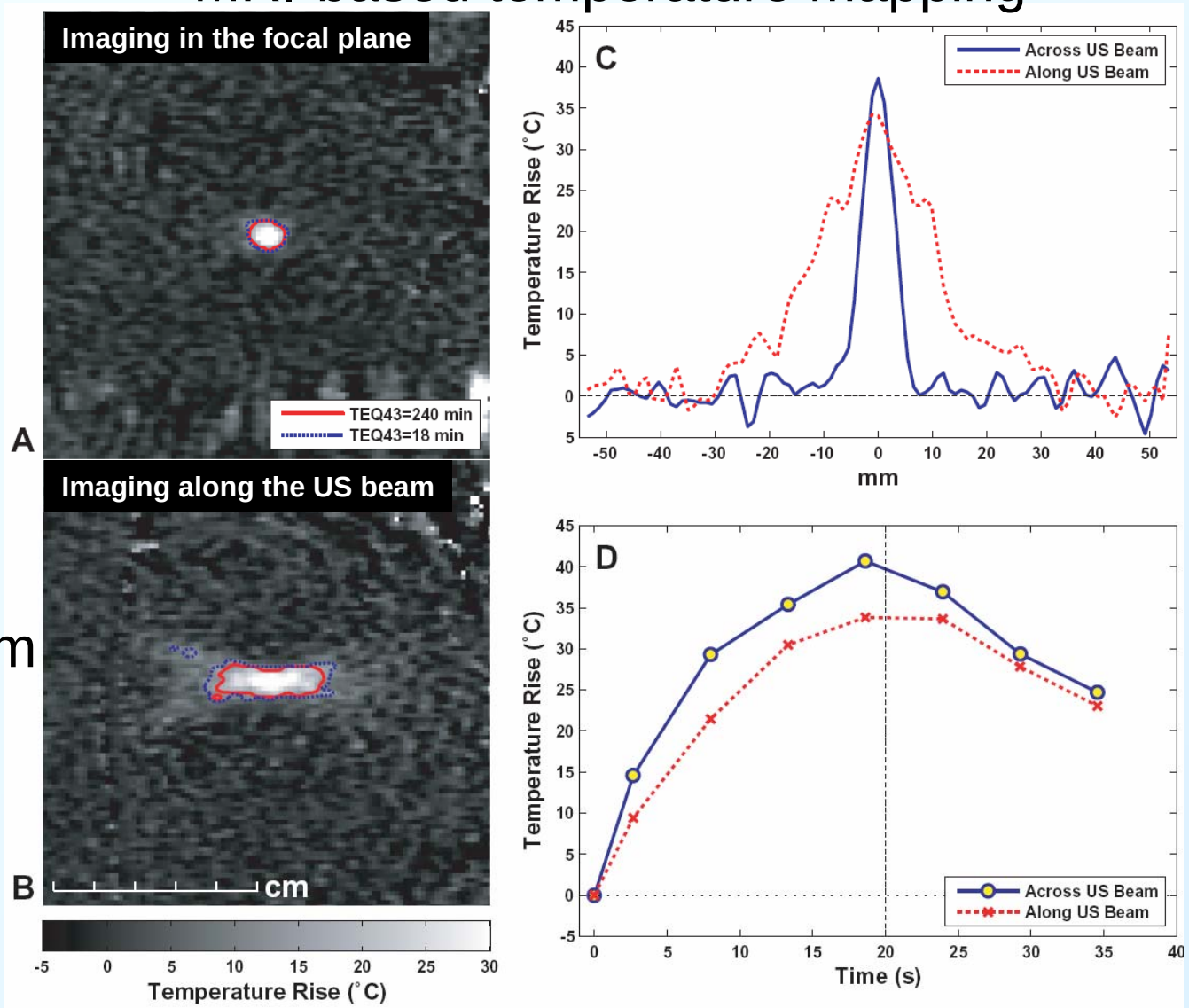
Uterine fibroid thermal ablation with MRI-guided focused ultrasound

MRI-based temperature mapping



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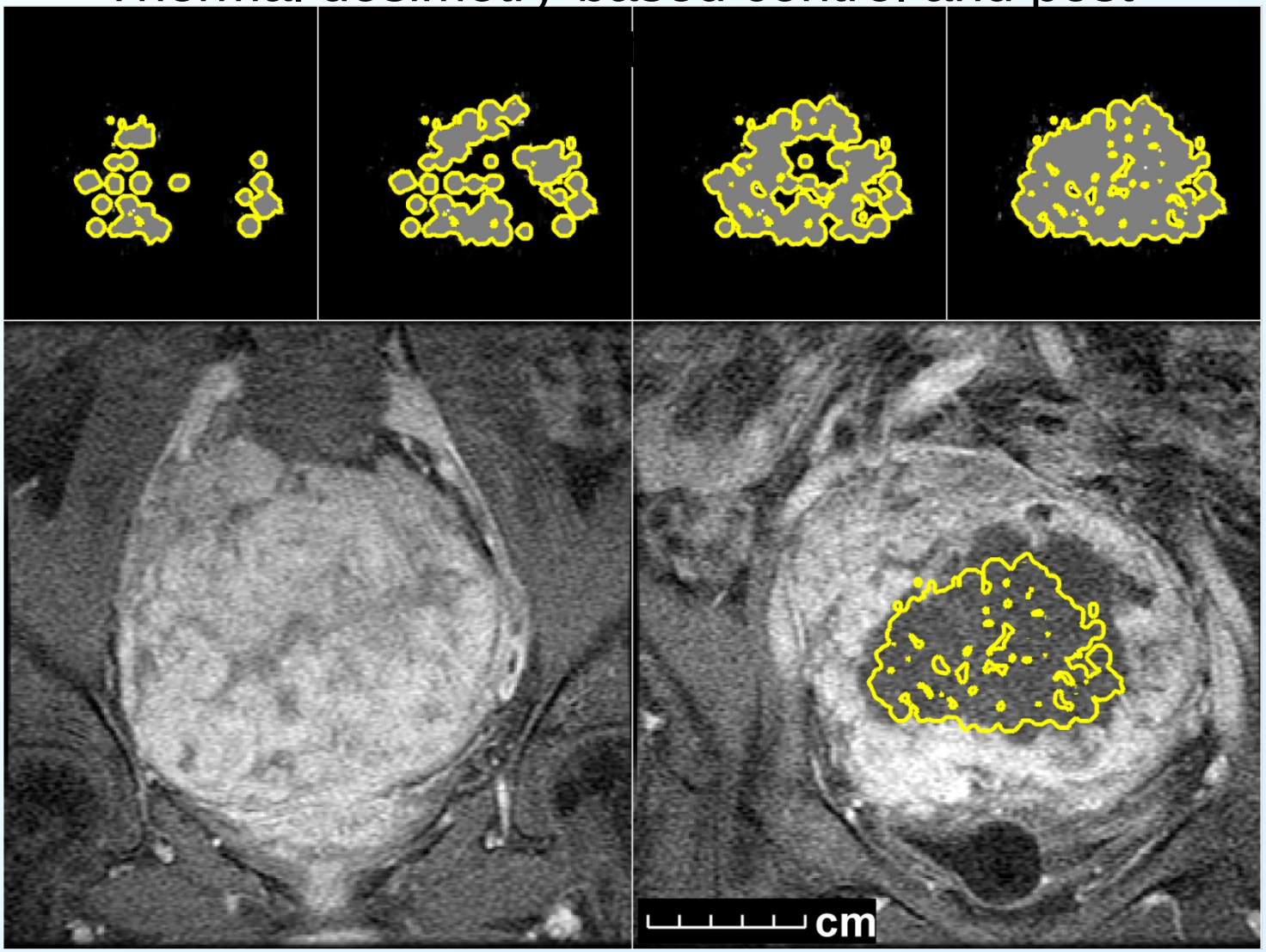
Uterine fibroid thermal ablation with MRI-guided focused ultrasound

