Application of Slicer in Prostate Intervention

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Nobuhiko Hata, PhD

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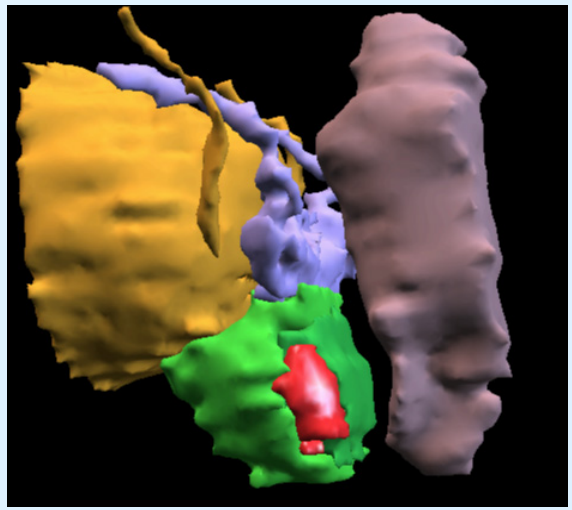
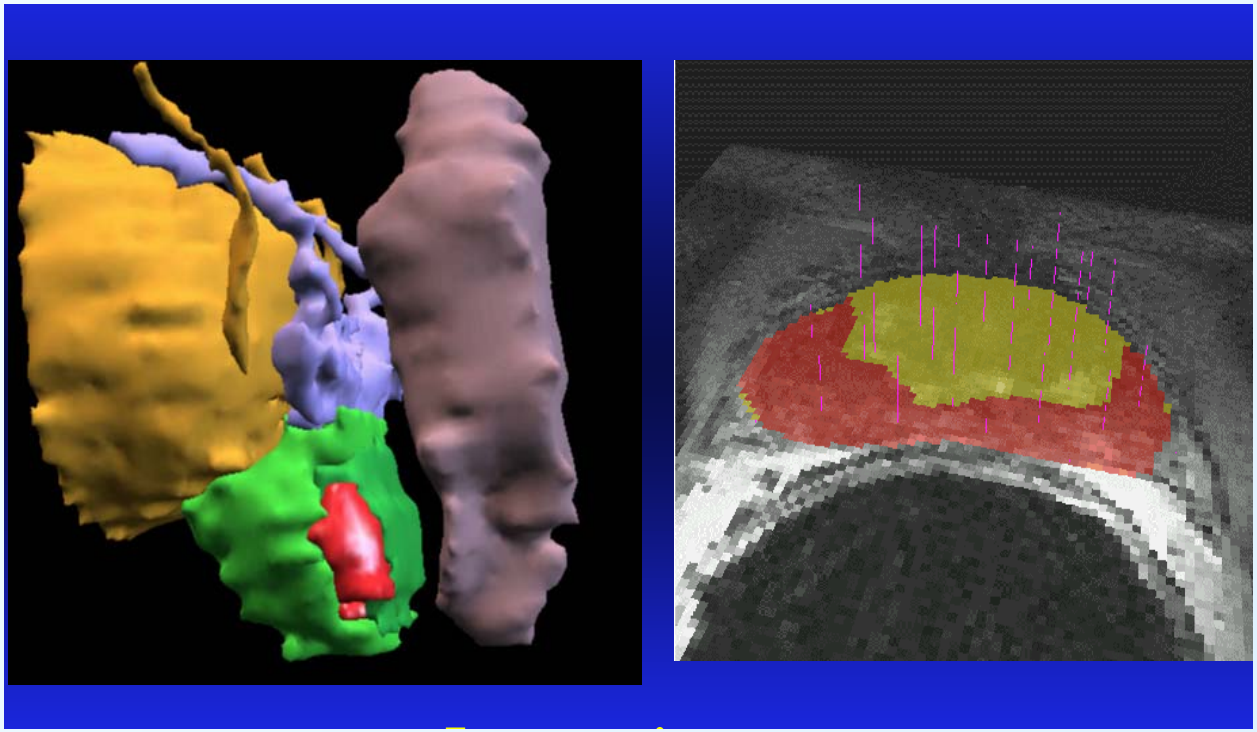


