Tutorial: Image Guided Therapy

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Learning objective

- To understand the fundamentals of medical imaging
- To understand the role of medical imaging to guide therapy and diagnosis – Image Guided Therapy
- To learn role of robotics in Image Guided Therapy research and key enabling technologies

Imaging in medicine

- We are in a perfect city to discuss medical imaging.

The Nobel Prize in Physics 1901

Wilhelm Conrad Röntgen

X-ray

X-ray Fluoroscope

The Nobel Prize in Physiology or Medicine 1979

Cormack

Hounsfield

EMI CT Scanner
London Science museum

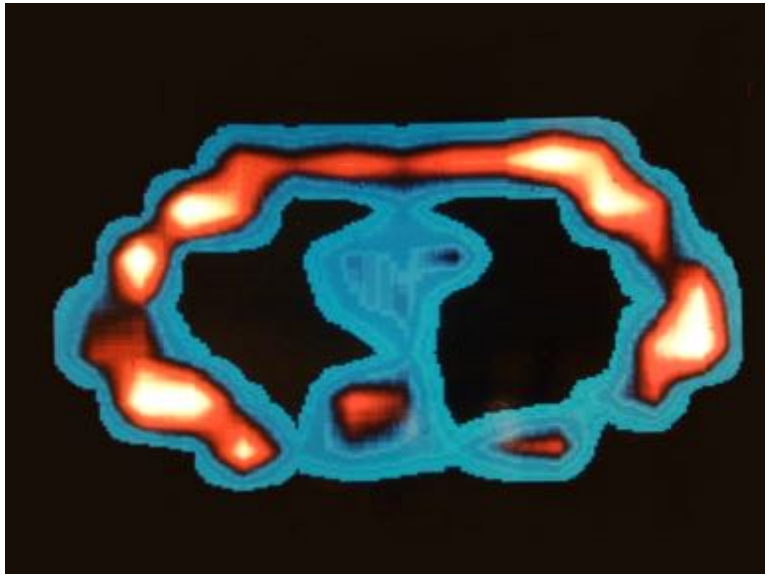
Slicer Demonstration of CT

Toshiba

The Nobel Prize in Physiology or Medicine 2003

Lauterber

Mansfield



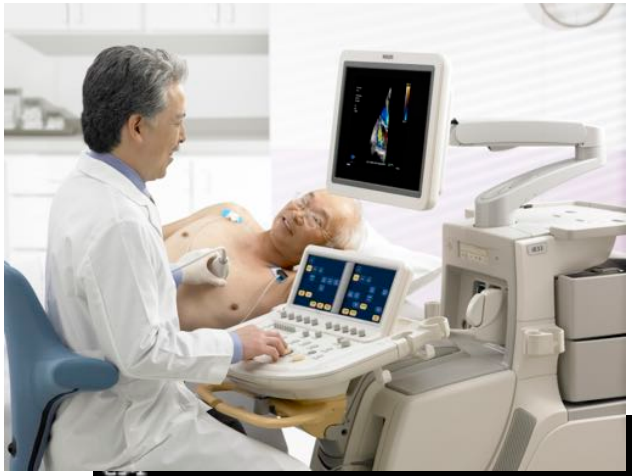
Mapping of Nuclear magnetic resonance (NMR): quantum mechanical magnetic properties of the hydrogen atoms in water and fat

Slicer Demonstration of MRI

Siemens

Japan Prize 1991

Wild

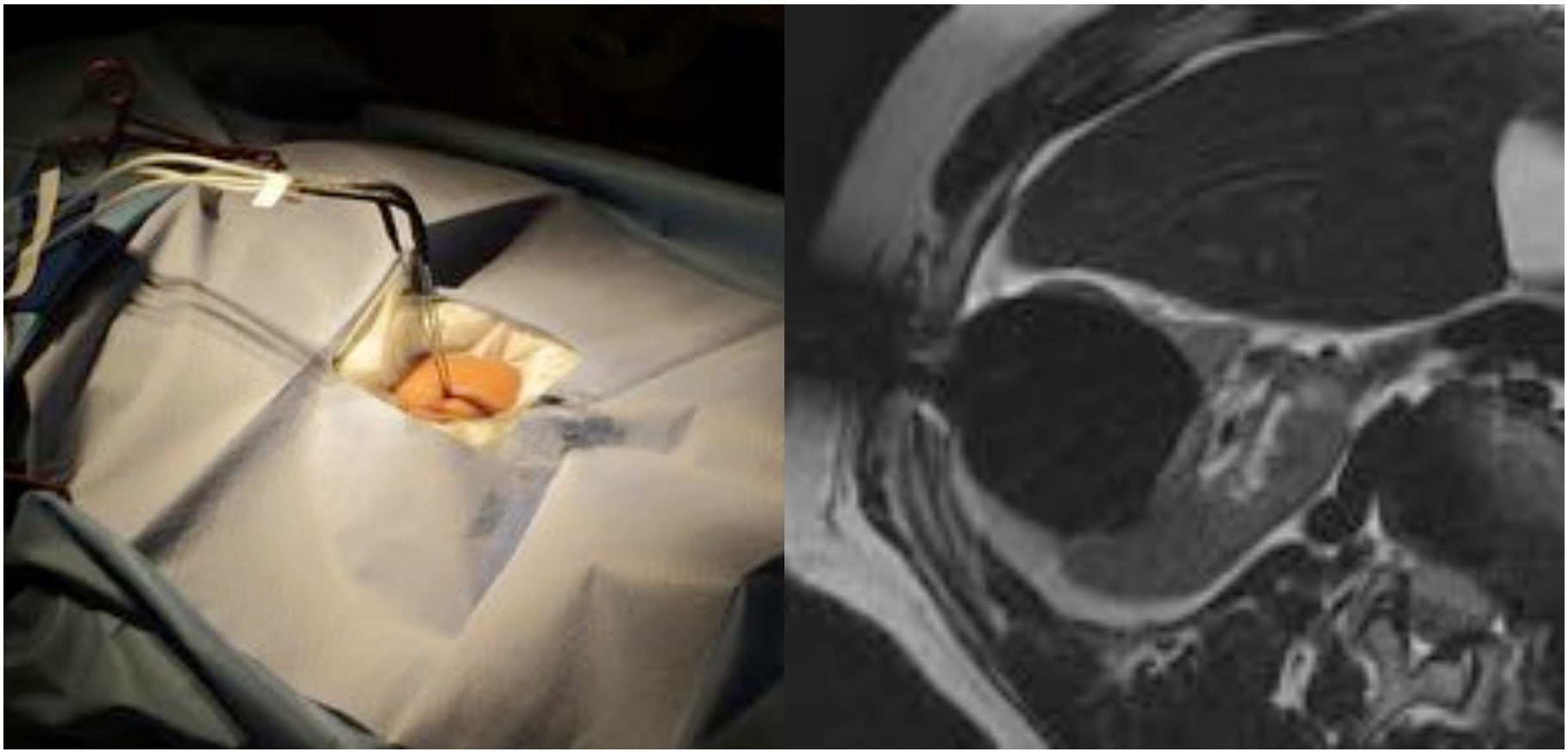


Philips

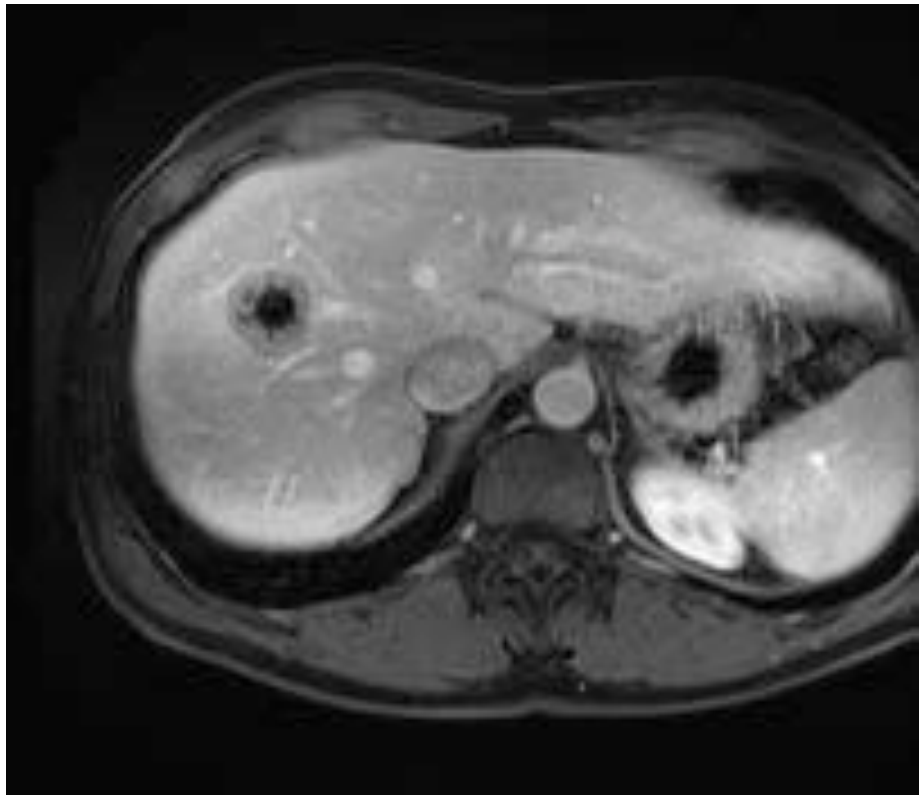
Image Guided Therapy

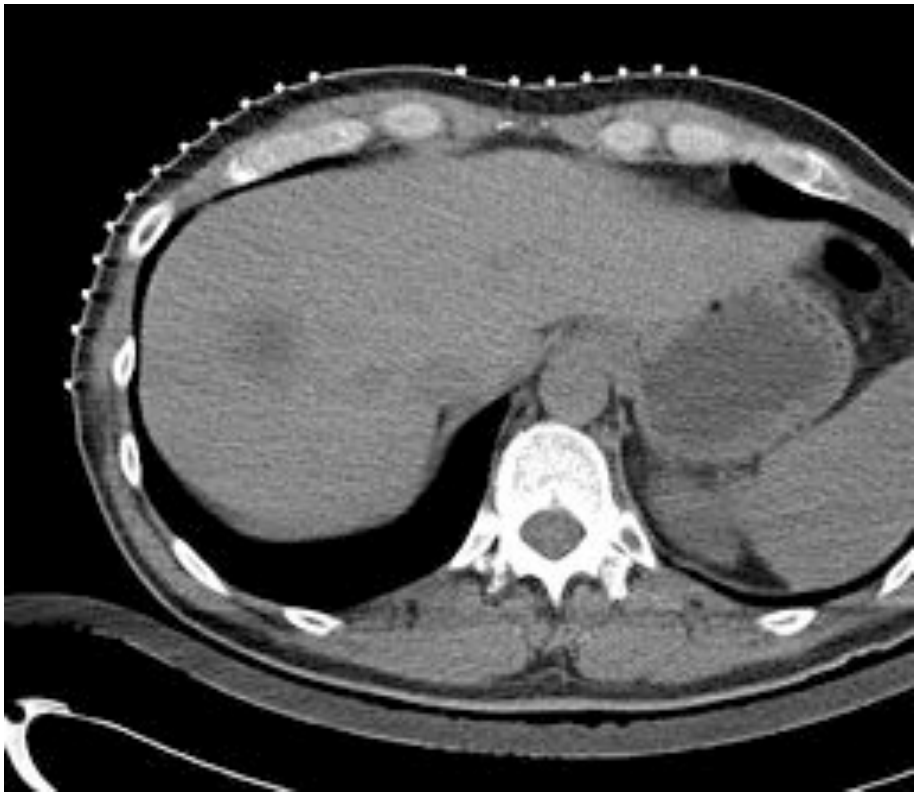
Philips

[QUIZ]



Liver Cancer





Unresectable liver cancers (some T1 to T4, N0, M0 tumors)

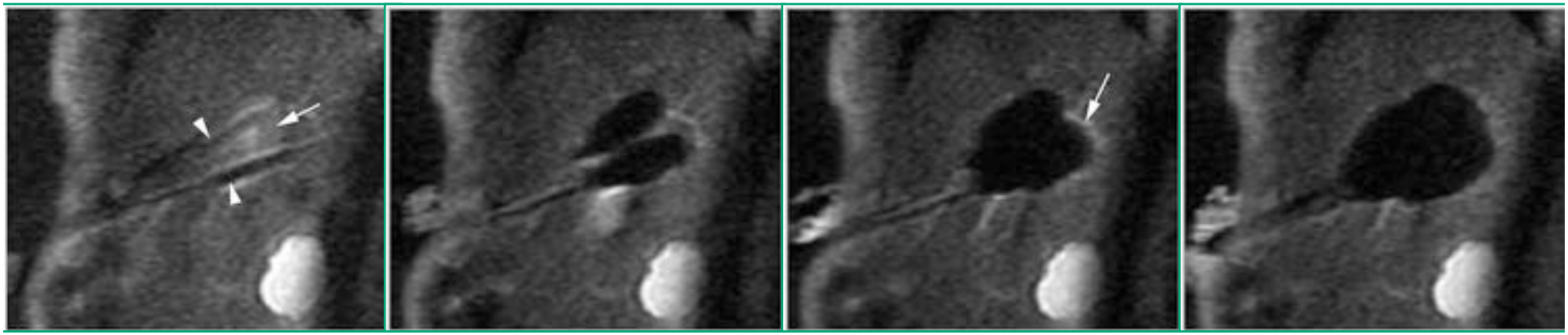
The tumor is too large to be removed safely

The tumor is in a part of the liver that makes it hard to remove (such as very close to a large blood vessel)

There are several tumors or the cancer has spread throughout the liver

Image Guided Therapy Example… Ablative therapy

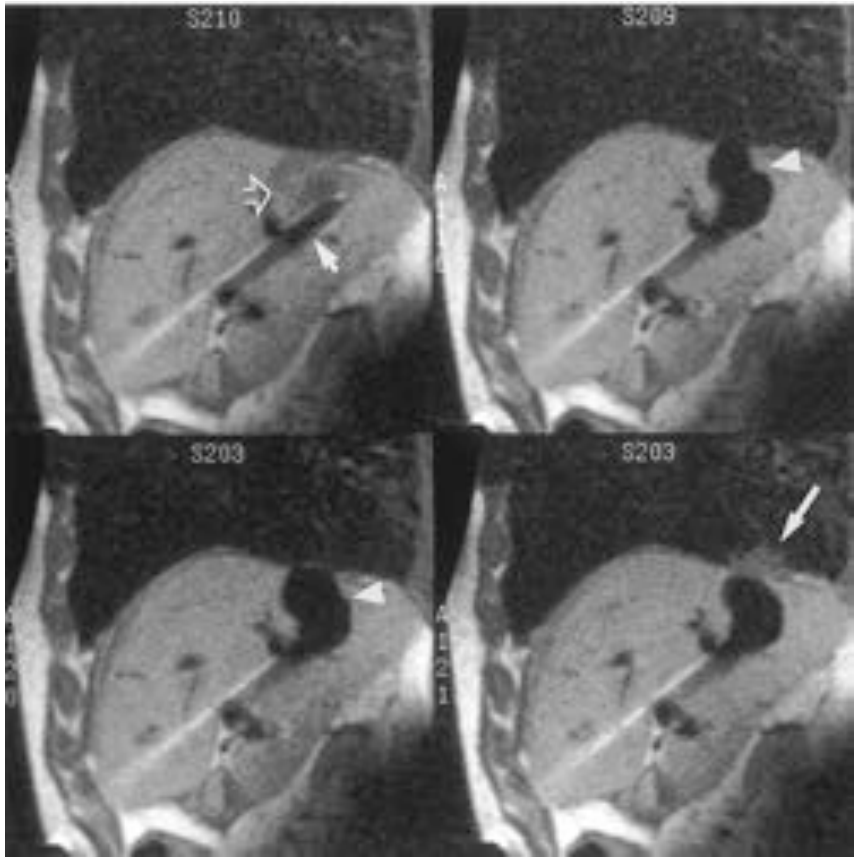
- Suitable for unresectable liver cancers
- Heat and cooling energy to destroy cancerous tissue
- Less invasive than open surgery
- Image guidance is crucial for [QUIZ]