Thermal dosimetry-based control and post-



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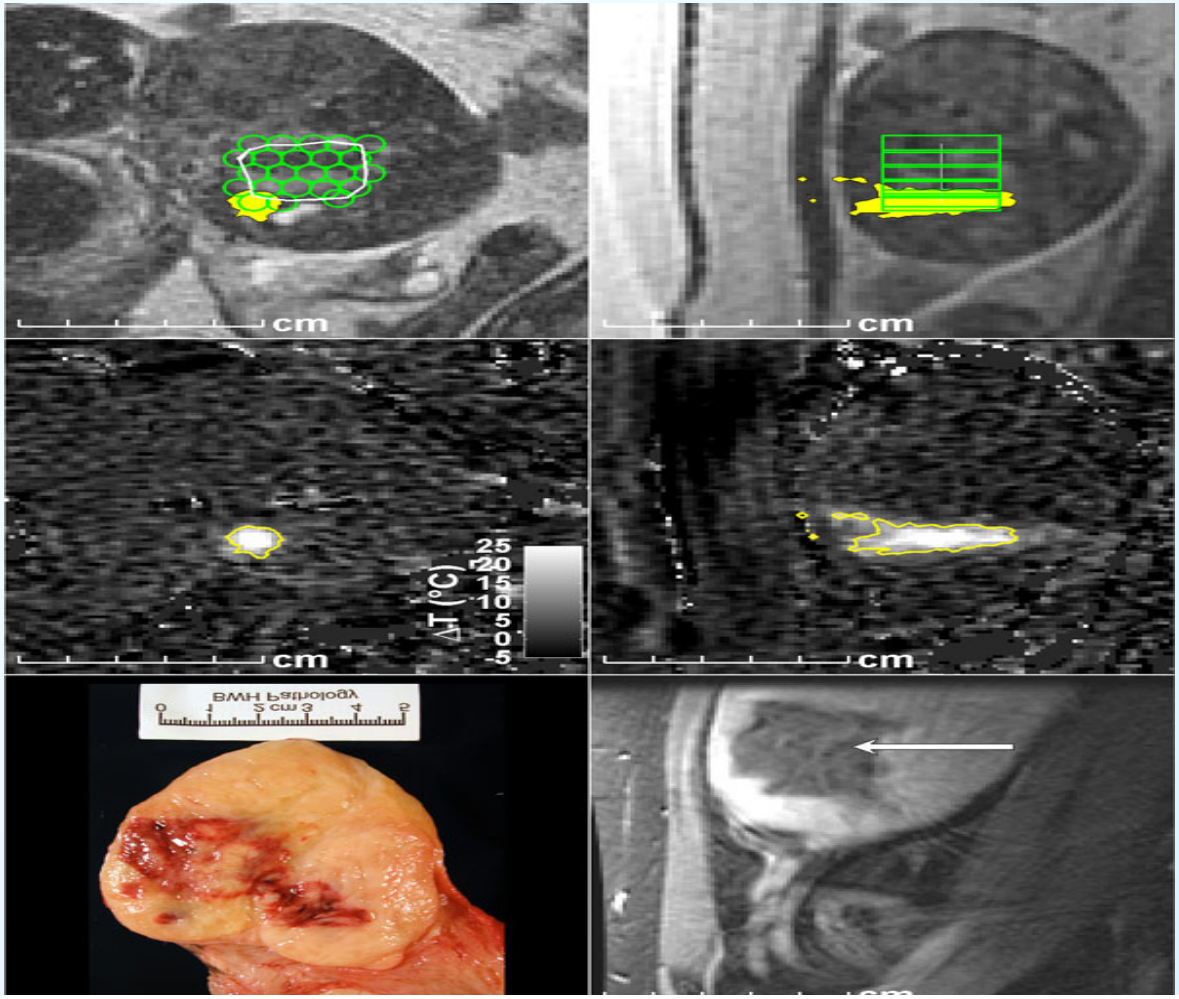
Brigham & Women's Hospital, Boston, MA

MR imaging-Guided Focused ultrasound surgery for uterine leiomyomas: A feasibility study



Tempany C, Stewart E, McDannold N, Jolesz F, Hynenen K. Radiology 2003: 226: 897-905