Image guided prostate therapy



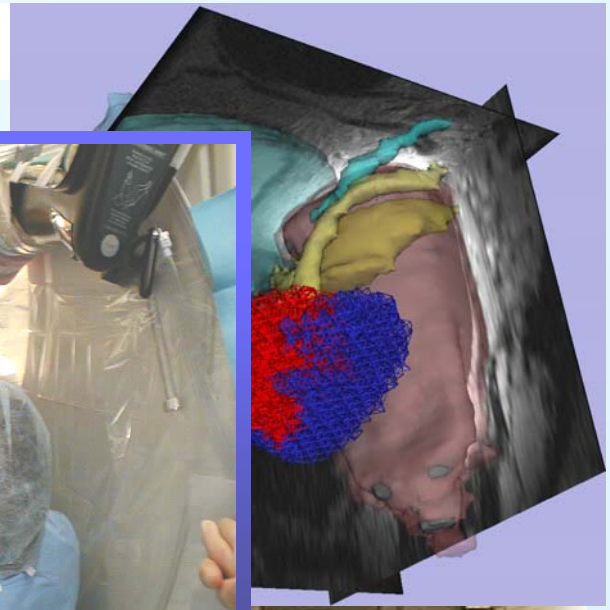
Clare Tempany, M.D.

Prostate cancer: Scope of the problem

- 1.5 million prostate biopsies per year
- 25 million men have had at least one negative biopsy
- 2003- 220,900 New cases were diagnosed
- 2015- 450,000 New cases will be diagnosed
- Approx 4-8% disease specific mortality rate
- How will we improve diagnosis and treat all these patients?
- Ideally
  - Non-invasive, low cost, effective therapy
  - Imaging Dx and Rx