Acad Radiol 2005;12:1100-109

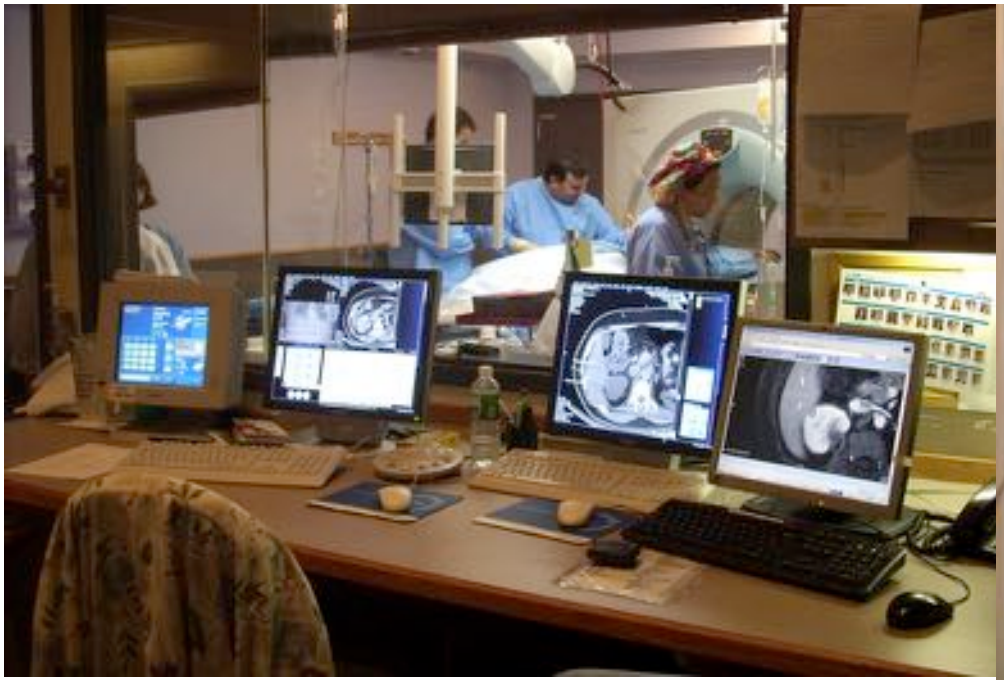
Role of Imaging for Therapy

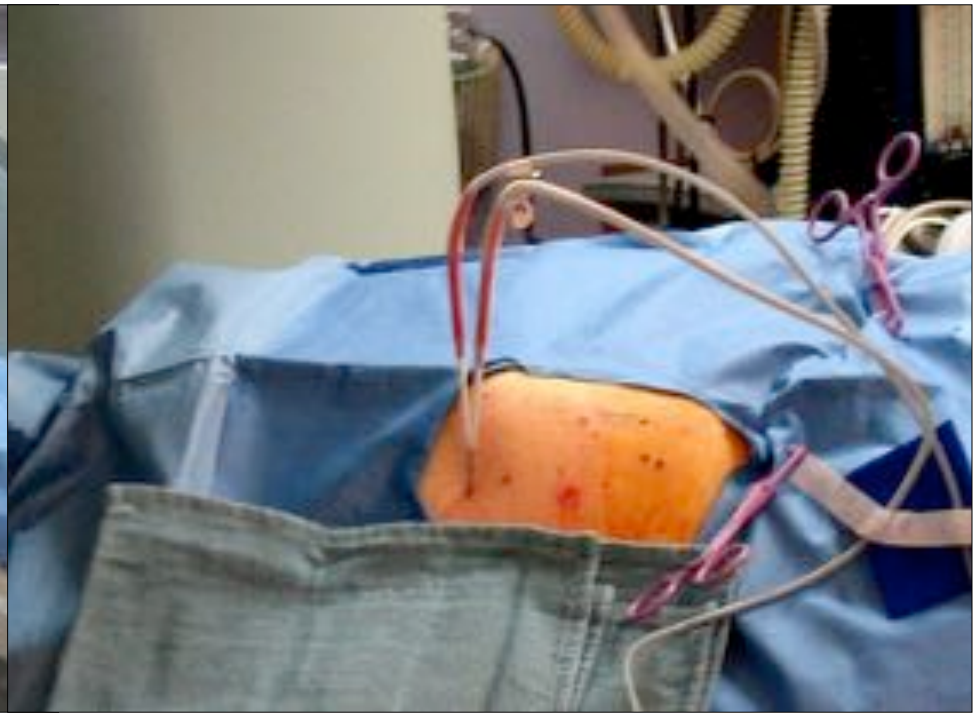
- Targeting
- Navigation and Guidance
- Monitoring



Song, Tuncali

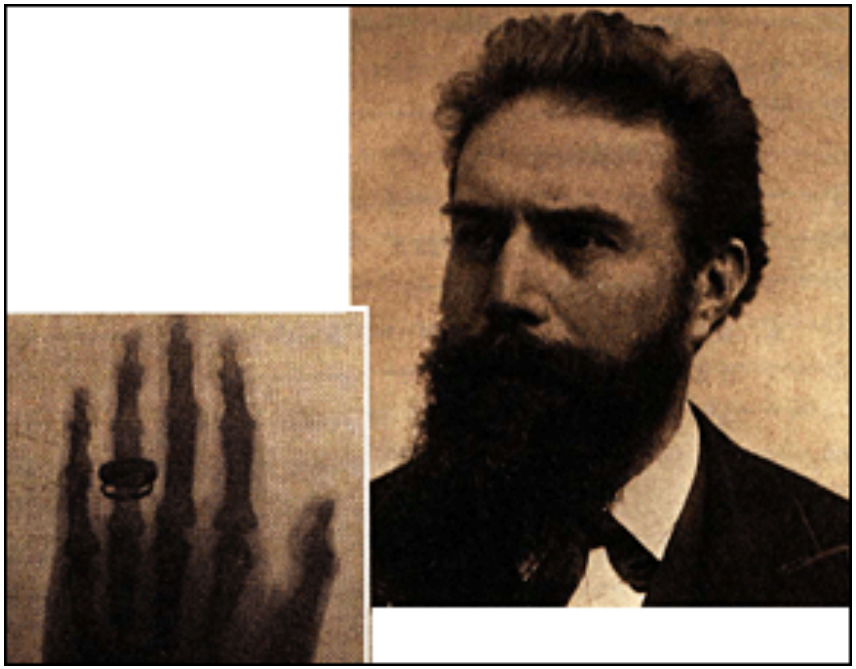
Image Guided Therapy





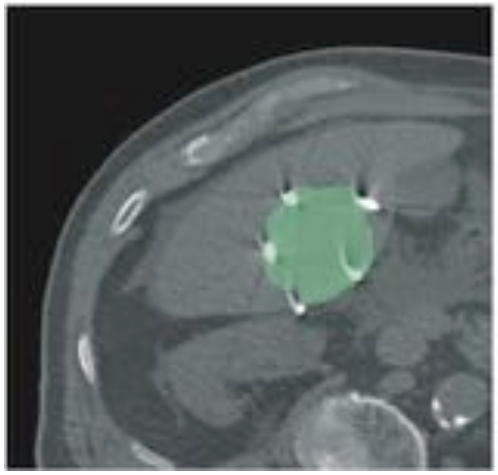
Roentgen

- Nov. 8, 1895: found X-ray
- Dec. 28:paper submitted
- Jan. 5:paper published
- Jan 13:First diagnostic imaging
- Jan 14: First image-guided therapy (needle removal)

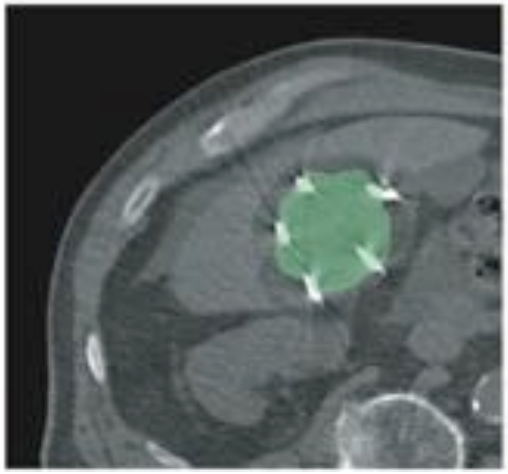


Problem statement

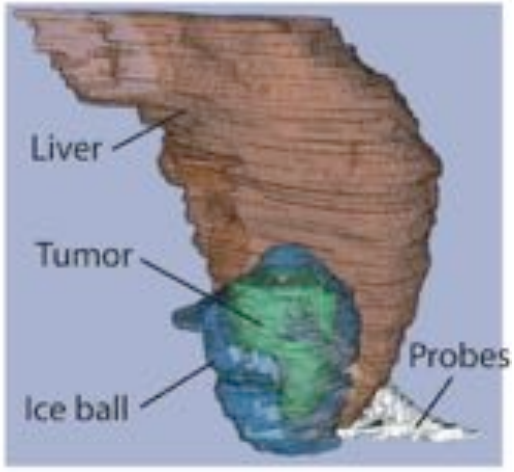
- Precise and controlled placement of ablative probes mandatory
  - To maximize the treatment effect
  - Minimize damage to surrounding critical structures
- Free hand approach limit physicians' precision placement of ablation tools.



Segmented tumor on CT with probes positioned



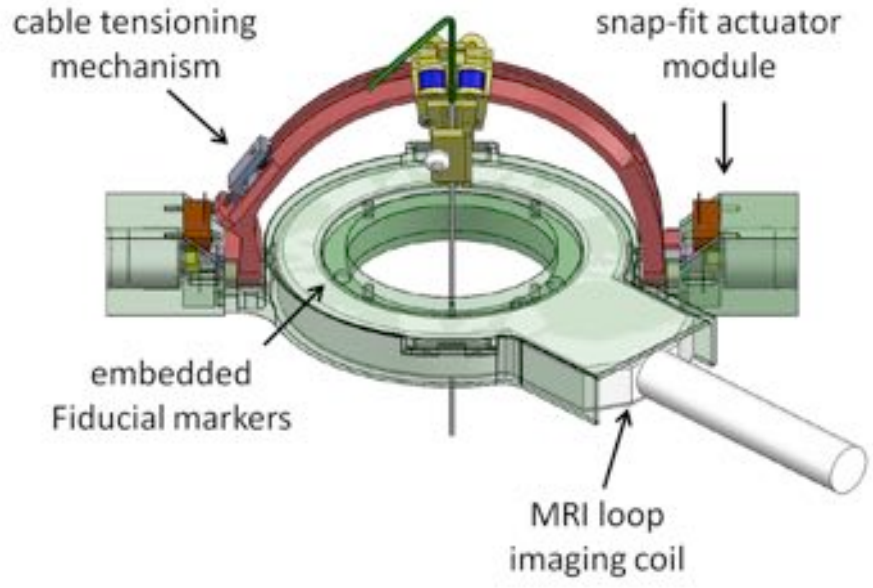
Segmented tumor on CT with ice ball

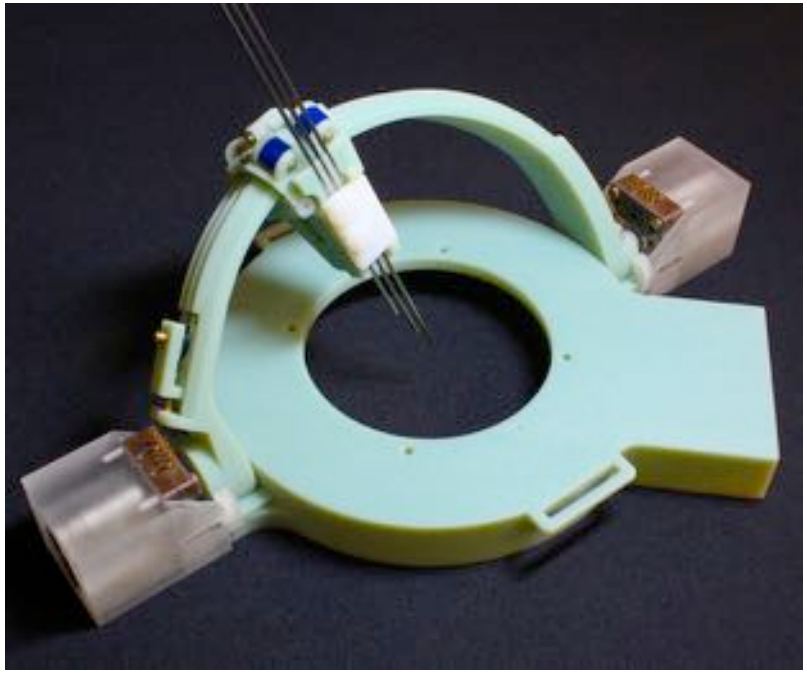


3D evaluation of ablation procedure

Needle positioning device on a surface coil for MRg liver interventions

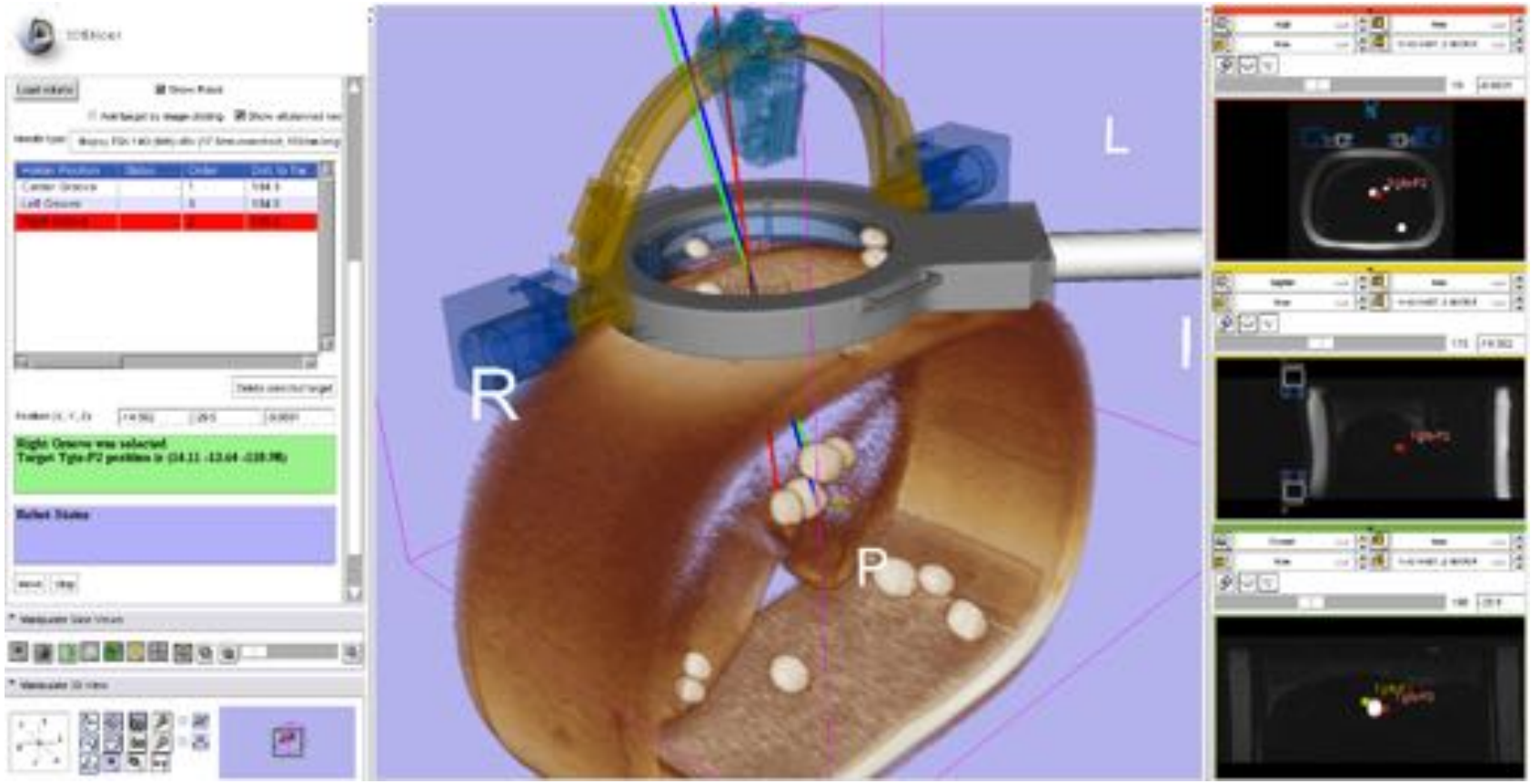
With Conor Walsh (Harvard) and Kemal Tuncali (BWH)