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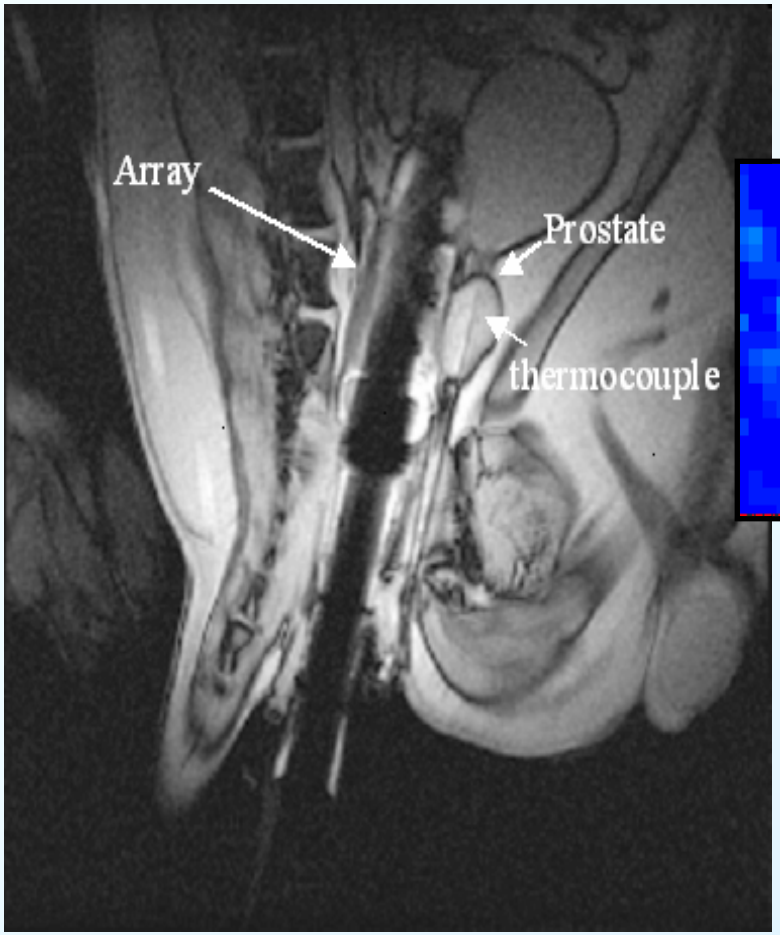
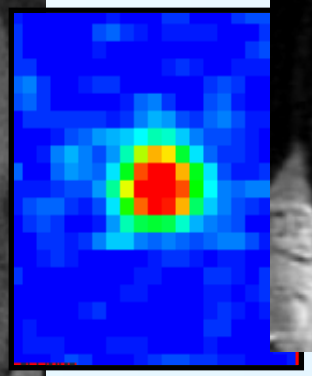
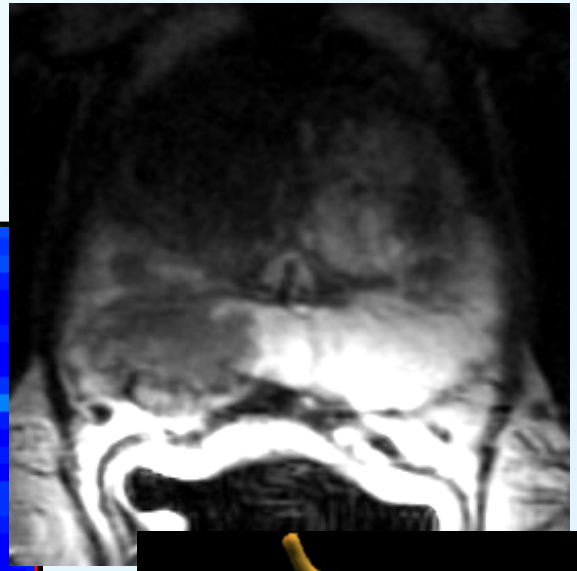
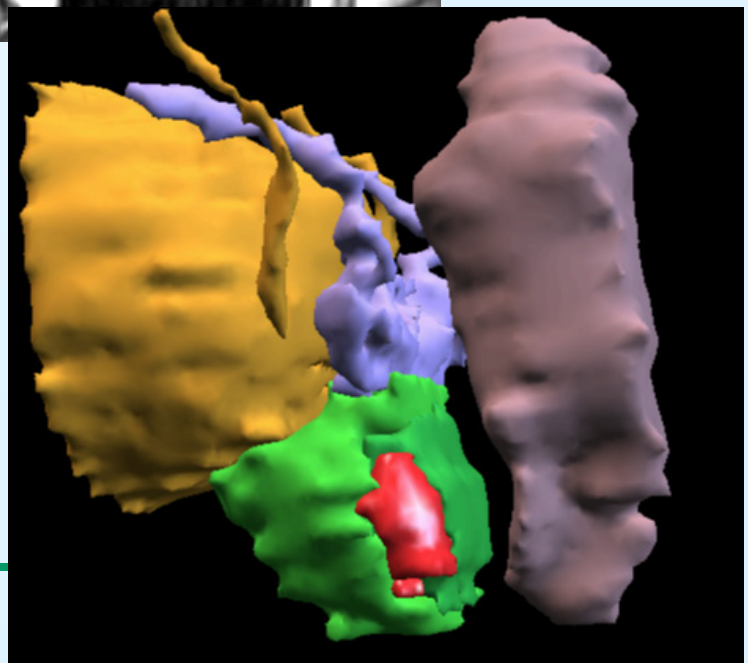
MRgFUS

prostate cancer treatment









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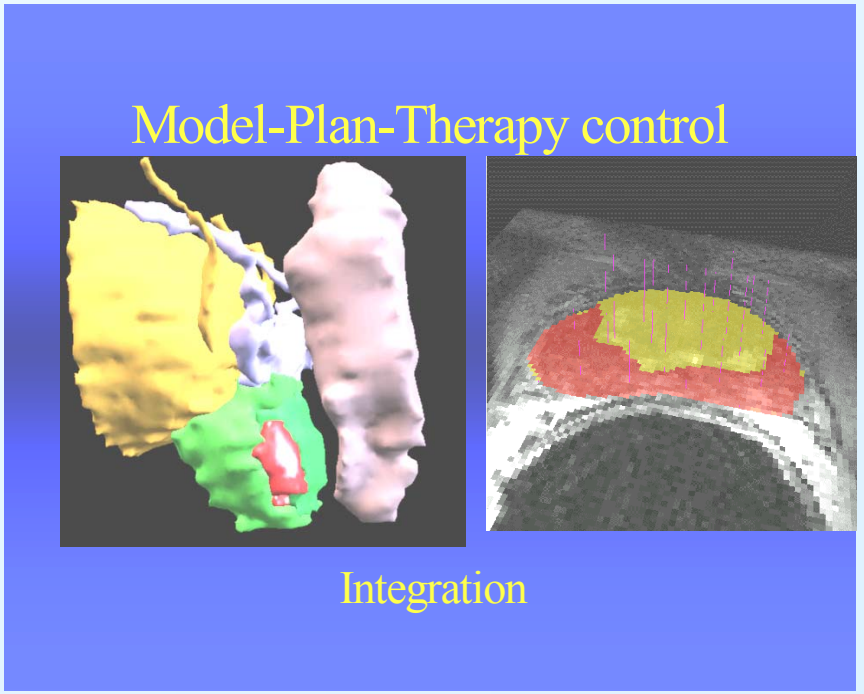
Specific Challenges in Prostate Cancer