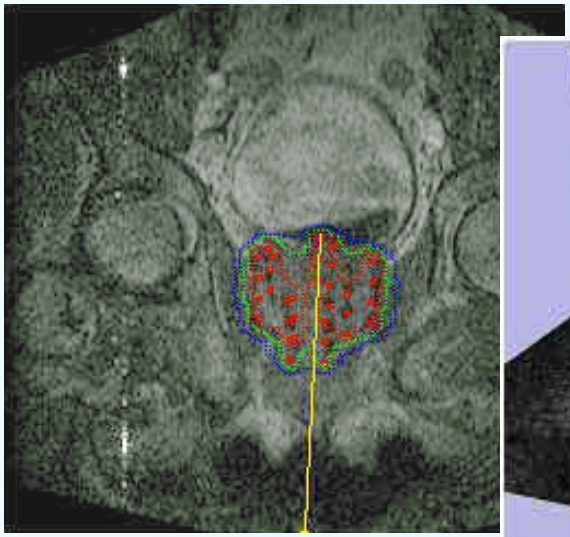
Image guided therapy

Prostate biopsy / brachytherapy

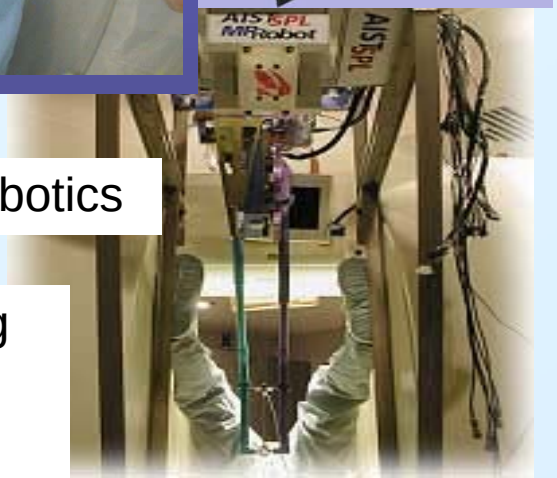


Prostate Imaging

Detection Staging



MR Robotics



SPL

Treatment monitoring
CALGB/Novartis-STI571

High Performance Computing
Gigabit network / Terabyte storage

Prostate IGT Research projects

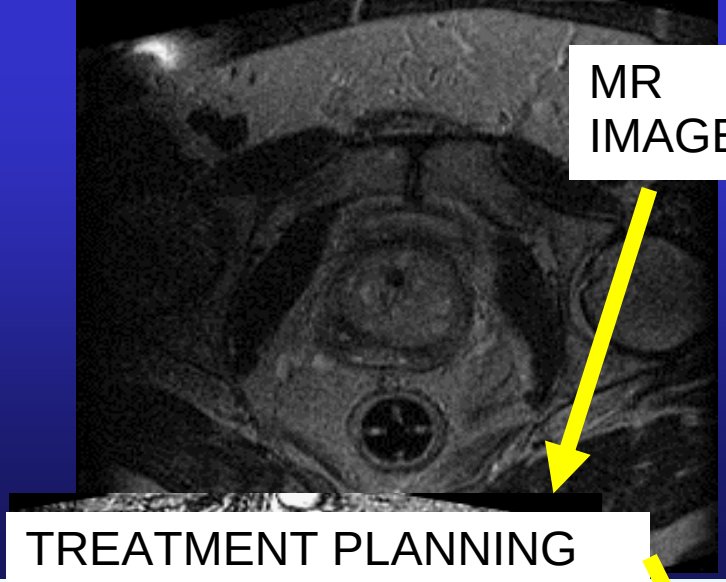
- Registration & Segmentation
  - Multi-modal image display
  - Seed definition-seed based dosimetry
- Clinical outcomes
  - Cancer diagnosis, control, toxicity and QOL
- Target definition
  - Multi-parametric data analysis and summation
- Optimized biopsy
  - Davatzikos et al-mathematical statistical model
- Robotic assist device /closed bore systems
  - Fichtinger, Burdette et al
- MRg Prostate cancer FUS
  - Hynynen et al

MR guided prostate interventions Biopsy and brachytherapy

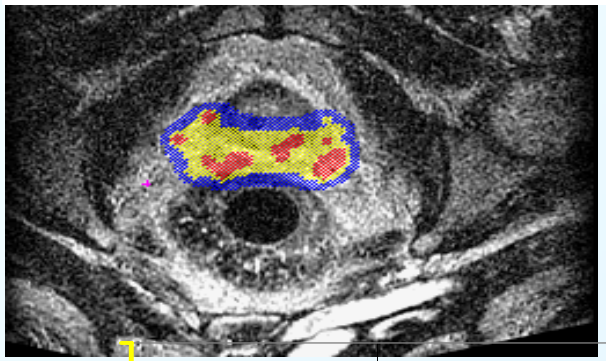
- Pre intervention imaging
  - 1.5T endorectal coil MRI
- Open 0.5T MRT system- GE medical
  - Procedure guided with real time MR
  - Plan
  - Guide
  - Monitor