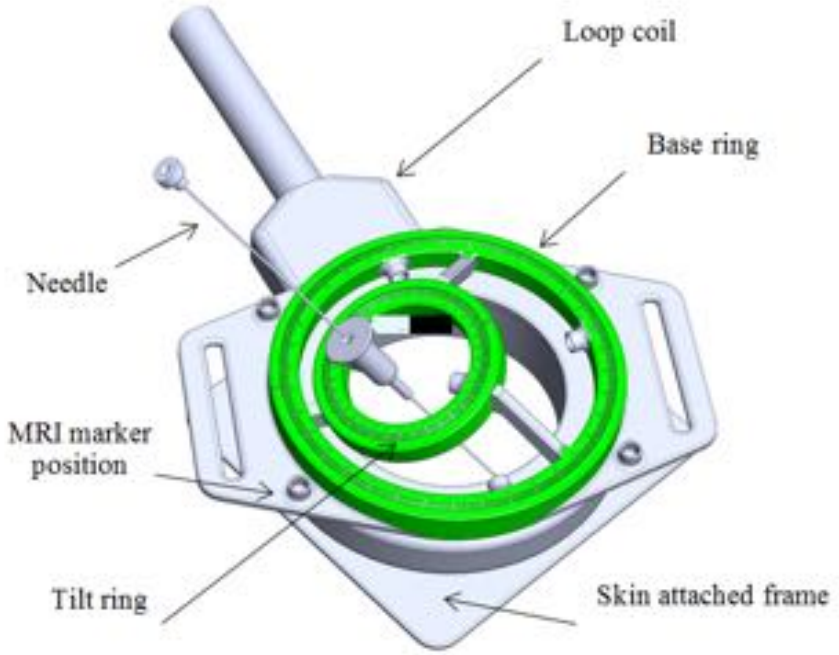


Wu, Torabi, Walsh (MIT/Harvard), Tuncali, Yamada, Hata (BWH), Fischer (WPI), NCIGT WS poster

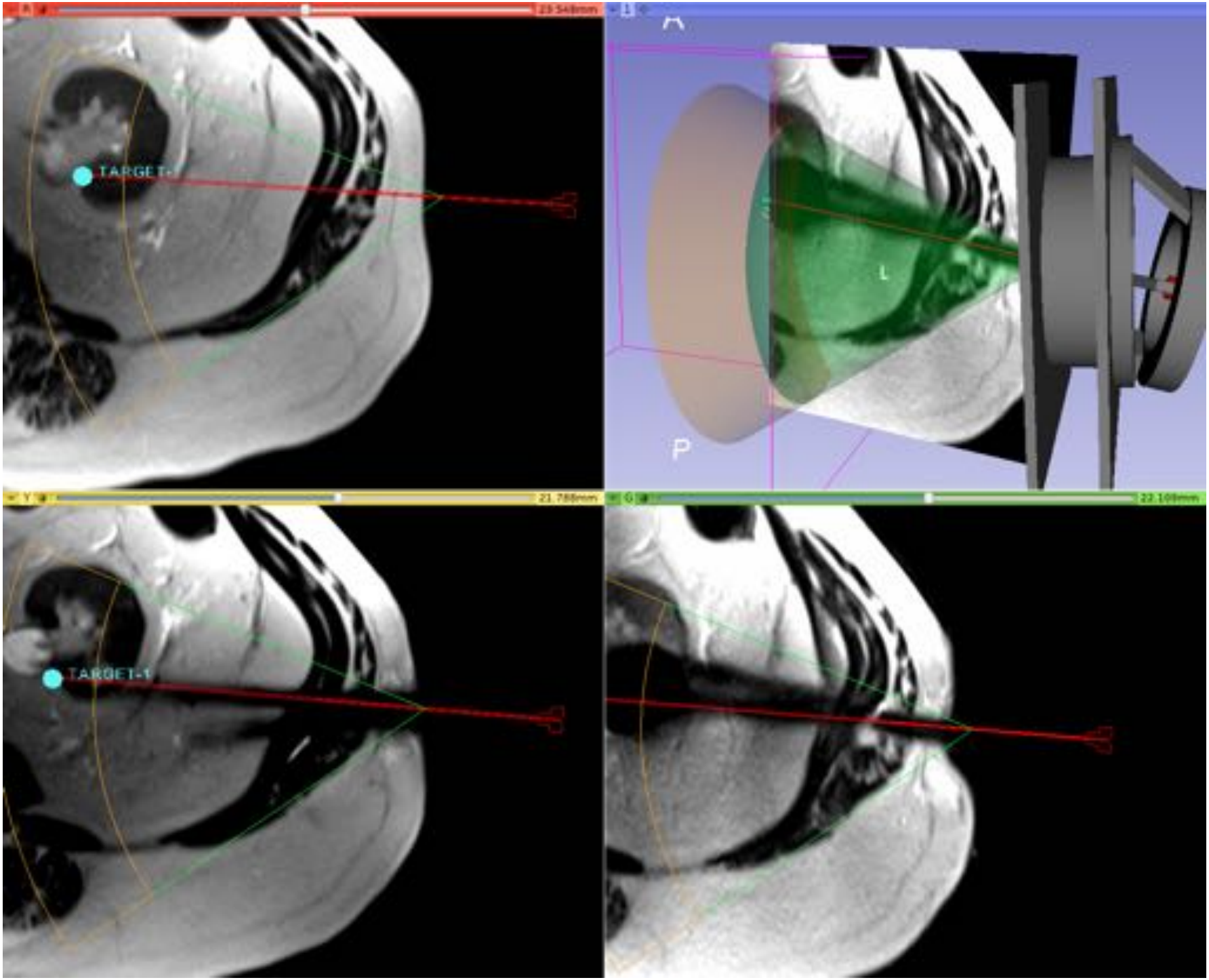
3D Slicer



Canon Robots for abdominal interventions



- Patient-attached, RCM at skin entry
- Can accommodate an imaging coil
- Fiducial marker based registration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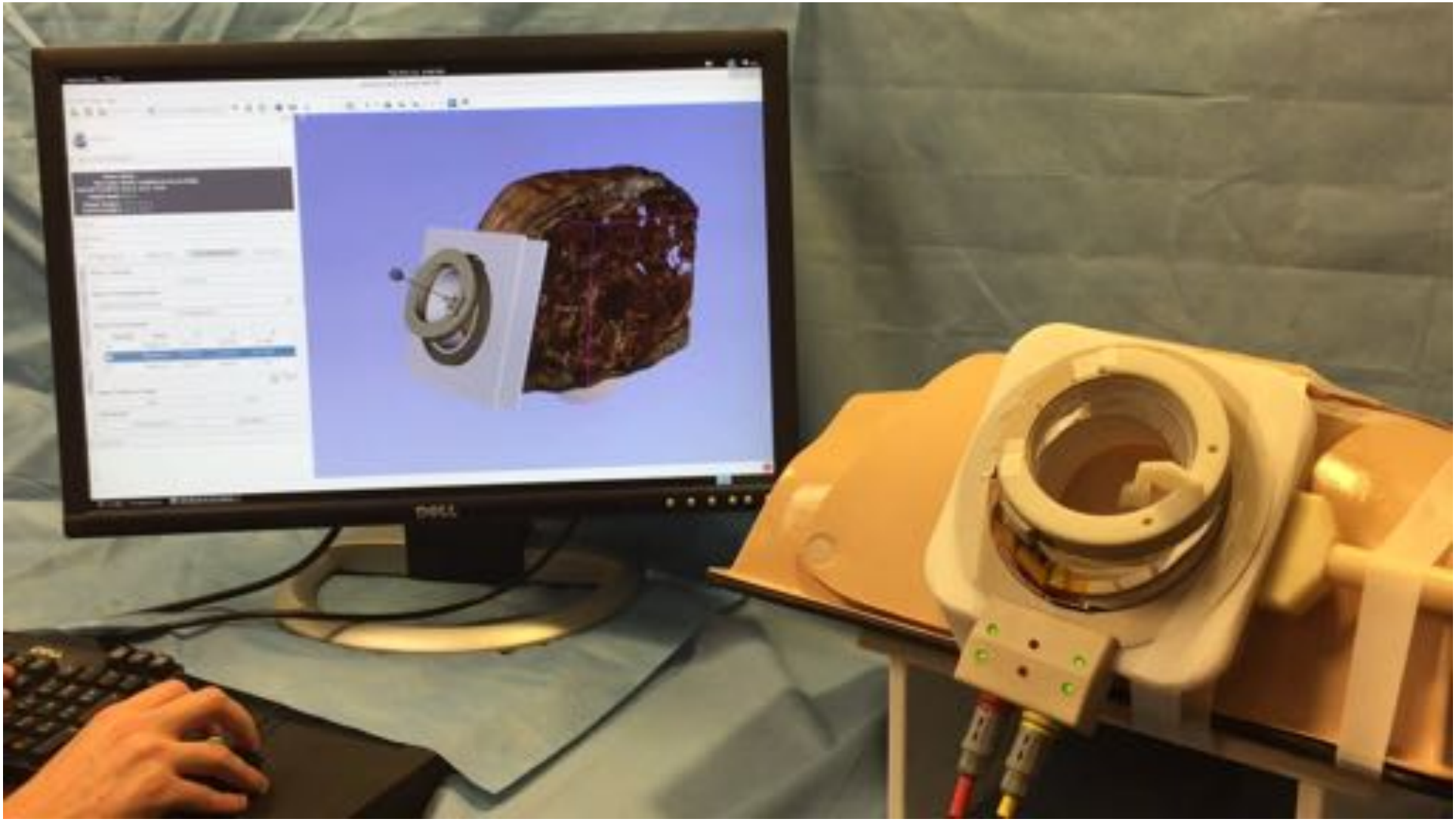
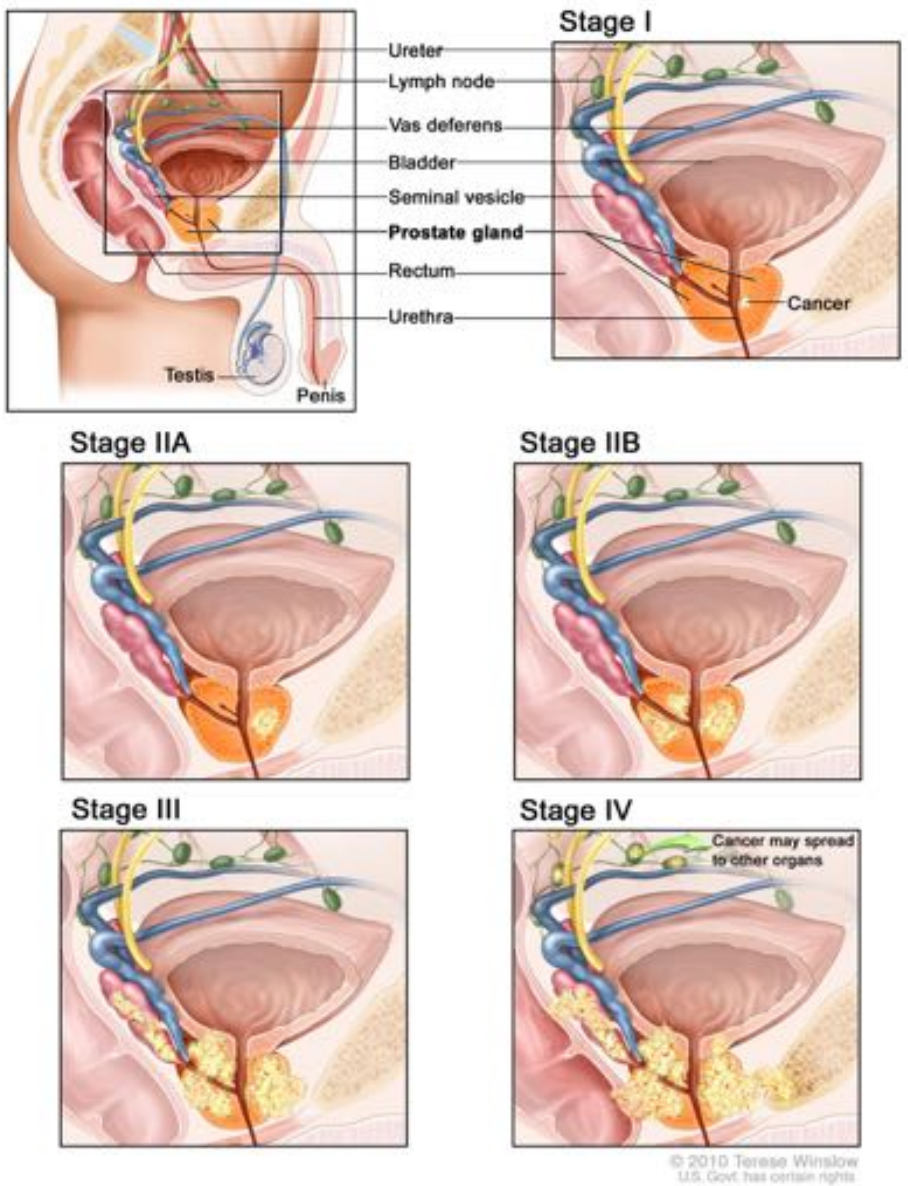


Prostate Cancer

- In the US, 220,000 men are diagnosed with Prostate cancer.
- 80% of prostate cancer patients have localized cancer, Stage I, cancer.
- Prostate cancer is slow glowing disease.
- 5 year survival rate of localized prostate cancer is 100%.



SEER 18 2006-2012, All Races, Males by SEER Summary Stage 2000

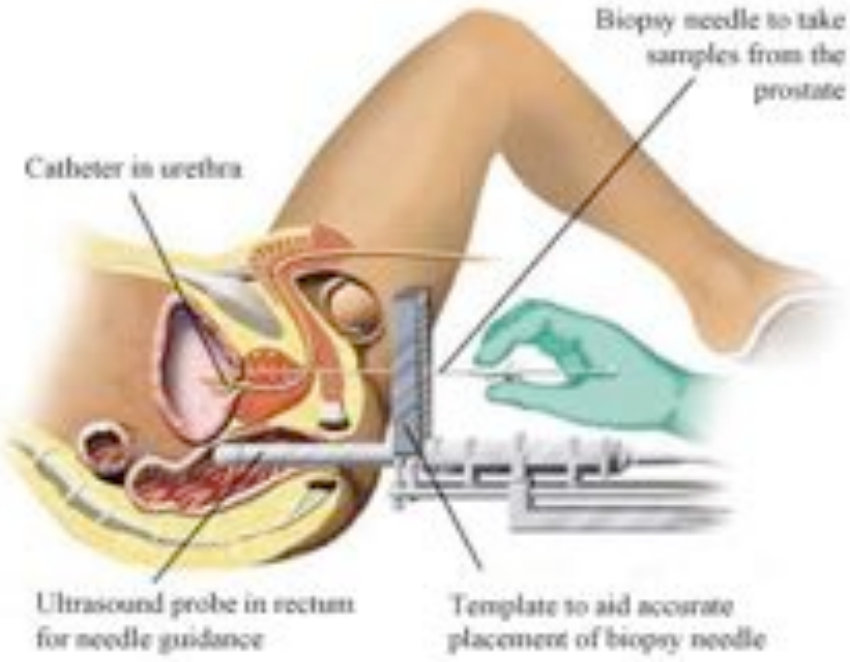
Treatment options for localized Stage I prostate cancer

- Watchful waiting.
- Active surveillance. If the cancer begins to grow, hormone therapy may be given.
- Radical prostatectomy, usually with pelvic lymphadenectomy. External-beam radiation therapy.
- Internal radiation therapy with radioactive seeds.