- In vivo marker of biological behavior
- In vivo definition of index disease
- Focal therapy/monitoring
  - Image guided/controlled and delivered



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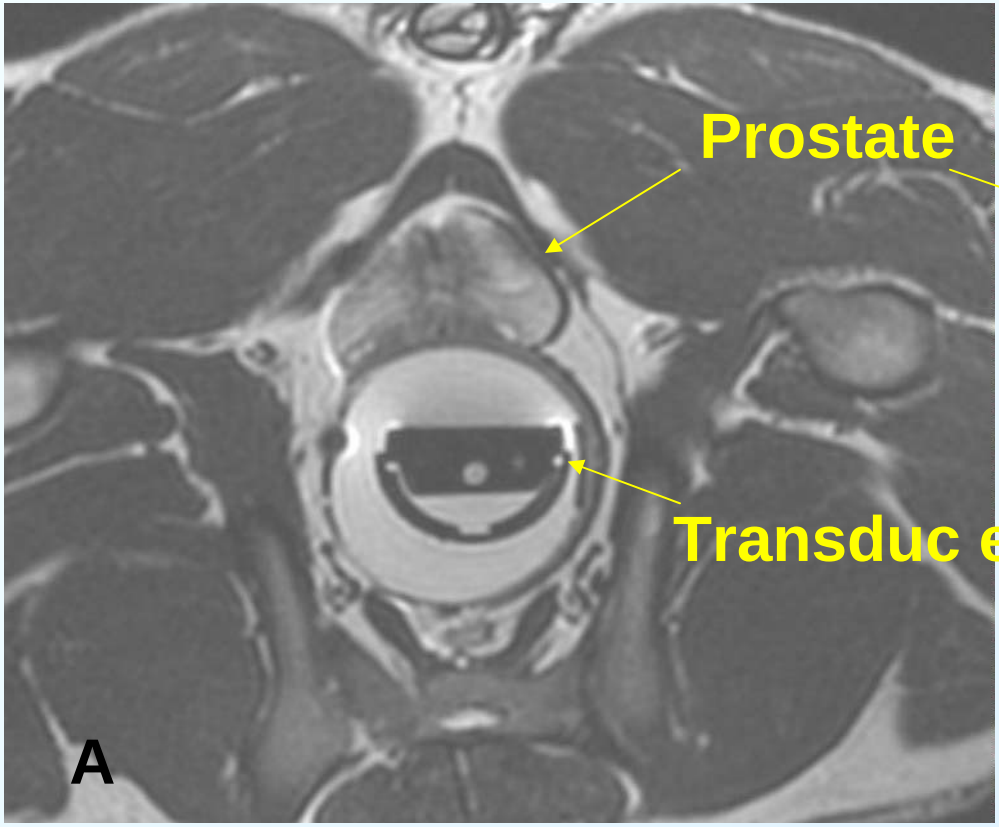
Prostate MRgFUS-Animal