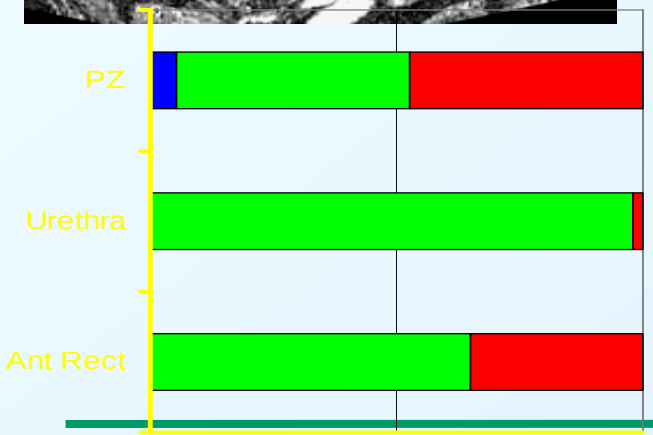
Brachytherapy program

MR IMAGE

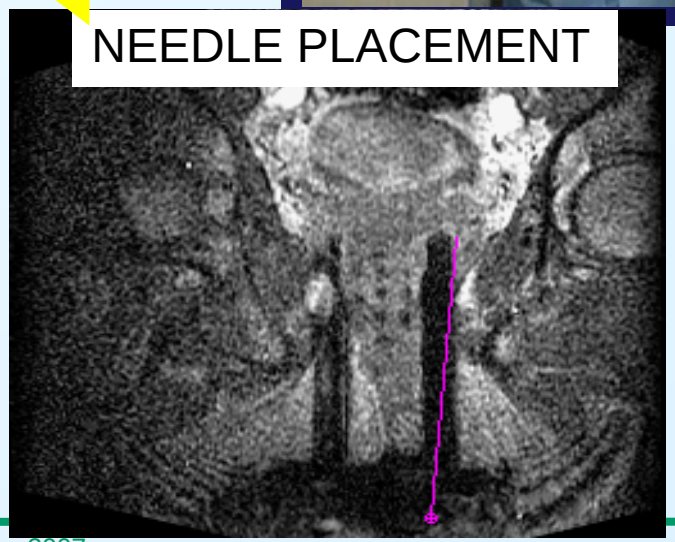


TREATMENT PLANNING





NEEDLE PLACEMENT



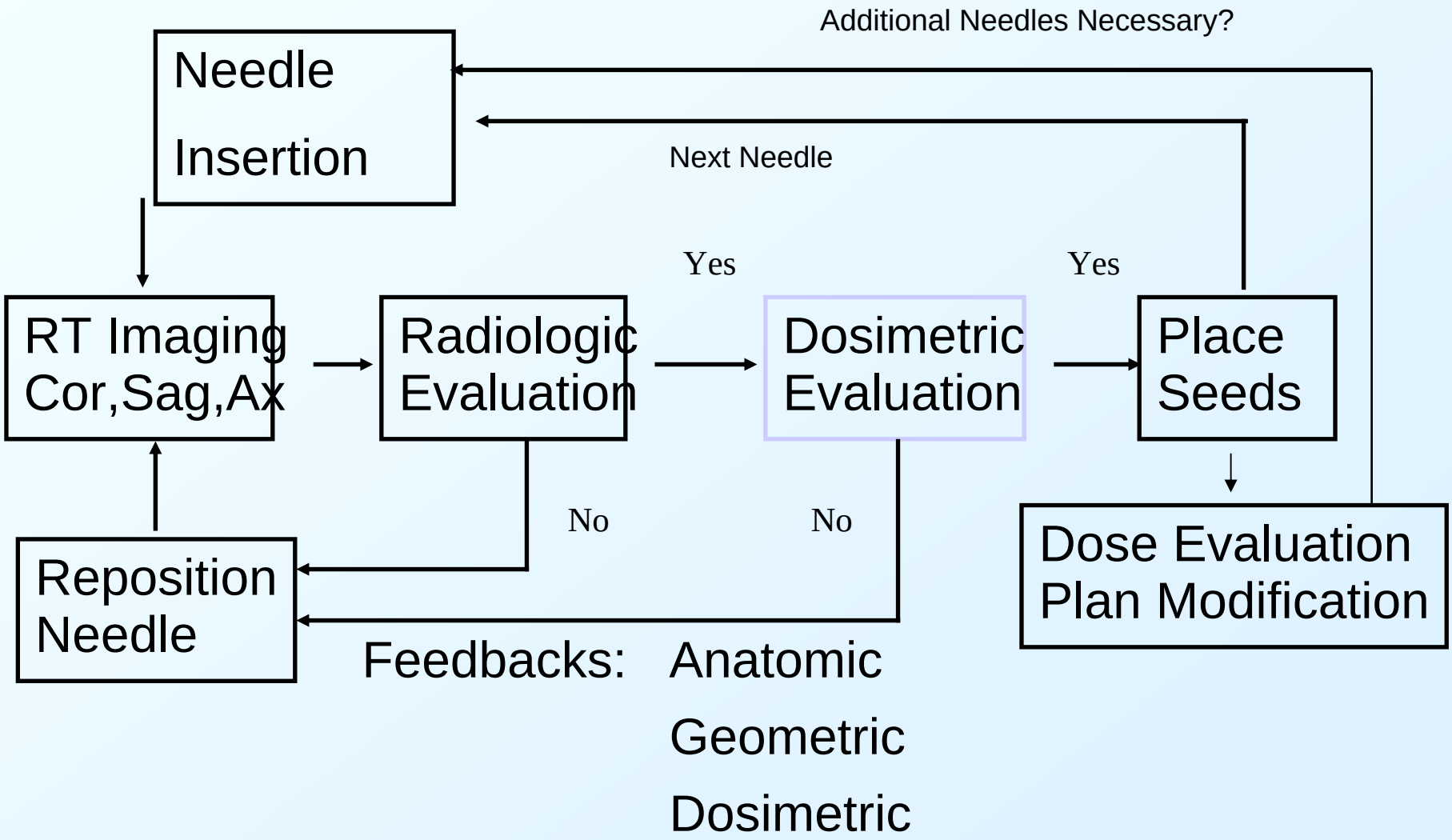
Est. 1997
D'Amico, Tempany, Cormack & Richie
2 per week
400 men Rx