Biopsy is crucial part of staging and making treatment decisions

Today's Standard Transrectal Ultrasound Prostate Biopsy Misses 25% of Significant Cancers

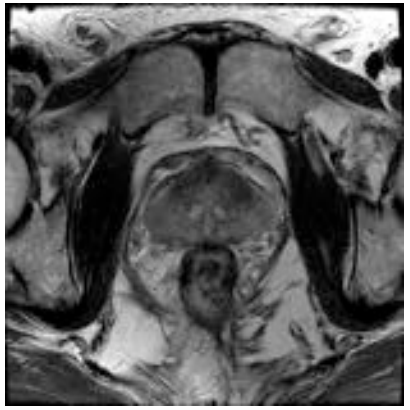
- Standard Transrectal Ultrasound biopsy procedure is inadequate because:
  - 6-12 locations are "blindly" sampled
  - High incidence of false negative results drives 31% repeat rate
  - Can cause serious complications
  - Low detection of tumors in prostate apex

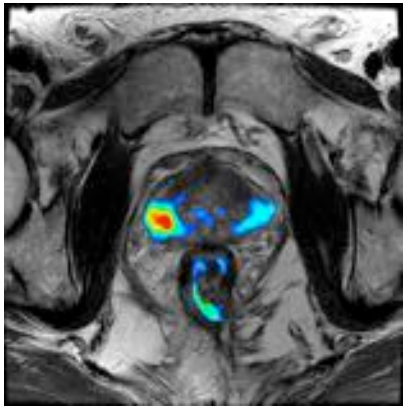


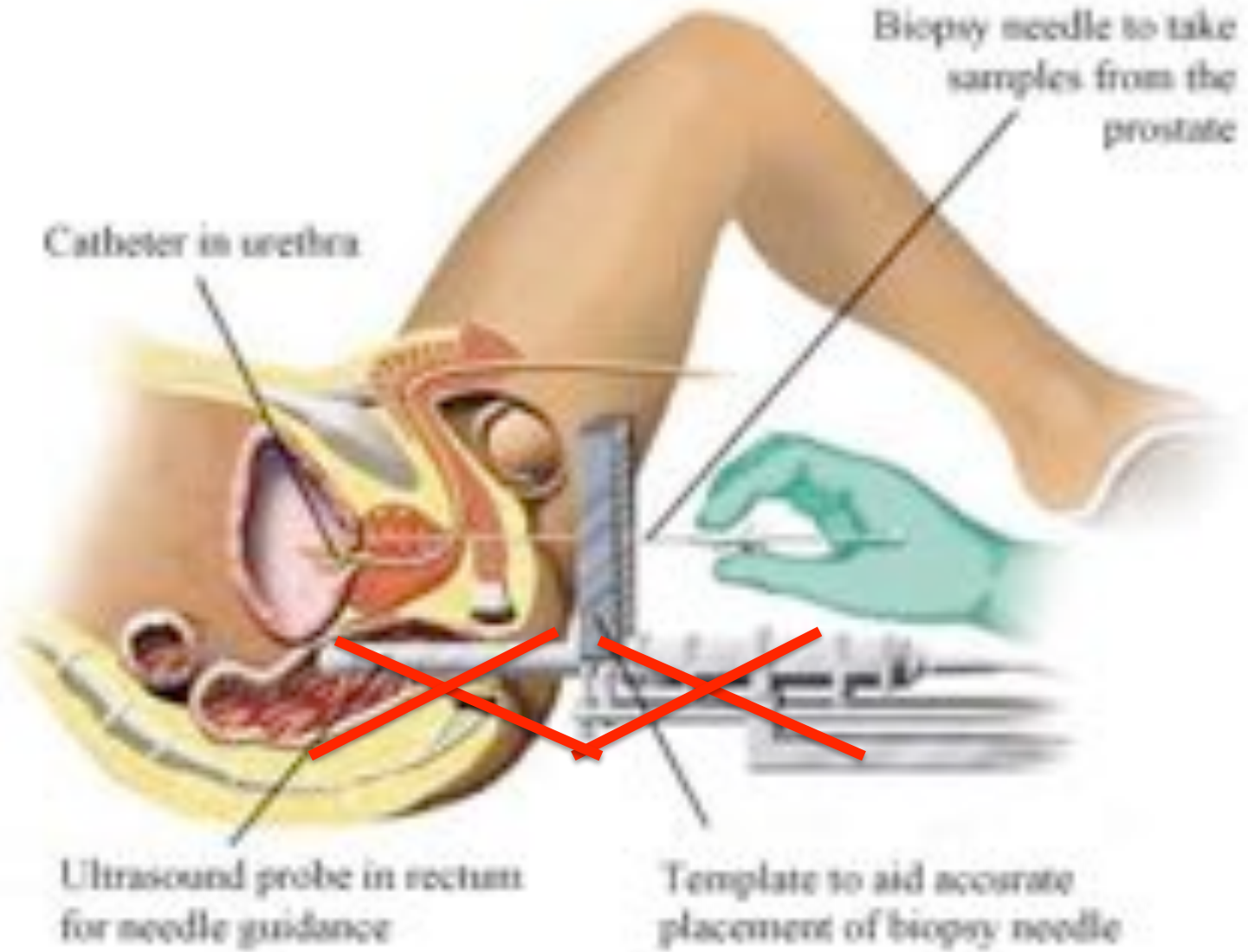
AUA

MRI and MRI-guided biopsies

- MRI of prostate can detect clinically significant cancers [Barentsz 12]
- MRI localizes prostate cancers better than digital exam and blind biopsy [Mullerard 05]
- Why not use MRI for guiding biopsy?



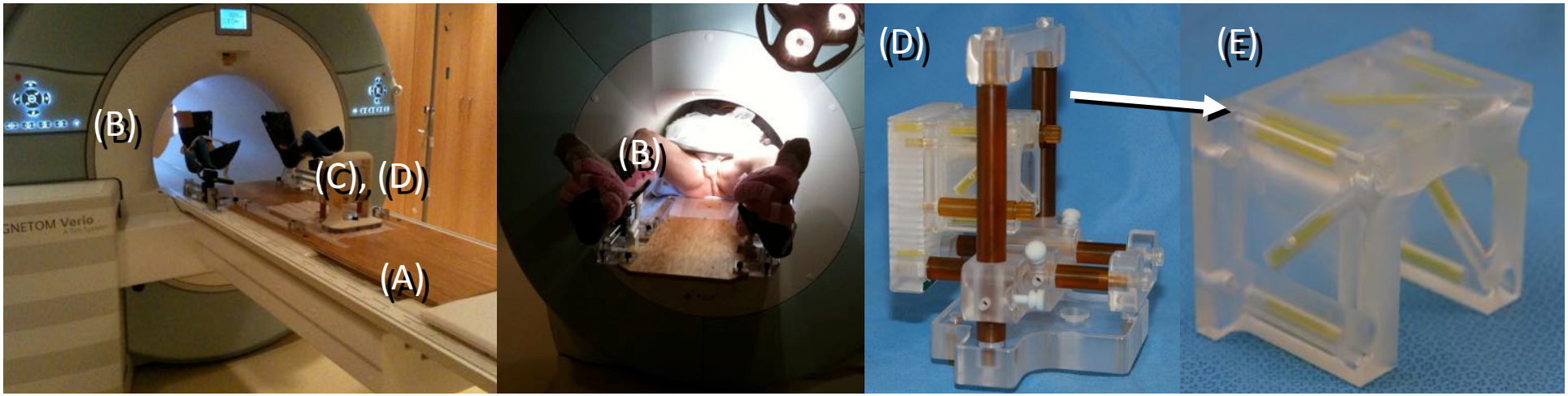



Biopsy needle to take samples from the prostate
Catheter in urethra
Ultrasound probe in rectum for needle guidance
Template to aid accurate placement of biopsy needle

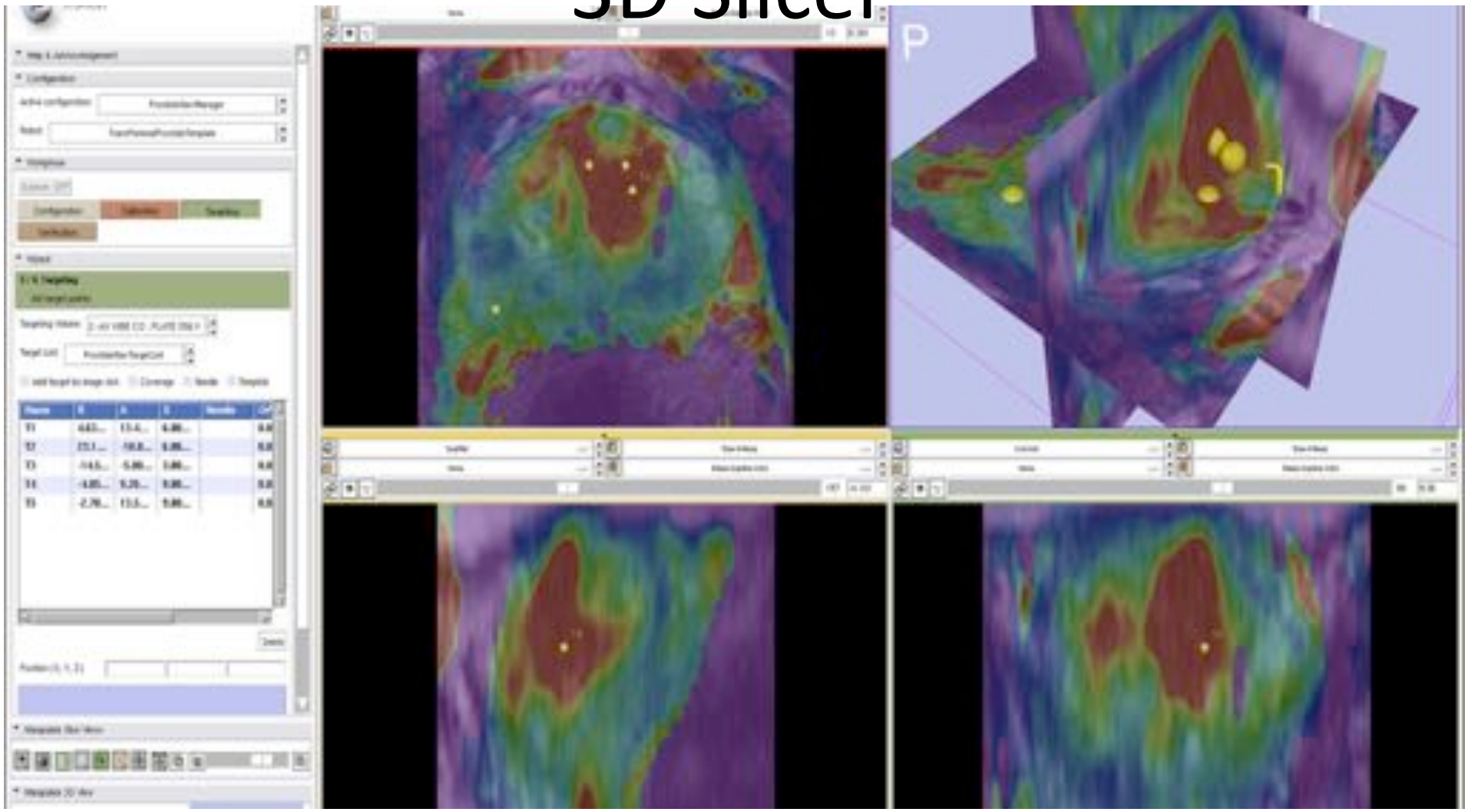
AUA

Prostate Intervention Tools

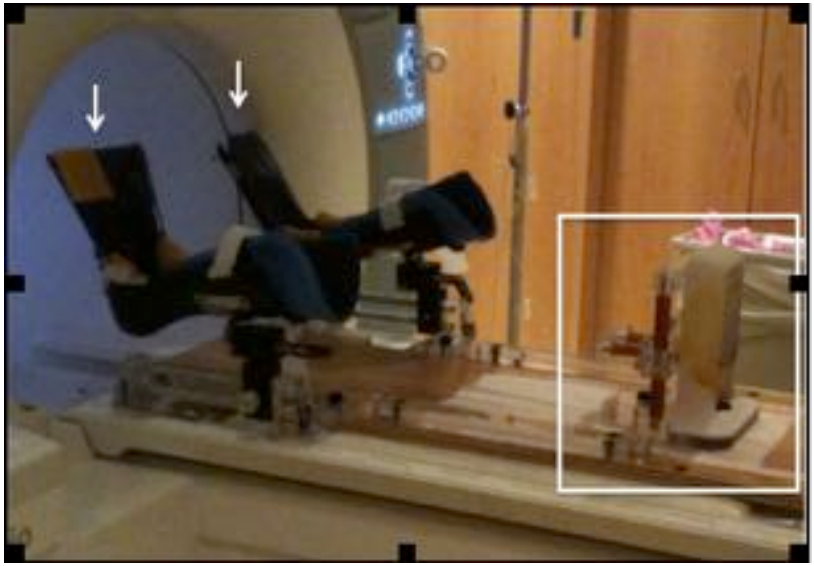
(A) Base board
(B) Leg support
(C) Stationary frame
(D) Template (plexiglas)
(E) “Z-frame”