Courtesy Insightec Inc

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Animal MRgFUS/Insightec

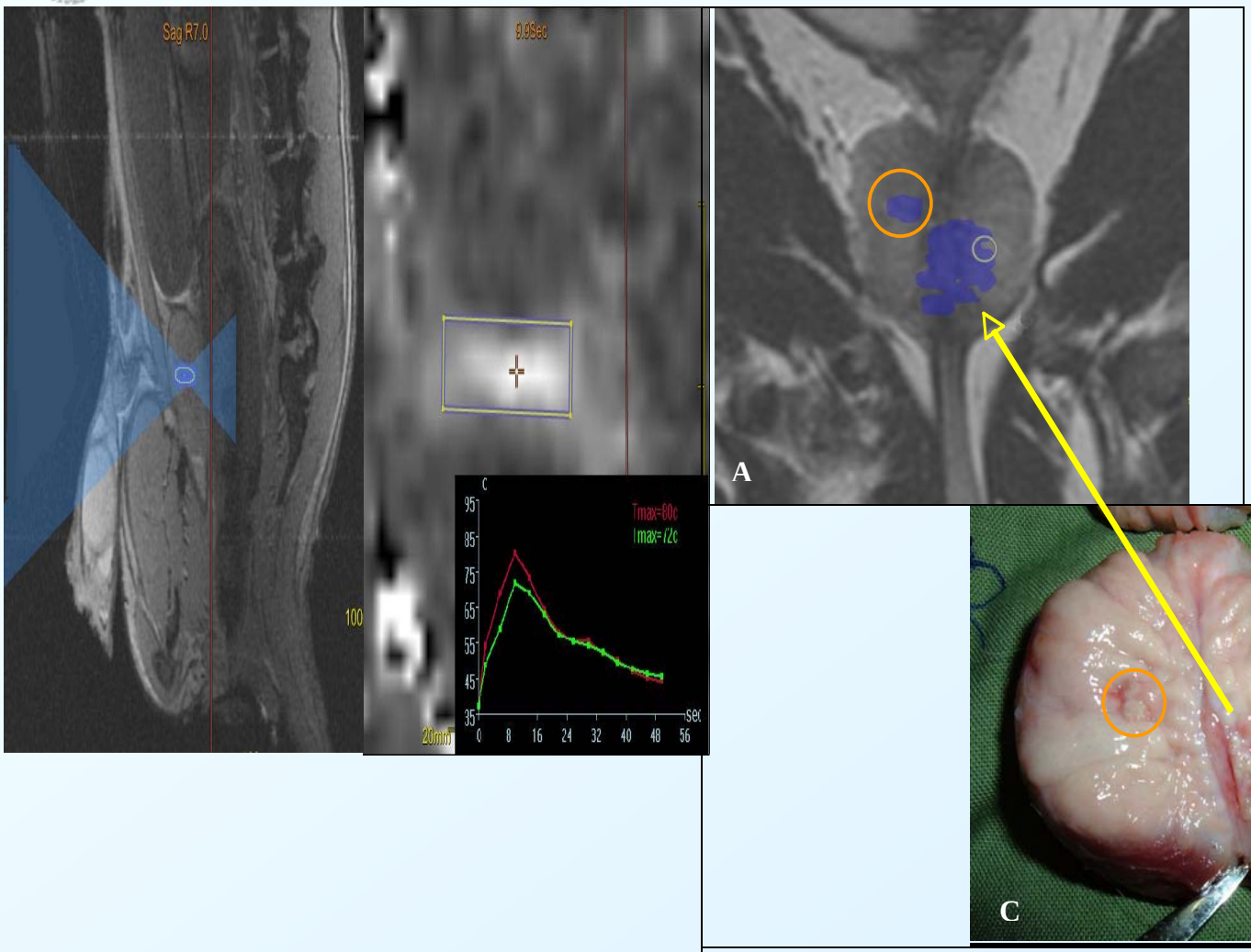

Figure 3: Prostate lesion: **A** Coronal planning image with accumulated dose; **B** Post treatment Coronal T1w contrast enhanced subtraction image; **C** Pathology image Ğpost treatment dissection

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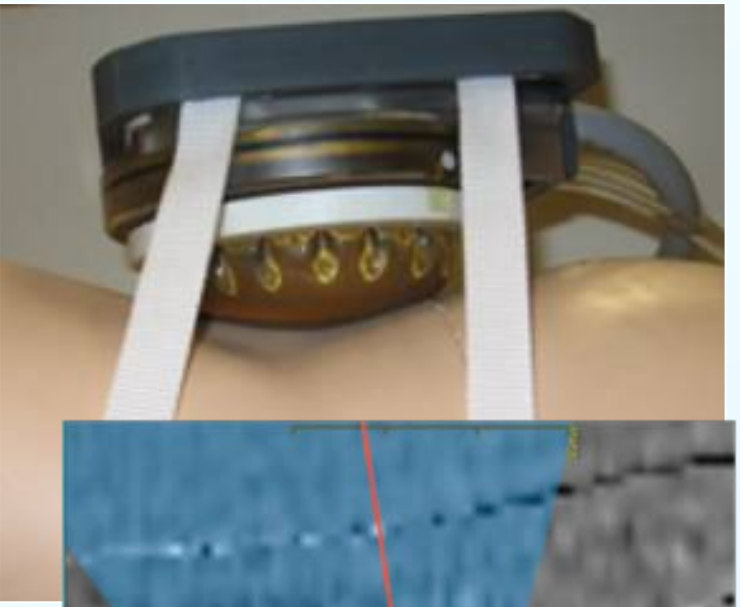
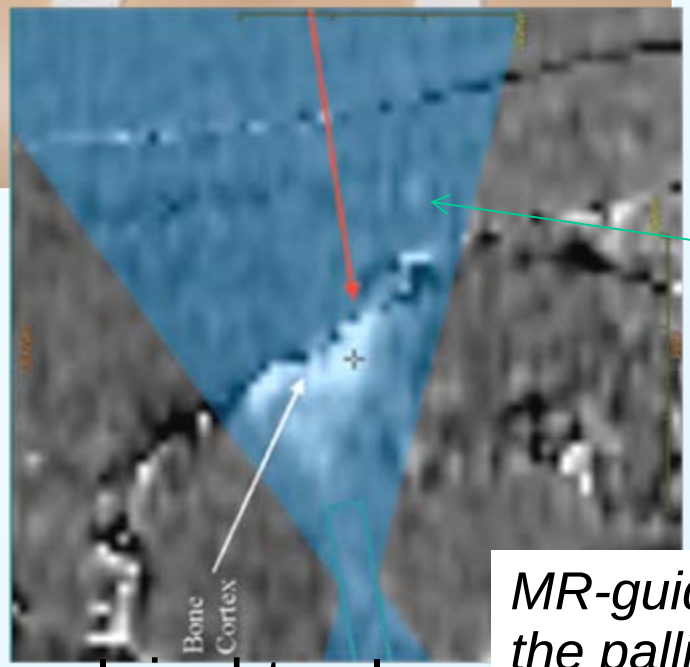
Bone MRgFUS

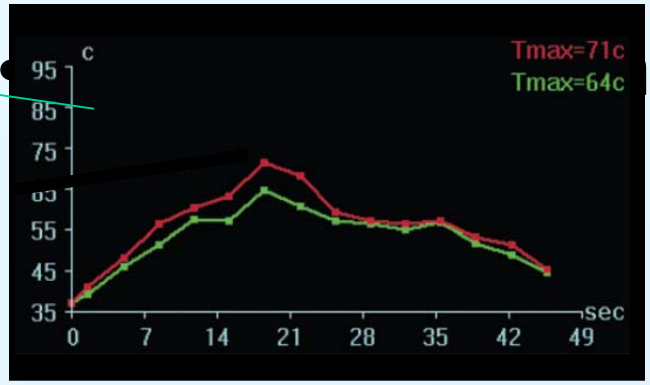




Inisghtec Inc

Pain palliation of bone metastases
Reduce pain meds

- Wide Beam Approach
- Low energy usage
- t Time



MR-guided focused ultrasound surgery (MRgFUS) for the palliation of pain in patients with bone metastases- preliminary clinical experience
R. Catane et al. Annals of Oncology 2006