Contouring PZ, urethra and rectum

Axial T2W image

Treatment plan

Needle Placement



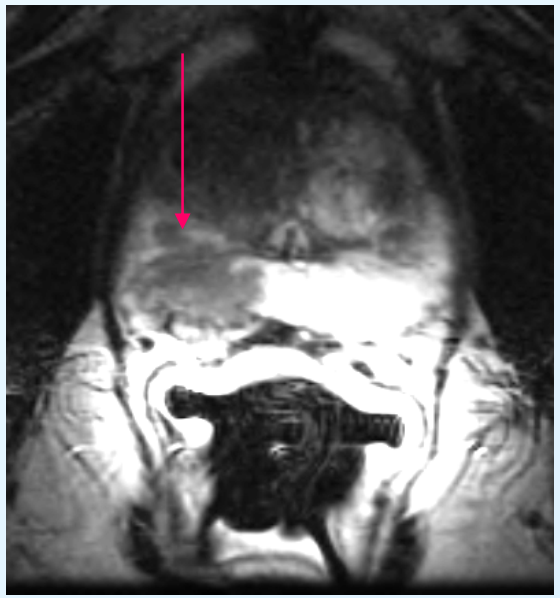
MR guided prostate biopsy

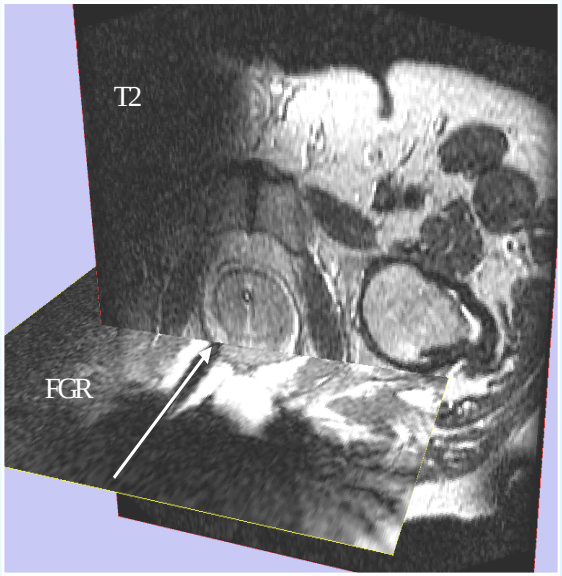
- Procedure
  - MR imaging-1.5T ecoil
    - MR/MRSI/T2maps/LSDI/DCE
      - Target identification
  - Open MR –0.5T Bx
- Patient population
  - Prior negative biopsy rising PSA
  - Prior rectal surgery (APR)