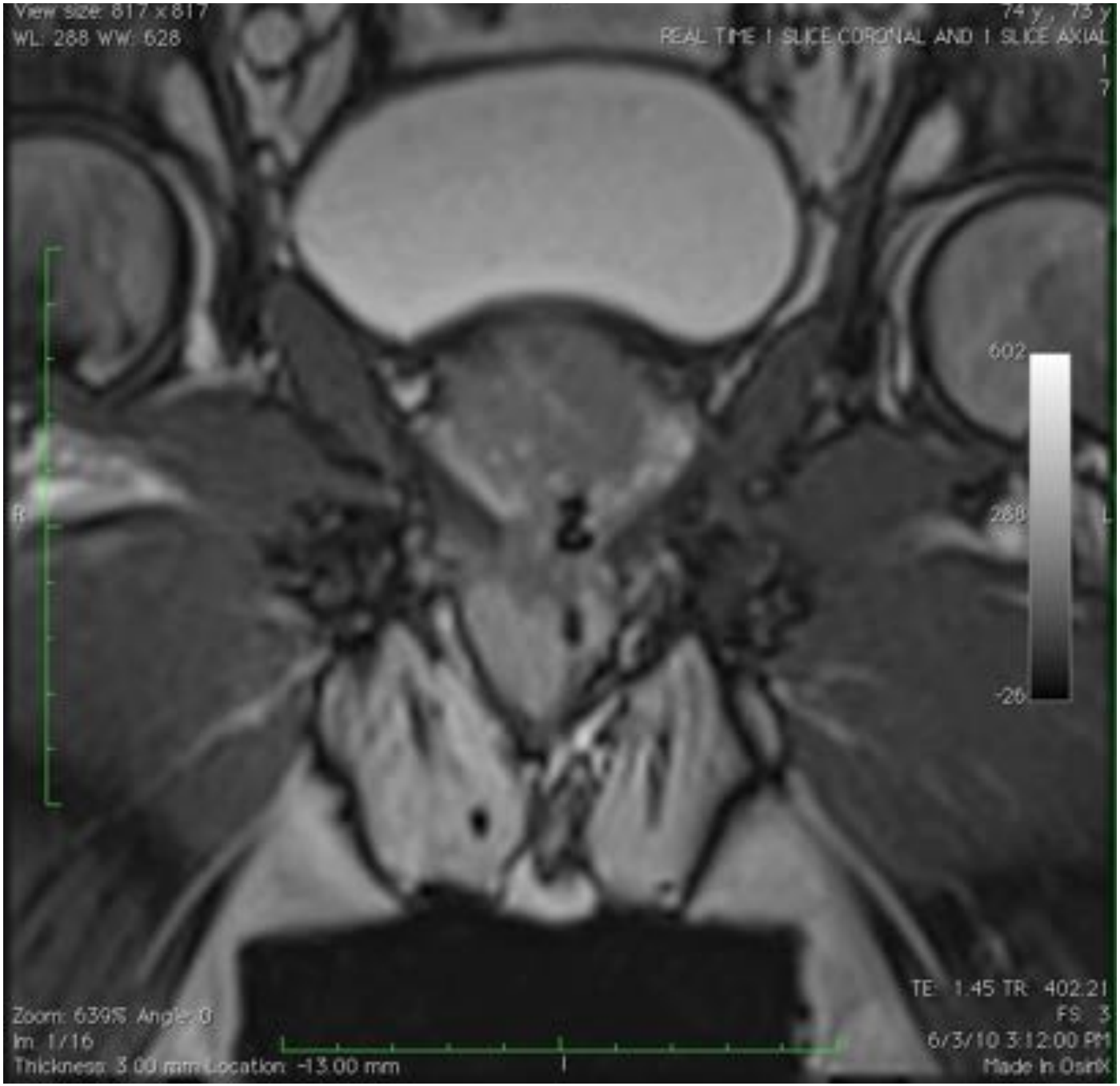
3D Slicer



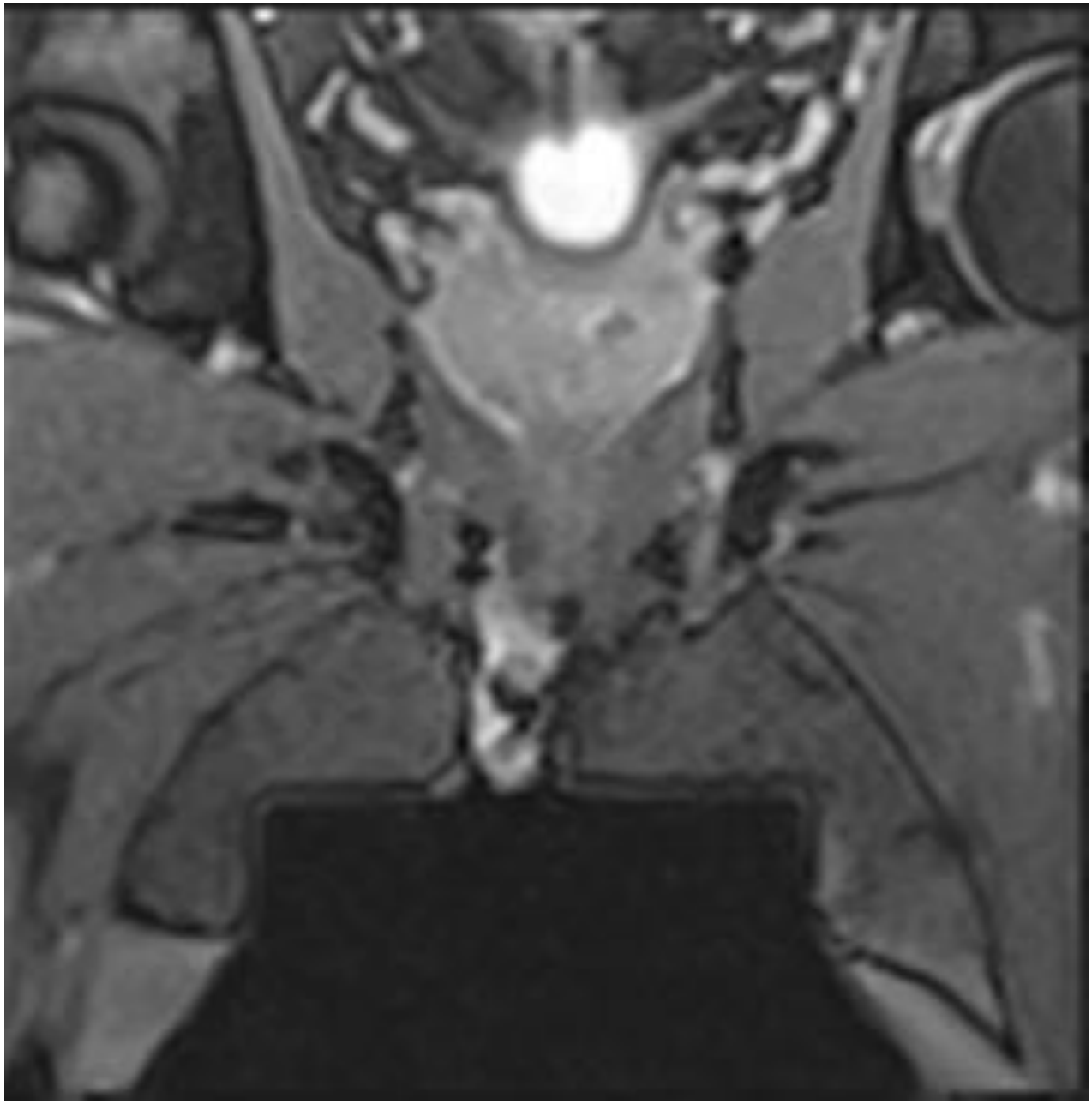
Tempany et al



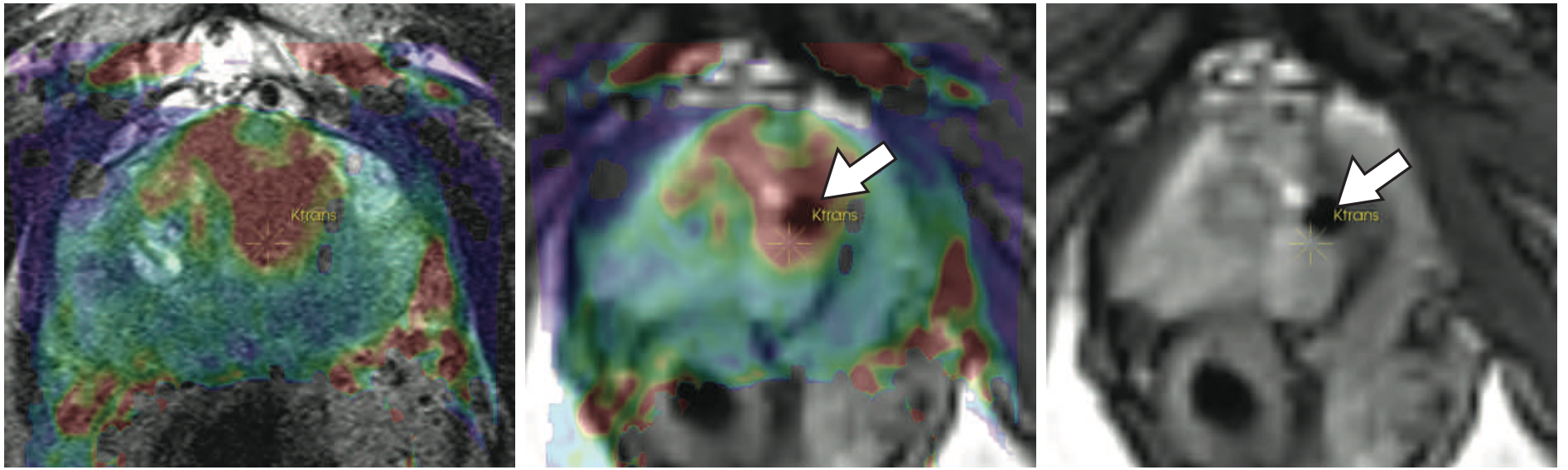
Tempany, Song, Tokuda, Kacher, Iordachita, Fairhurst, Kanan, Tuncali