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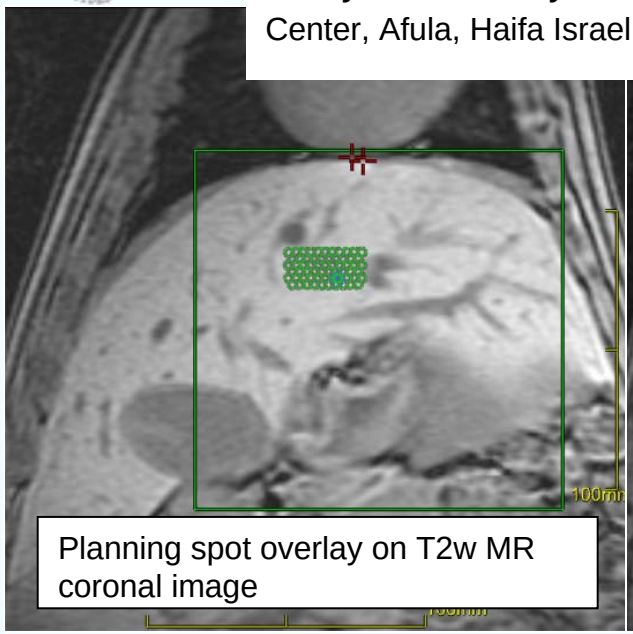
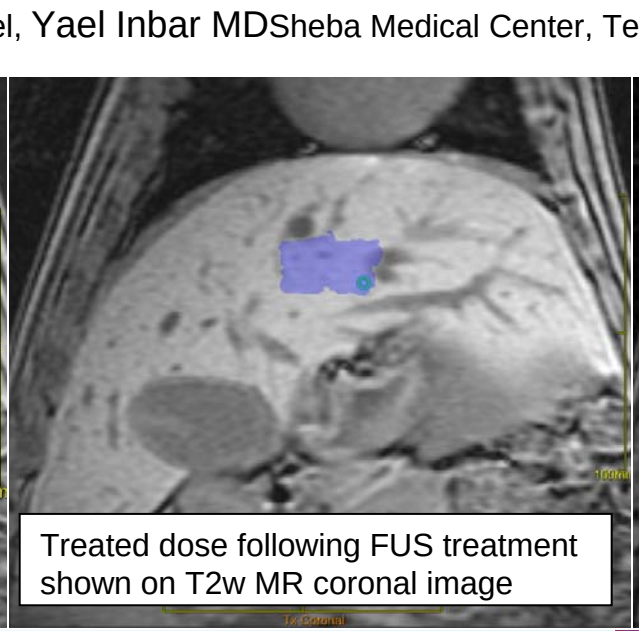
MRgFUS of focal liver disease

Wadyslaw Gedroyc MD St Mary's Hospital London, England Doron Kopelman MDHaEmek Medical Center, Afula, Haifa Israel, Yael Inbar MDSheba Medical Center, Tel-Hashomer Israel



Planning spot overlay on T2w MR coronal image

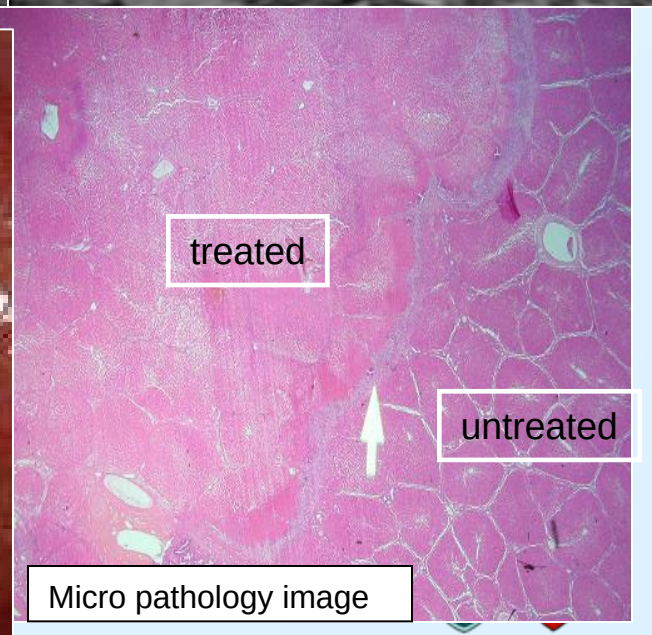


Treated dose following FUS treatment shown on T2w MR coronal image

T1w coronal MR image showing the lesion that was created

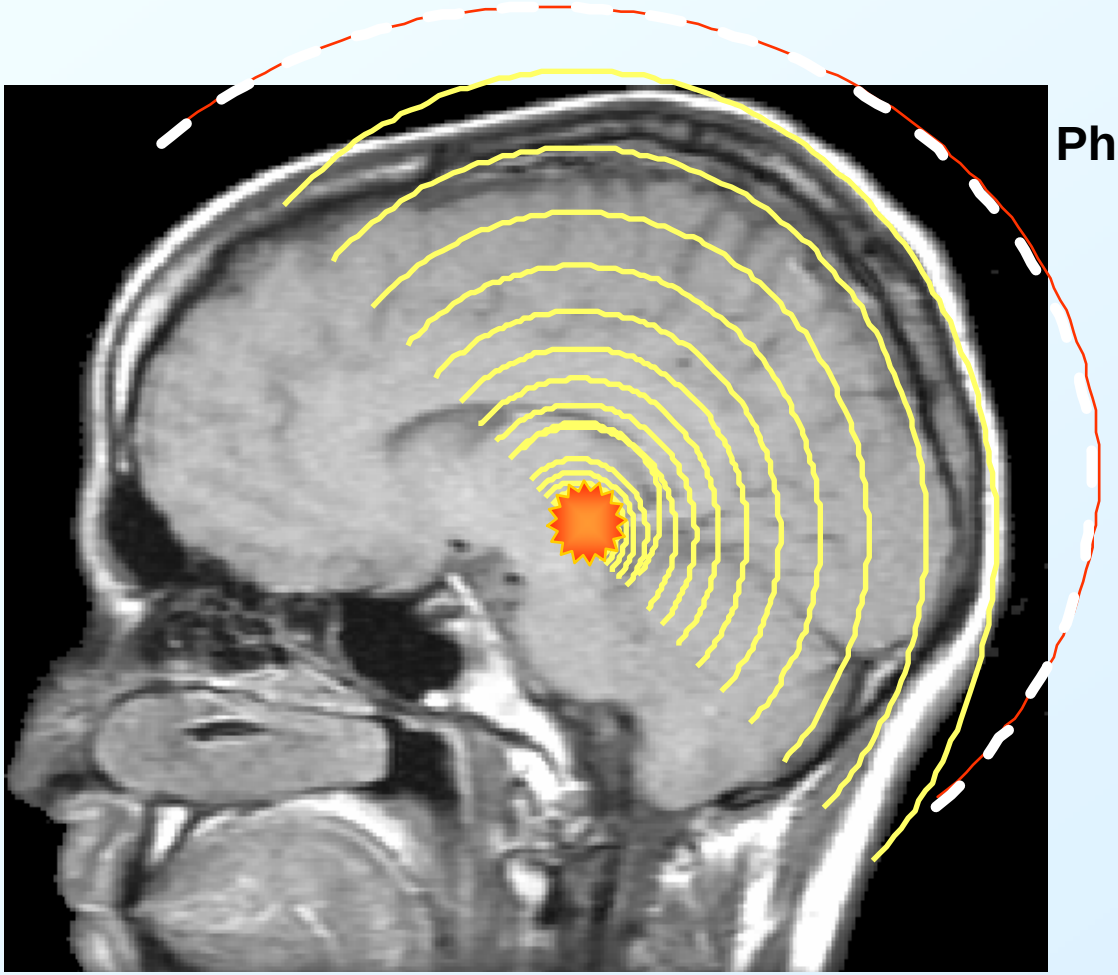
Contrast enhanced T1w subtraction image showing the lesion.