Tempany et al



Tempany et al

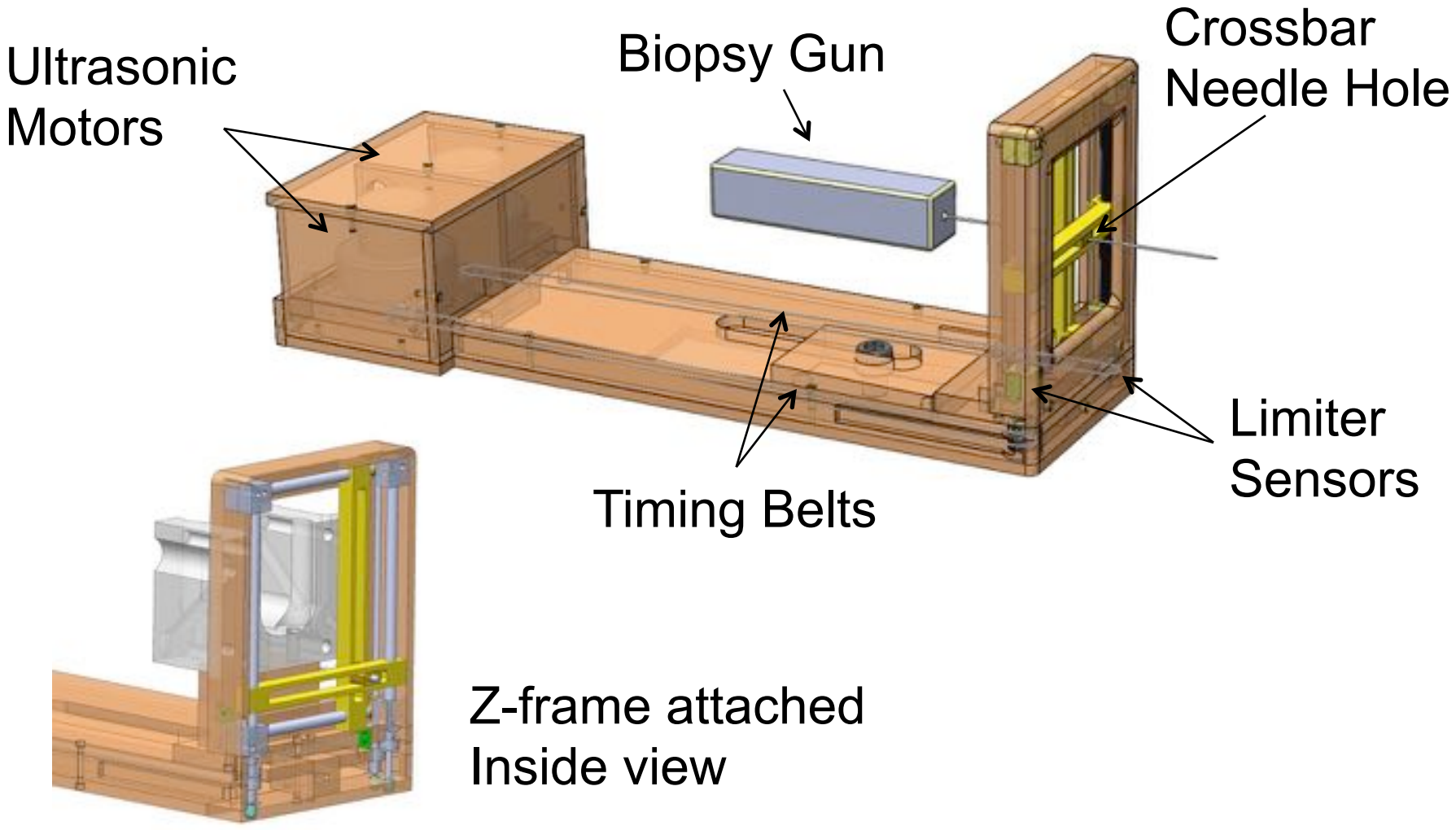


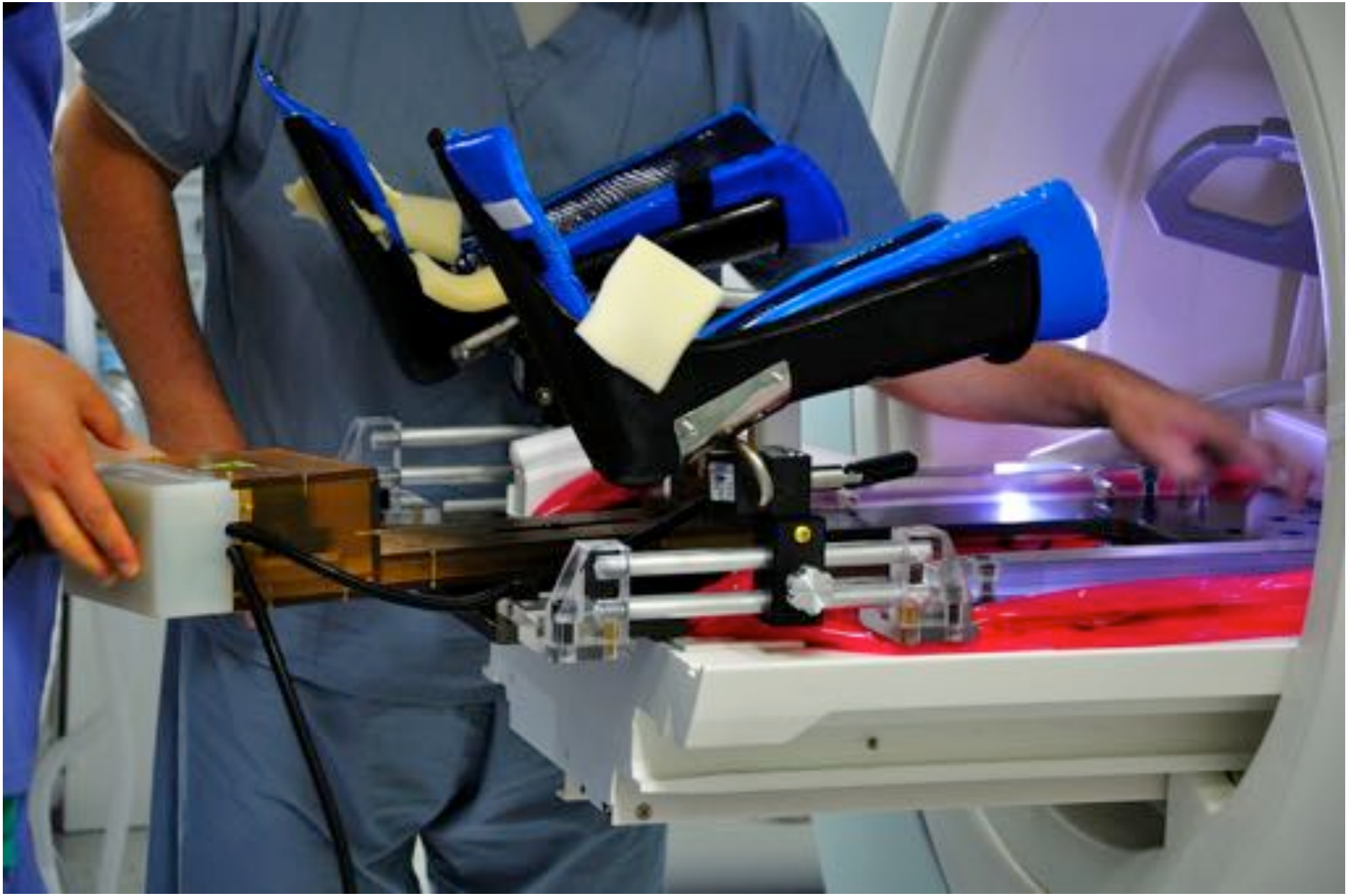
Tempany, Fennessy, Tuncali

Smart Template

Song, Tokuda, Tuncali, Tempany

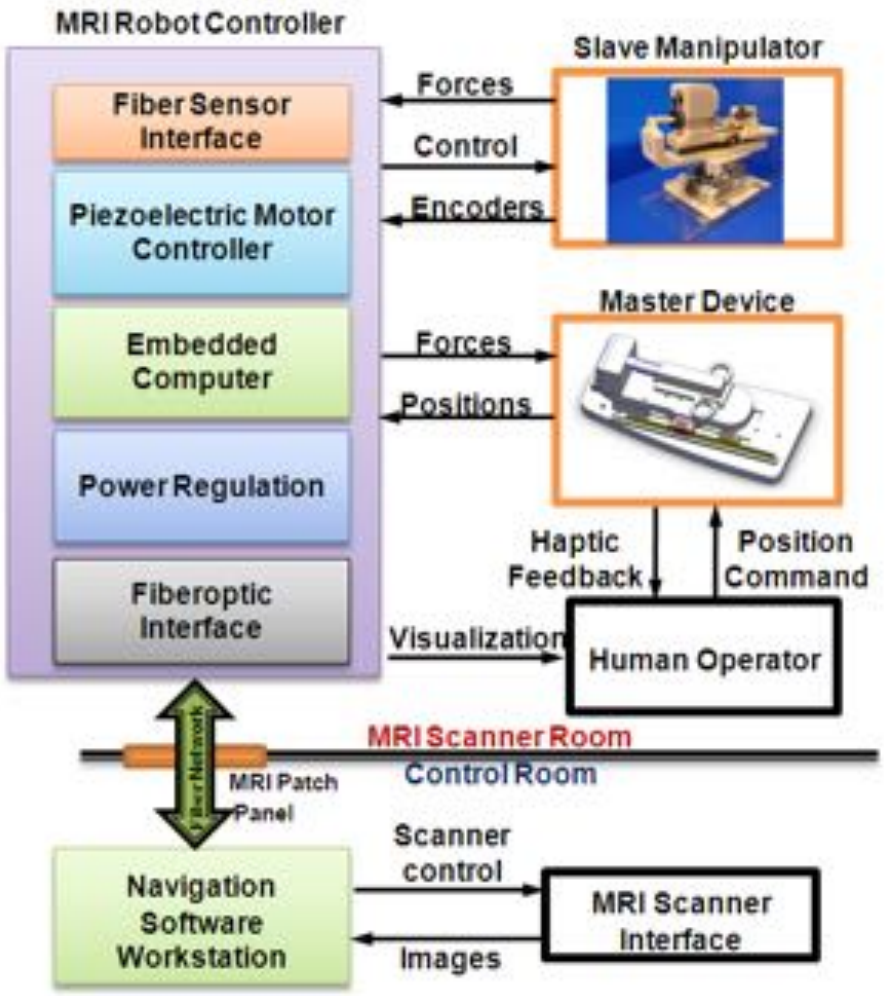
Smart Template Design

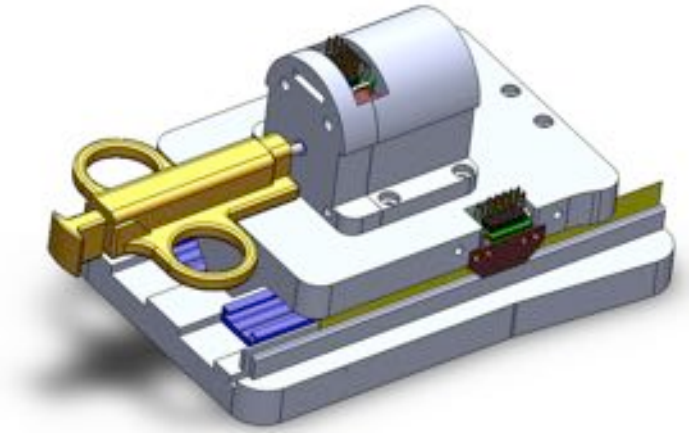


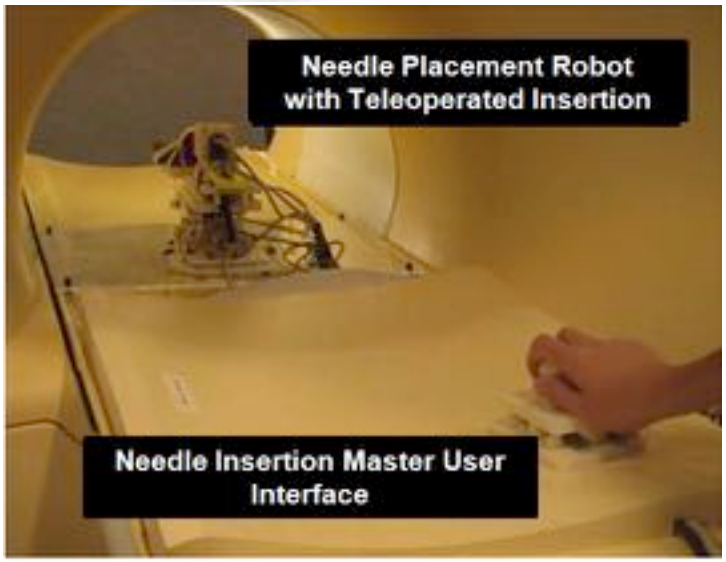


Teleoperation to Control Robotic Insertion

Greg Fischer, WPI

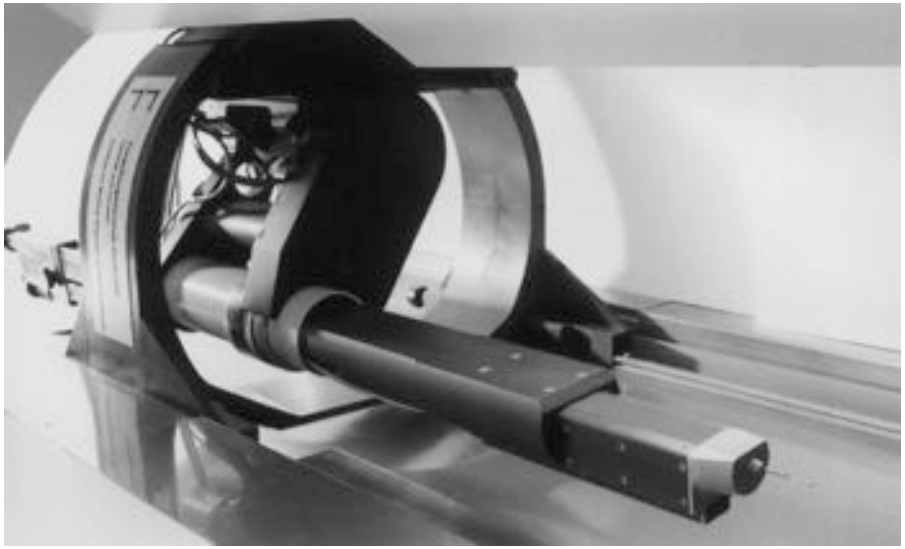


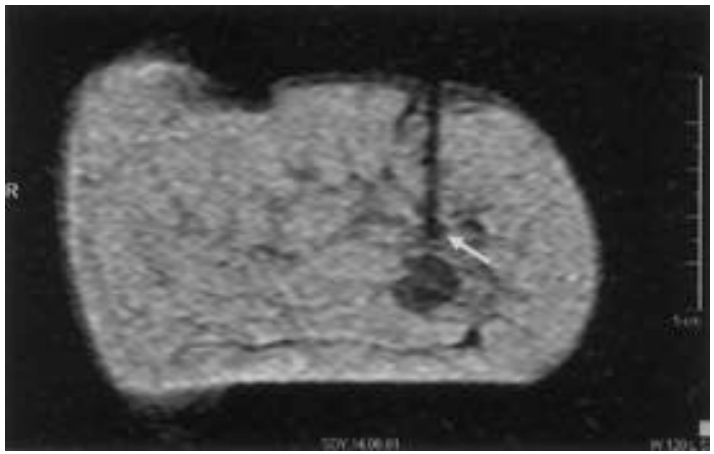




ROBITOM, University of Jena

- Kaiser Fischer et al 2000
- Pfleiderer et al 2008
- Breast biopsy
- 1.5T scanner
- 14 cases tested

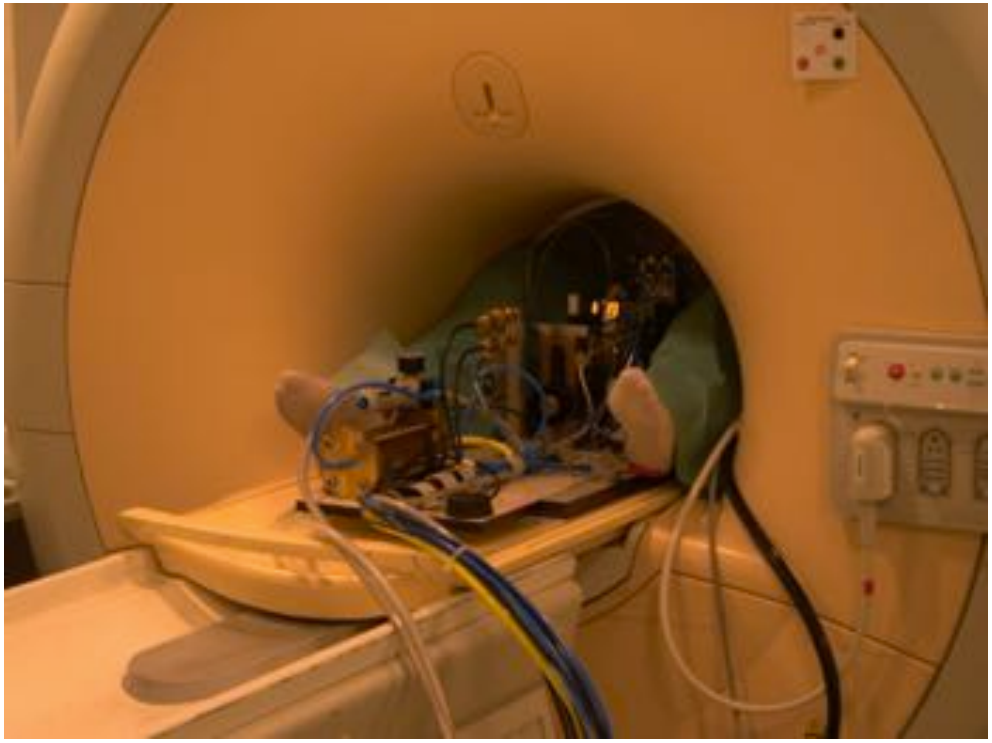




Pfleiderer et al 2008

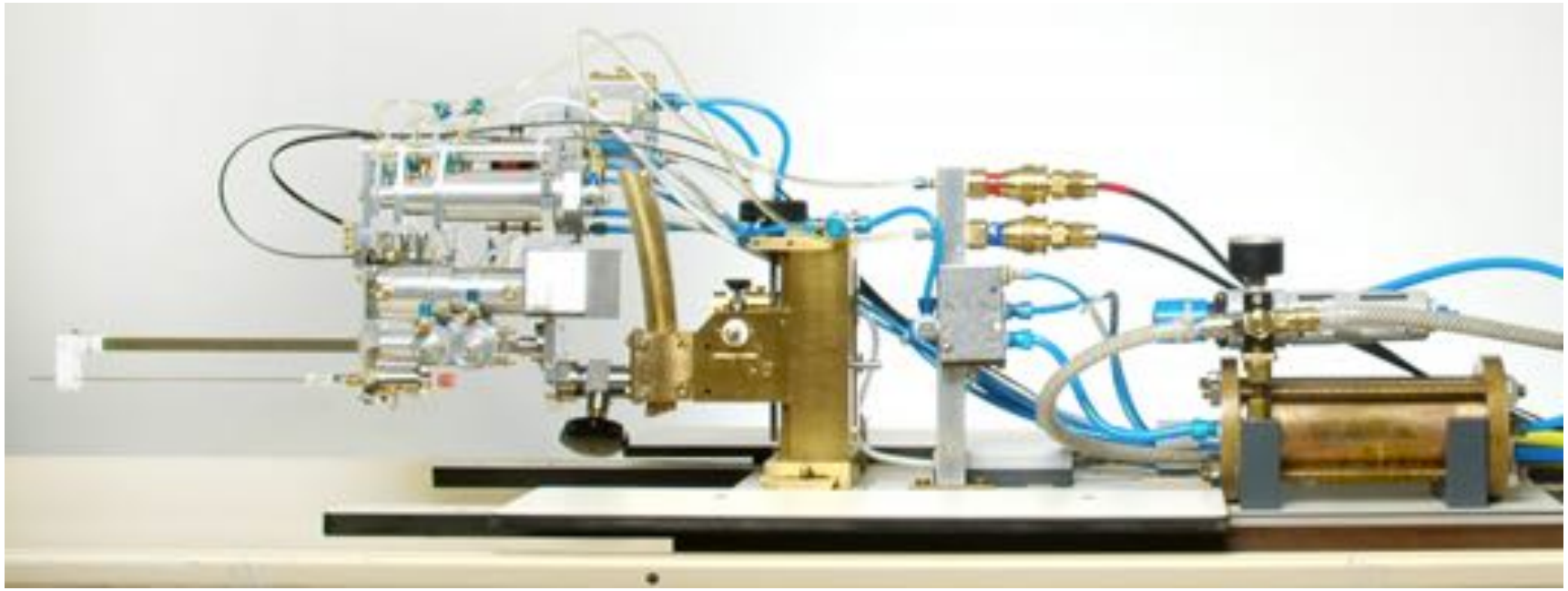
Utrecht Prostate Robot

- 1.5T
- van den Bosch 2010
- Deliver fiducial gold markers inside prostates of patients eligible for external beam radiotherapy treatment (EBRT)



Utrecht Prostate Robot

- "The robot *tapped* the needle stepwise towards this position while controlling the step size (typically 5 mm) and the needle depth."
- "During the tapping fast 2D MR scans were acquired to track the needle trajectory on-line and to independently monitor the needle depth"



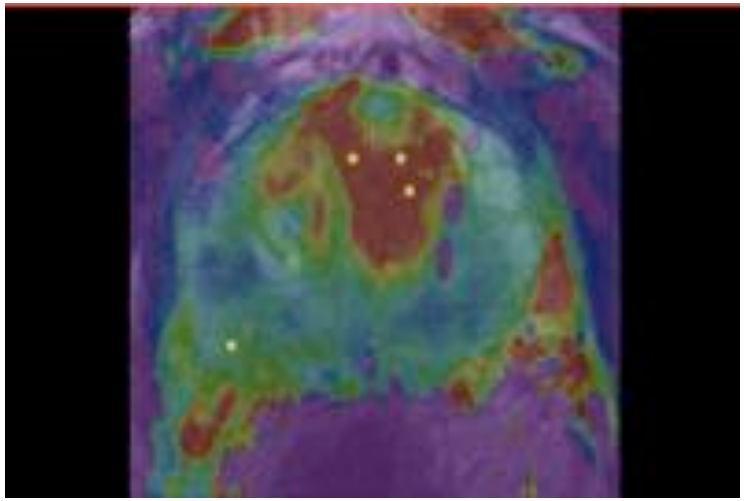
Questions?

Fundamentals of Robotics in IGT

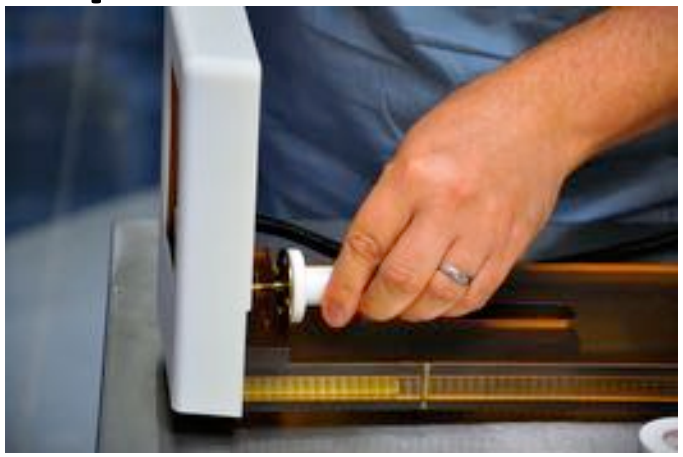
Design consideration

- Disease and anatomy
- Procedure (approach, medical tools, anesthesia)
- Metric for clinical success
- Participants in the procedure
- Workflow
- Devices involved