Macro pathology image one month following the procedure showing the central hepatic vain and the adjacent lesion



Micro pathology image

Large Phased Array Transducer



Clement, et al., A hemisphere array for non-invasive ultrasound brain therapy and surgery. *Phys.Med Biol* 45 (12):3707-3719, 2000.

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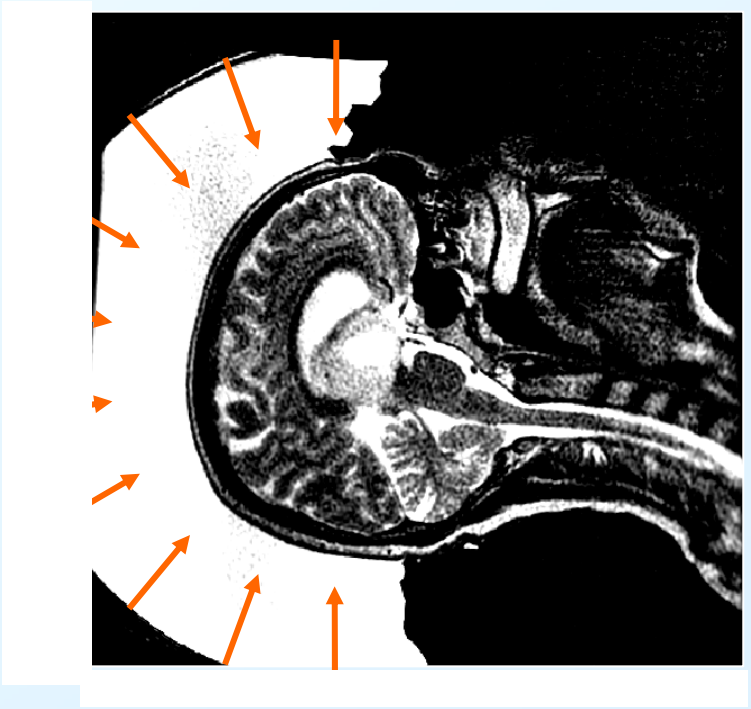
Brain tumor thermal ablation with MRI-guided focused ultrasound

Noninvasive brain tumor ablation using transcranial focused ultrasound



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ExAblate 3000, 4000 (InSightec, Haifa, Israel)

BWH IGT Vision for the future

- Widespread/multidisplinary IGT
- Multi-modal imaging and multi faceted therapies
- BBB disruption
  - Targeted drug delivery
- Ablations
  - Thermal (FUS), cryo, laser
- Image guided thoracotomy, mastectomy
- Robotic or enabling technologies

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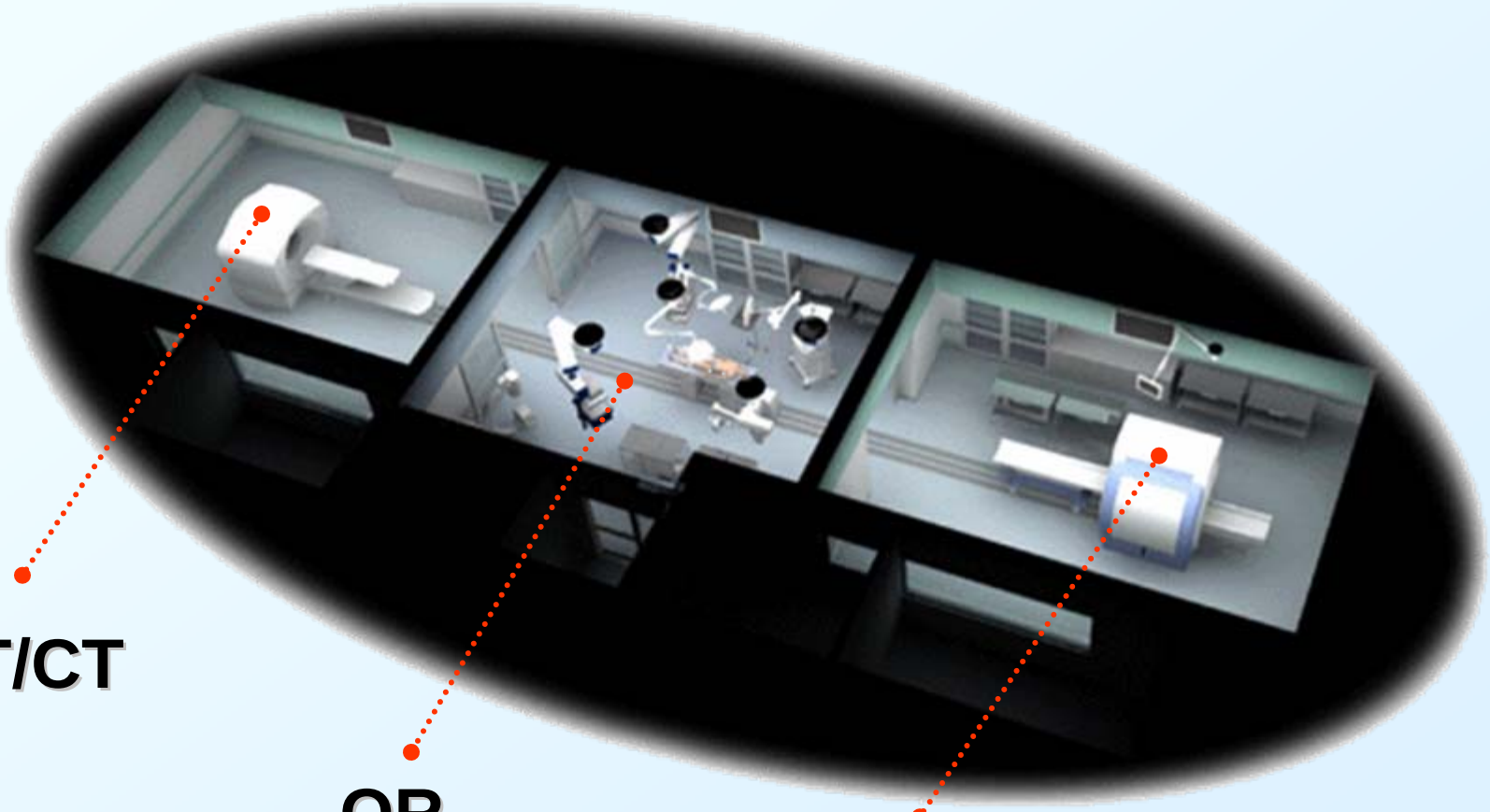
AMIGO

Advanced Multimodality Image-Guided Operating Suite



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Amigo Components

- Modular multi-room facility
  - Surgical/interventional suite Table System
  - MRI (Magnetic Resonance Imaging)
  - Focused Ultrasound Surgery (FUS)
  - Other Imaging: US, X-RAY, Pet-CT
- Navigation software and 3D SLICER
- Interactive and Adaptive imaging Platforms
- Live image display systems-data wall
- Full IT integration

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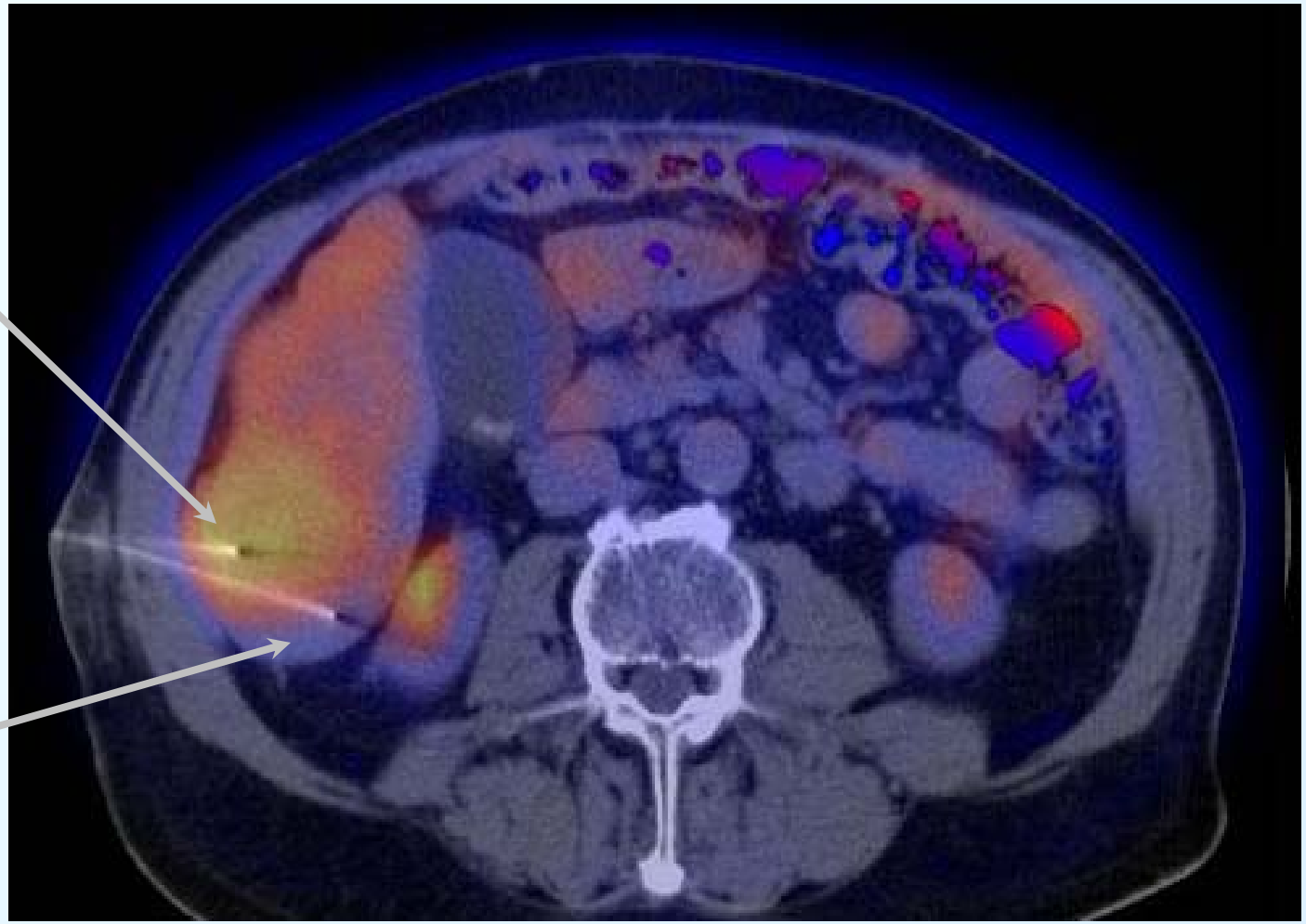
PET/CT-guided Biopsy

Viable tumor

No viable tumor



MIPAV – Medical Image Processing and Visualization (MIPAV) software – NIH
McAuliffe et al IEEE Proceedings 2001

Silverman, Morrison et al BWH

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For More Information

- National Center for Image Guided Therapy
  - http://www.ncigt.org
- Surgical Planning Laboratory
  - http://www.spl.harvard.edu
- National Alliance for Medical Image Computing
  - http://www.na-mic.org

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Conclusions

Revolutionary "game-changing" technologies

- Multiple clinical applications
- Clinical integation into practice has many challenges:
  - Health care inertia/System constraints
  - Technical Resources
  - Growth/Investment issues
- Significant demands at early stage of penetration
  - Be cost effective
  - Be efficient
  - Enormous challenges--Not for the faint of heart
- *All are disruptive technologies*

Bottom line motivator:

Extra-ordinary rewards and benefits for our patients

© N

Bottom Line: Improved Patient Care

- Provide new capabilities that transcend human limitations in intervention
- Increase consistency and quality of interventional treatments