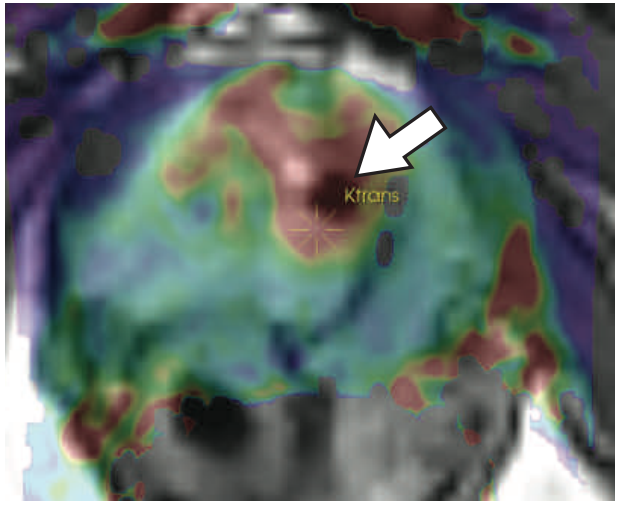
Technical Components



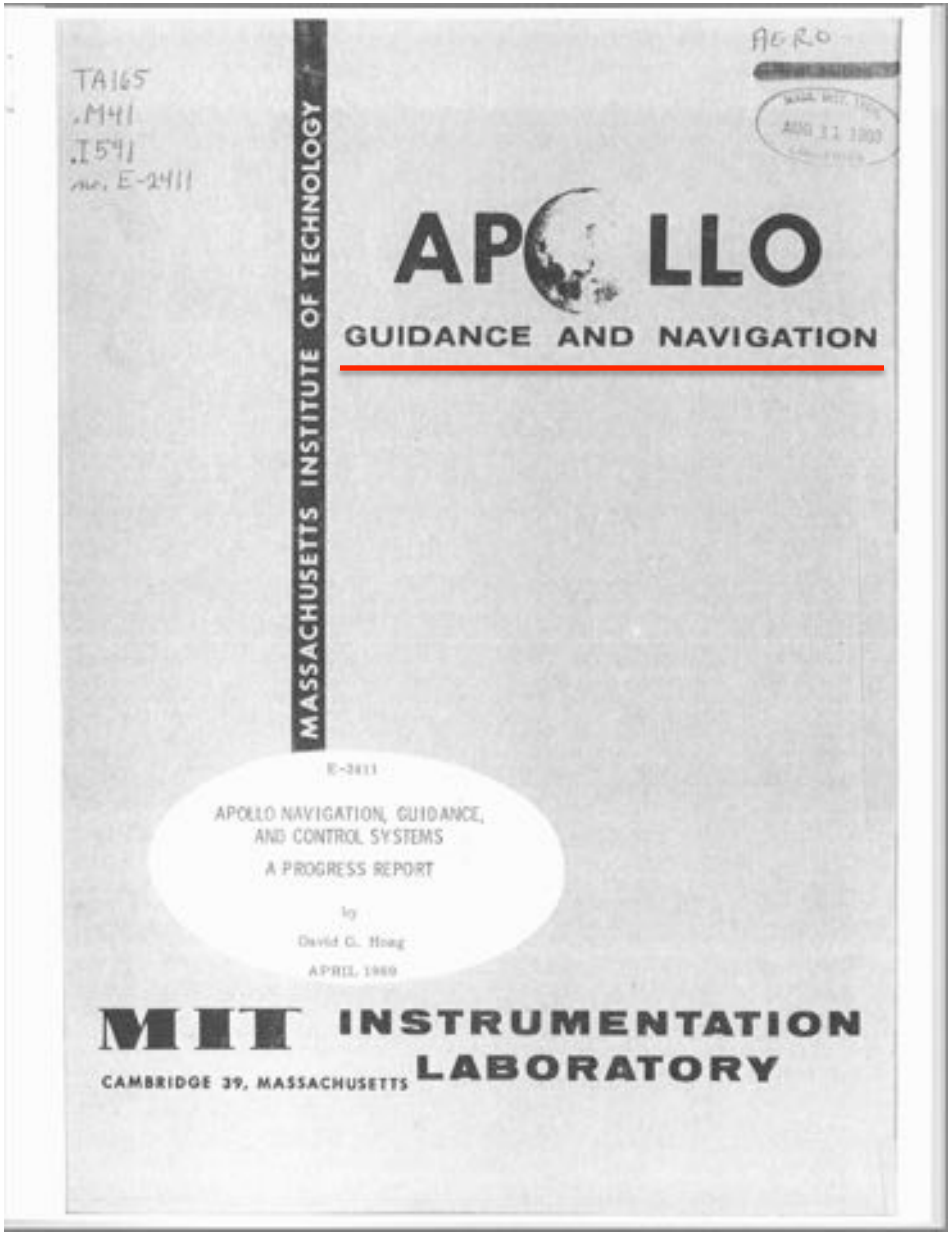
Targeting

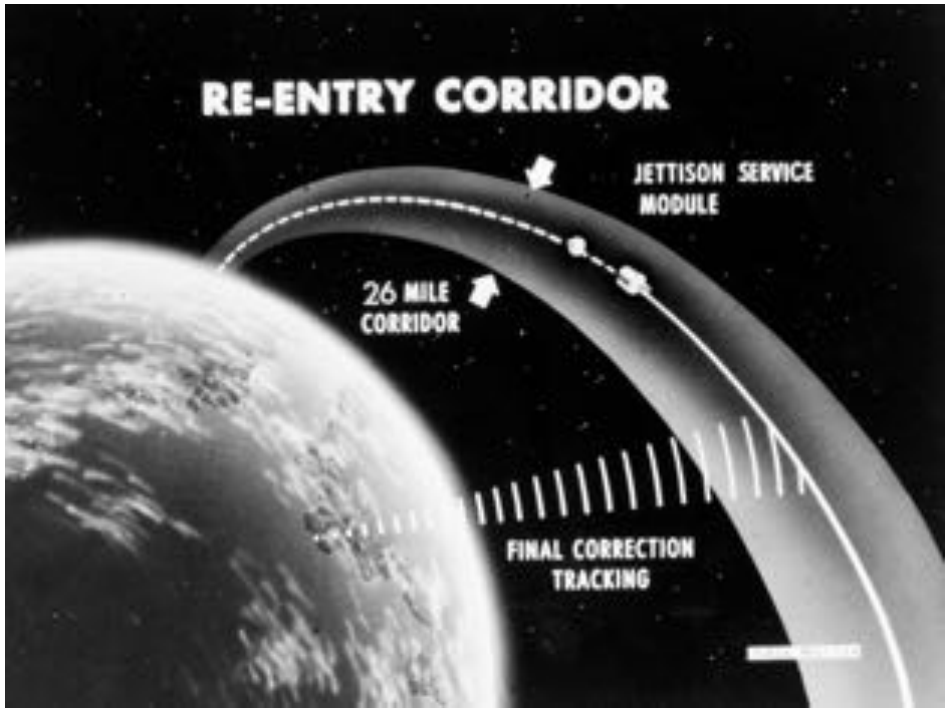


Navigation and Control



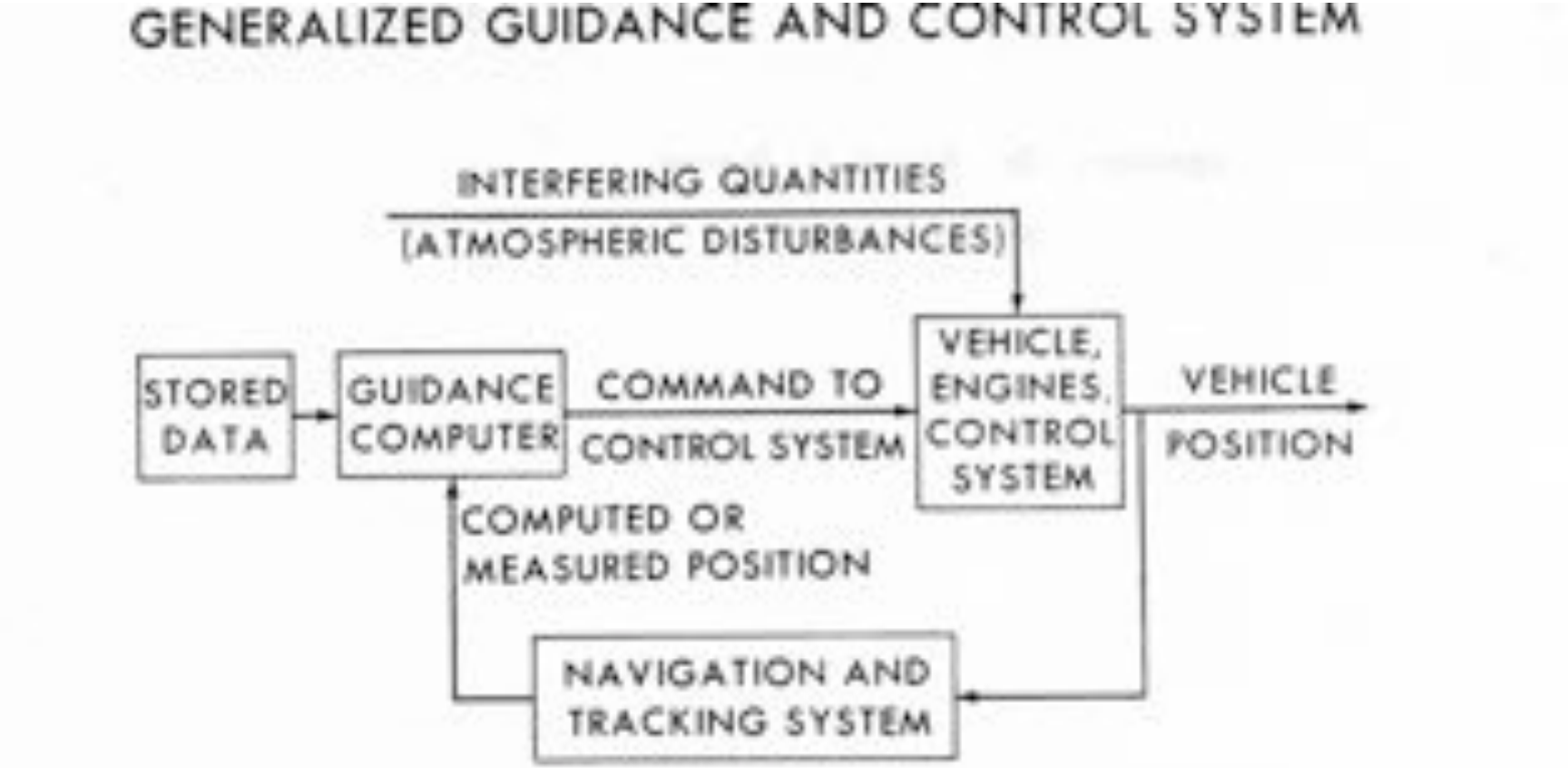
Monitoring





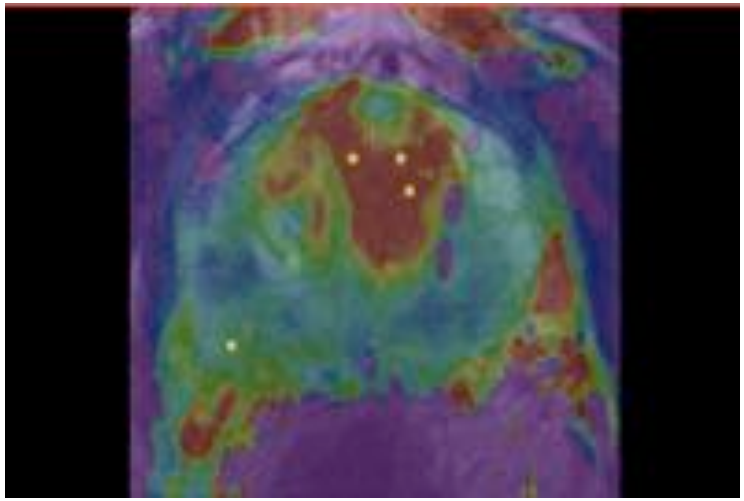
Roles of robotics can be best described using space technology as analogy.

Guidance, Navigation and Control

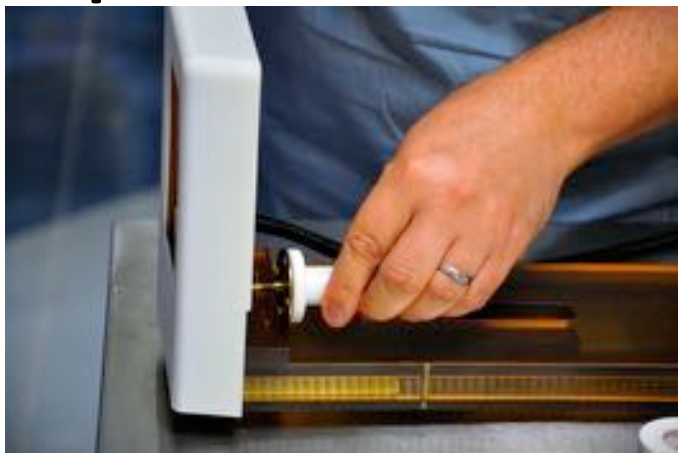


Charles Stark Draper and MIT Draper Labs (1969)

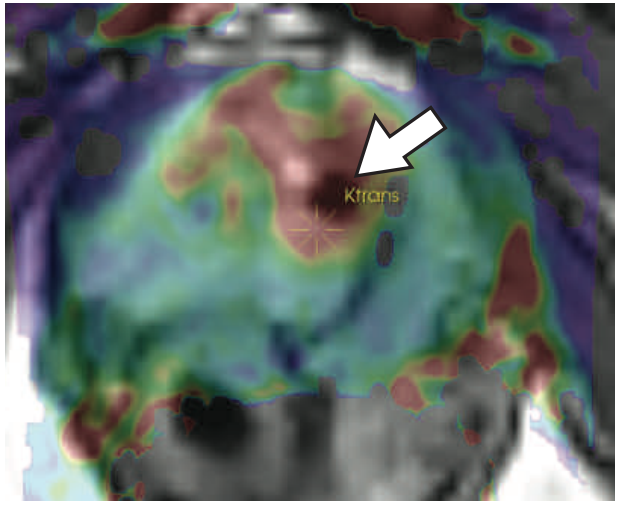
Technical Components



Targeting



Navigation and Control



Monitoring

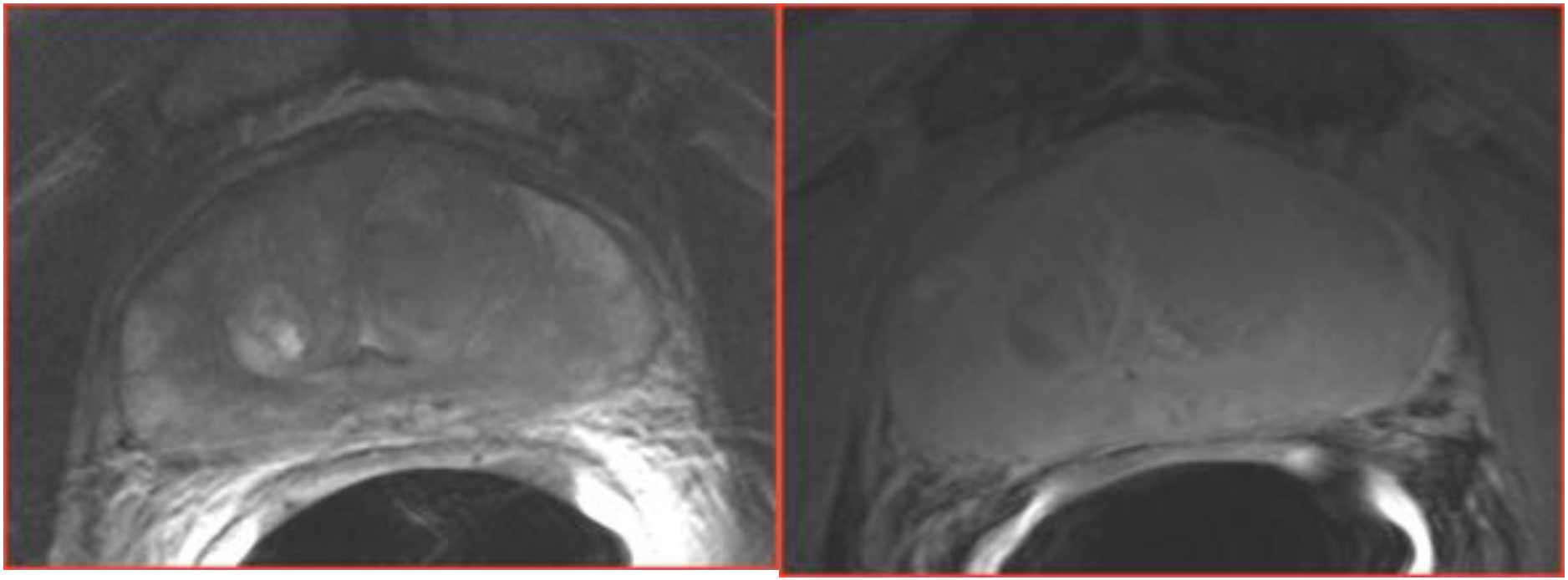
Enabling engineering methods in Image Guided Therapy

- Imaging
- Graphics
- Control

- Tracking/Guidance/Navigation in action (demonstration)
- Image processing (demonstration)
- Vision -> motion compensation and detection
- Registration
  - Registering a device to images

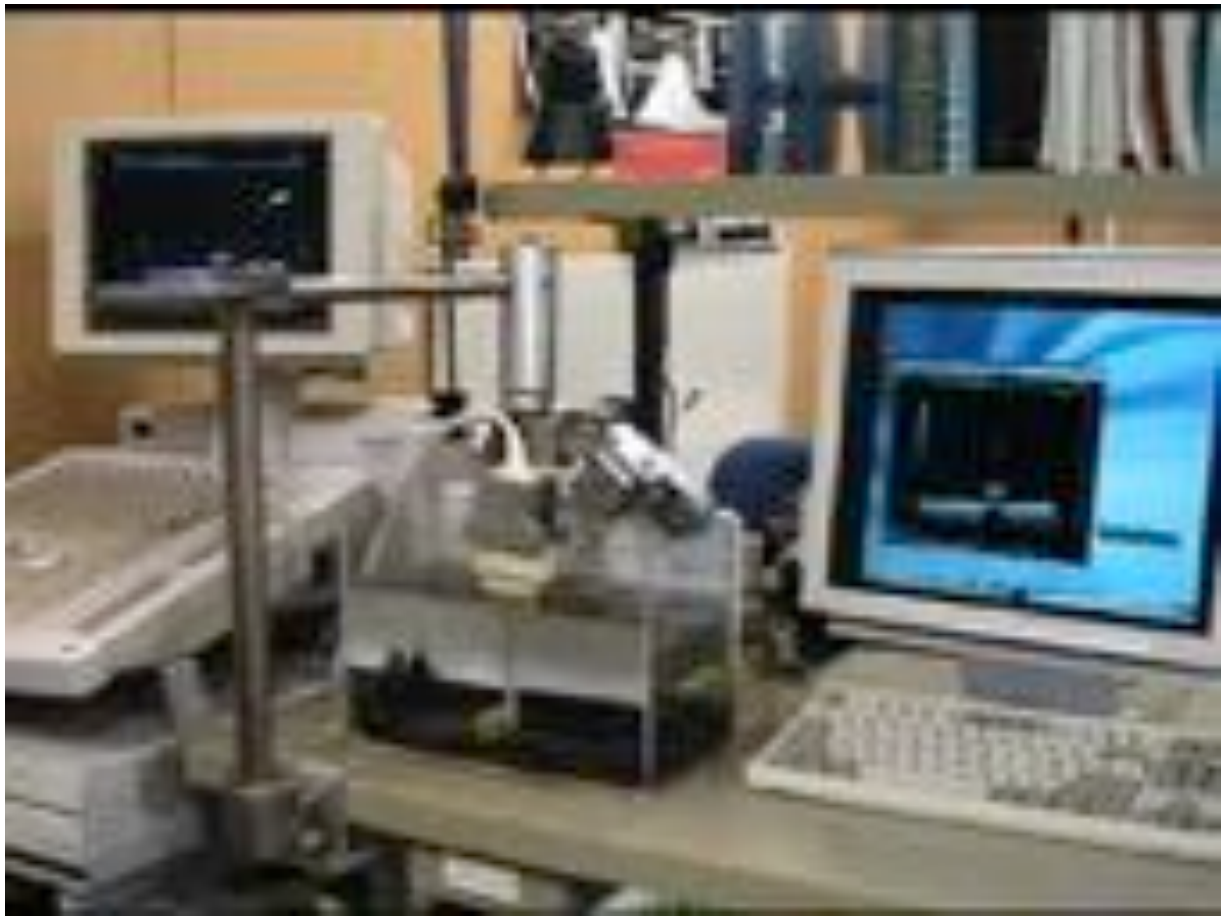
Slicer IGT Demonstration

Image Processing
Deformable Registration of Pre- and Intra-procedural Images



BrainsFit Module in 3D Slicer
Rigid, Affine, B-spline deformable registration
Federov et al, ISMRM 2011

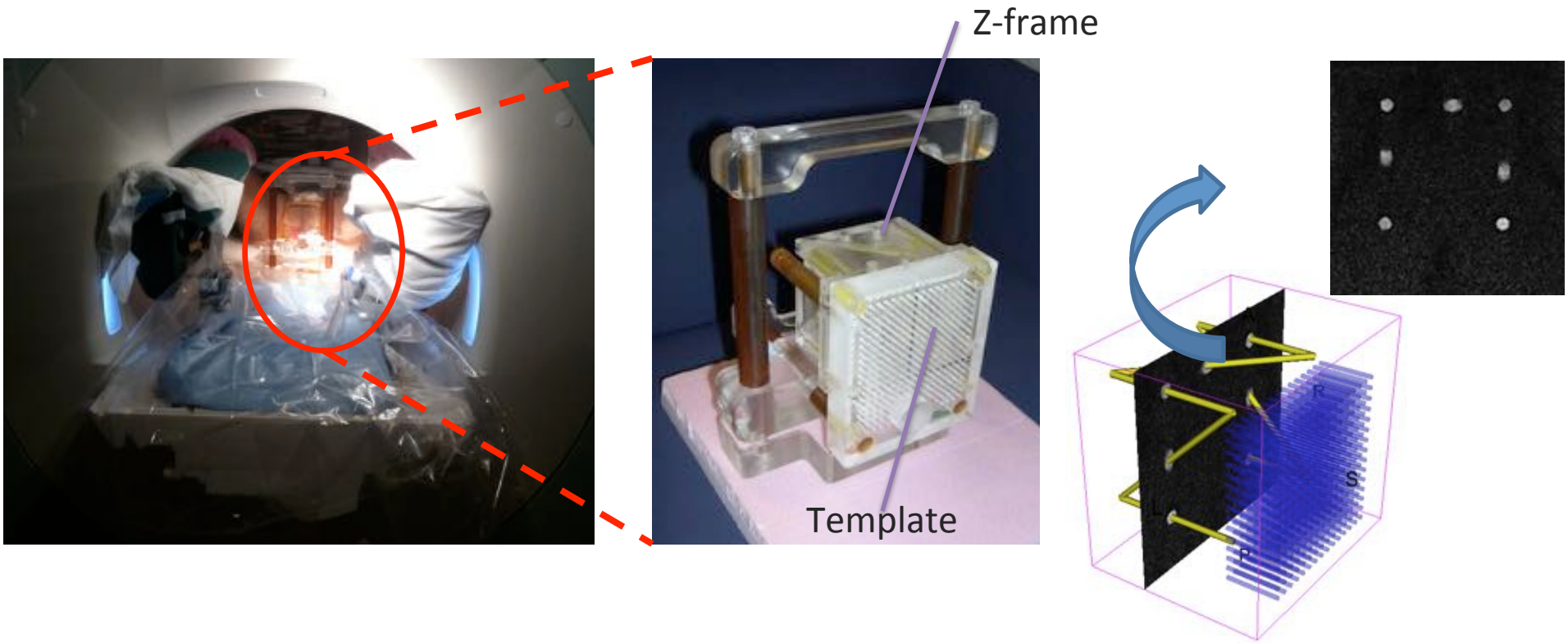
Vision- Image-based Motion Adaptive Instrument



Hong J, Hata N, et.al.,*Phys Med Biol*, 49(3), 441-455, 2004

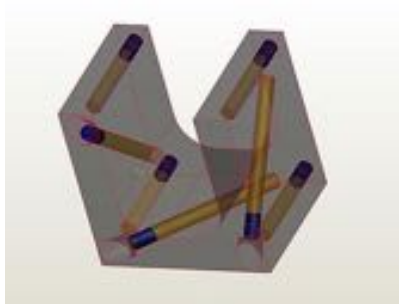
Tool to image registration

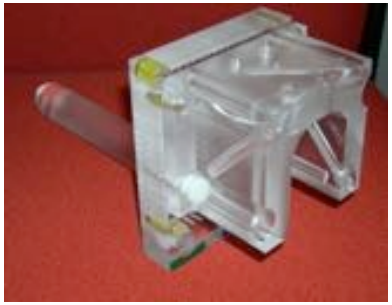
- Mandatory to use devices and robots in IGT
- To register the template guide's coordinate system to images
- Often disruptive to clinical workflows



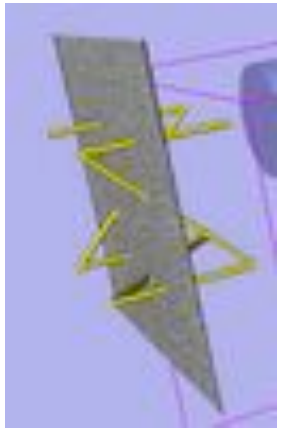
Design consideration

- Disease and anatomy
- Procedure (approach, medical tools, anesthesia)
- Metric for clinical success
- Participants in the procedure
- Workflow
- Devices involved

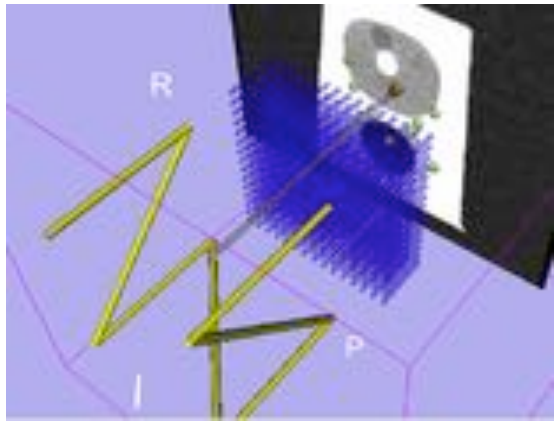




MRI scan



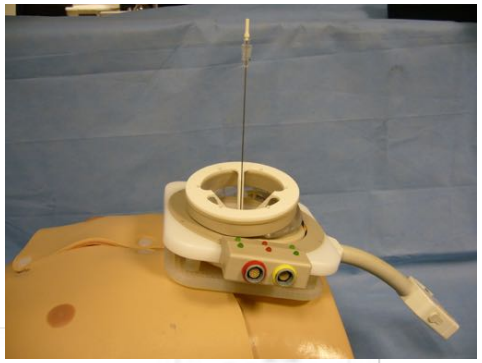
Registration
MRI vs. design
model



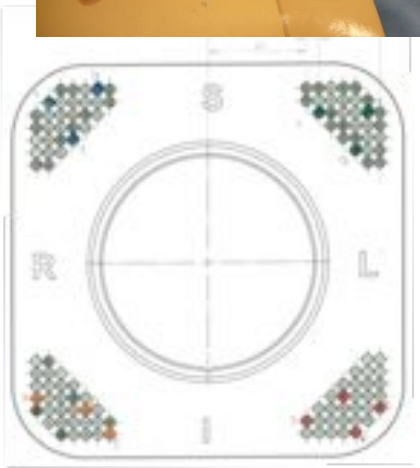
Temlpate and
MRI registered

DiMaio et al

Registration for abdominal robot



Fiducials in Σ_{IM}
(T1-weighted MR Image)



Fiducial frame

Physical Device

Σ_{IM}

T_{IM}^{R}

T_{IM}^{F}

Σ_{F}

Σ_{R}

T_{F}^{R} (known)

Image Guided Therapy Market Segments: Not Independent Silos, the Boundaries are Blurring…

Image Guided Surgery: $1.4 Billion

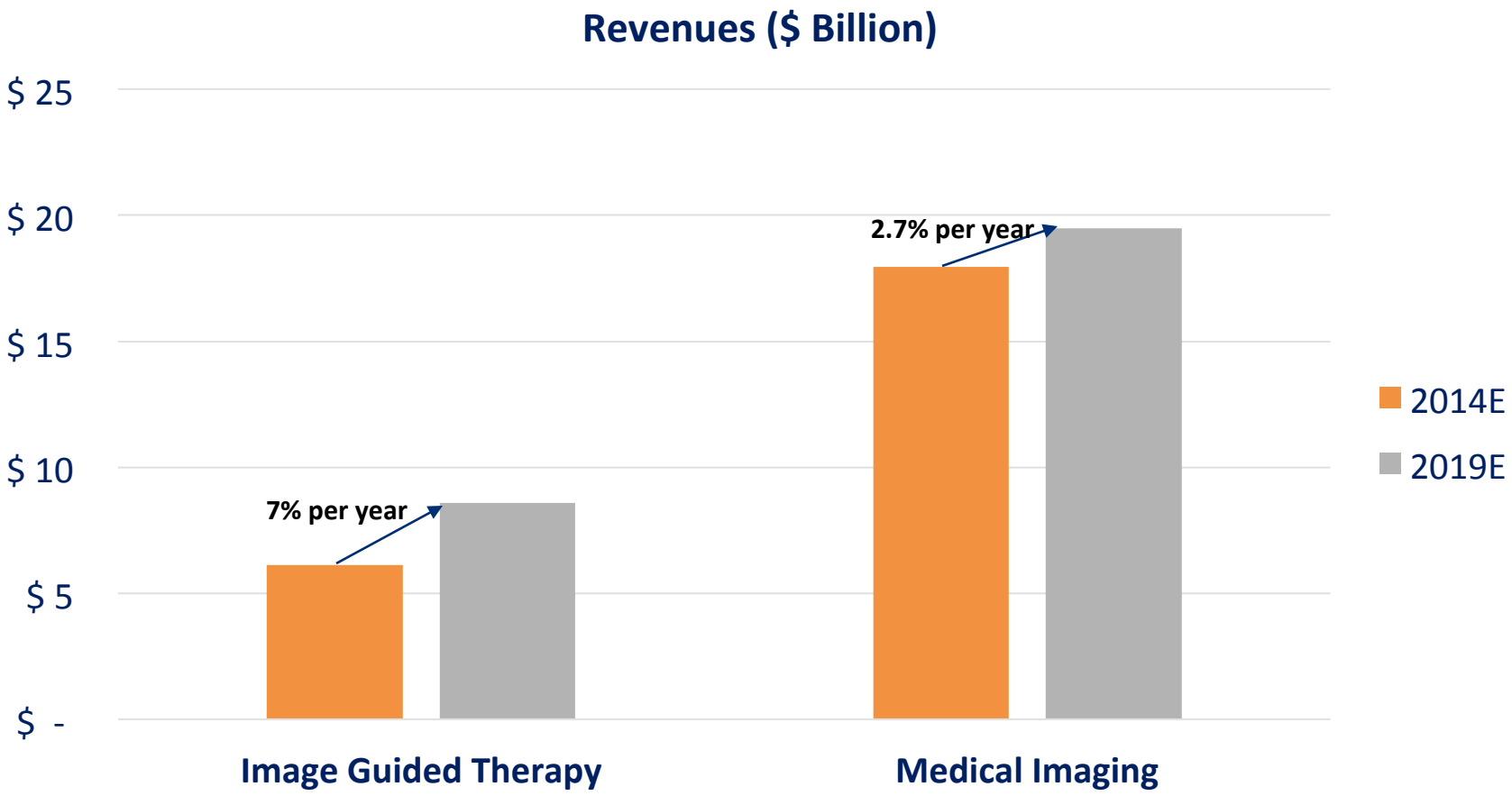
Robotics Assisted Surgery: $2.6 Billion

Robotic Radio Surgery: $560 Million

Navigation Systems: $1.6 Billion

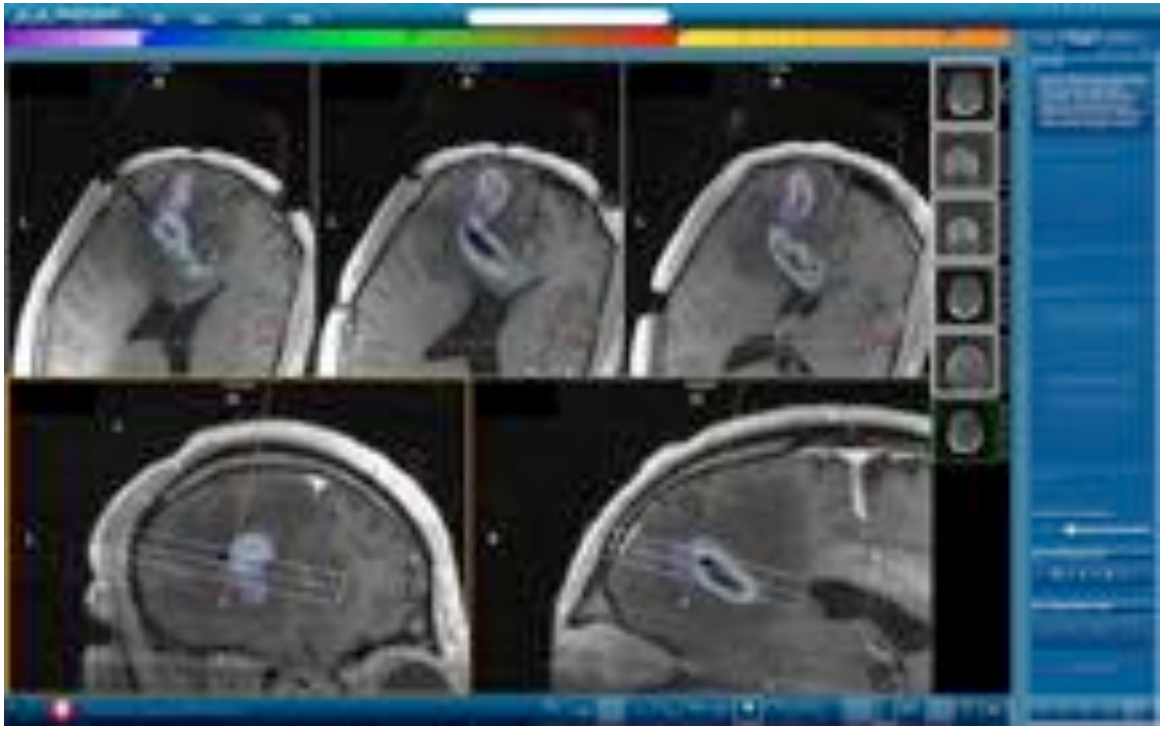
Frost & Sullivan 2014 Estimates for U.S., Western Europe, and Asia

Image Guided Therapies are Growing > Twice as Fast as Medical Imaging Market

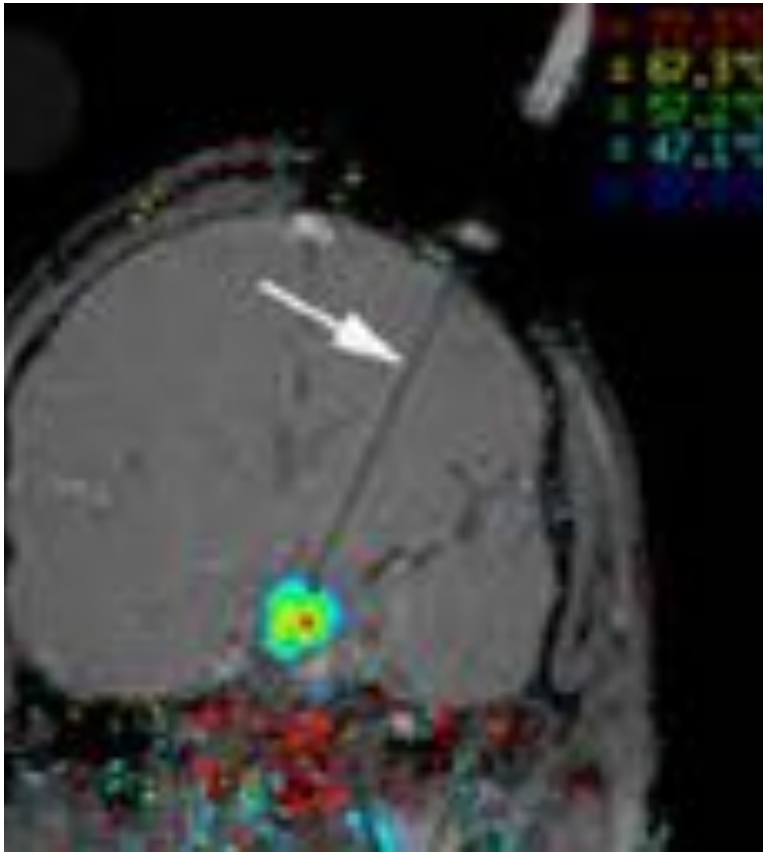


Market: U.S., Western Europe, and Asia (excluding China and India)
Source: Frost & Sullivan

Monteris



Visualase MRI-guided laser ablation of brain tumor and epilepsy



- 1999-2007
  - SBIR grant from the NIH
  - Over $7.2M in NIH and state grant funding
  - $9.4M in private investments
- 2006
  - First in man study
- 2007
  - The device received FDA 510(k) clearance for neurosurgery
  - then general surgery and urology
- 2014
  - the company was acquired by Medtronic for up to $105M

Conclusion - Image Guided Therapy

- Provides significant benefits for healthcare systems and patients
  - reduced patient trauma
  - shorter recovery times and hospital stays
  - lower costs from fewer medical errors and complications.
- Improves accuracy and efficiency of complex surgical procedures

Real-time intraoperative imaging

- Captures changes in patient anatomy
  - not apparent through pre-operative imaging
- With Robotics, enables physicians to create exact detailed surgical plan
  - the best incision site, the optimal path to the targeted area, and what critical structures must be avoided
- Converts open surgery to minimally invasive procedures
  - offering new alternatives for patients who would have been considered inoperable in the past