MR-guided prostate biopsy program

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

TARGET





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

Coronal FGR with Needle/T2W

Navigation and Guidance

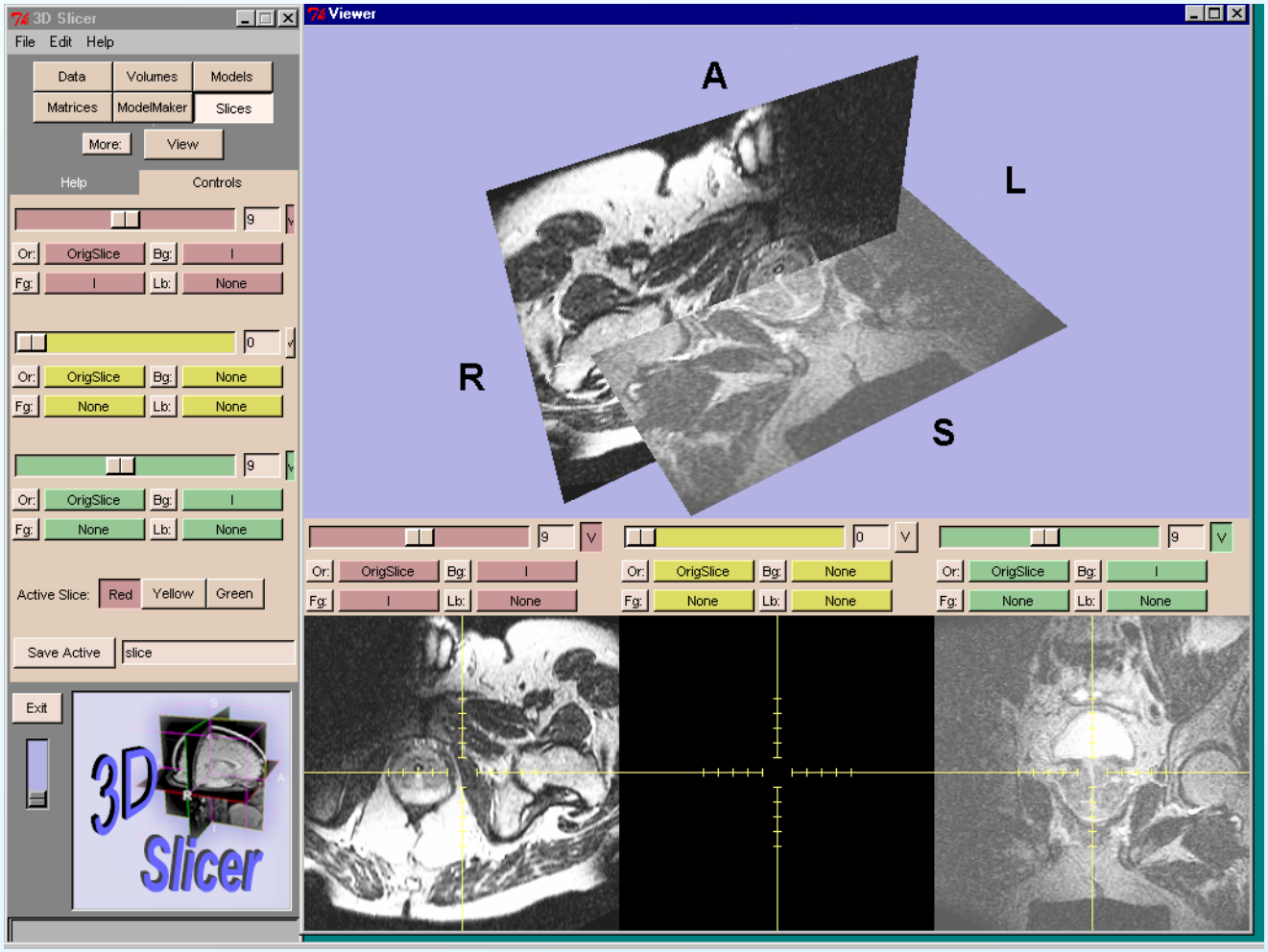
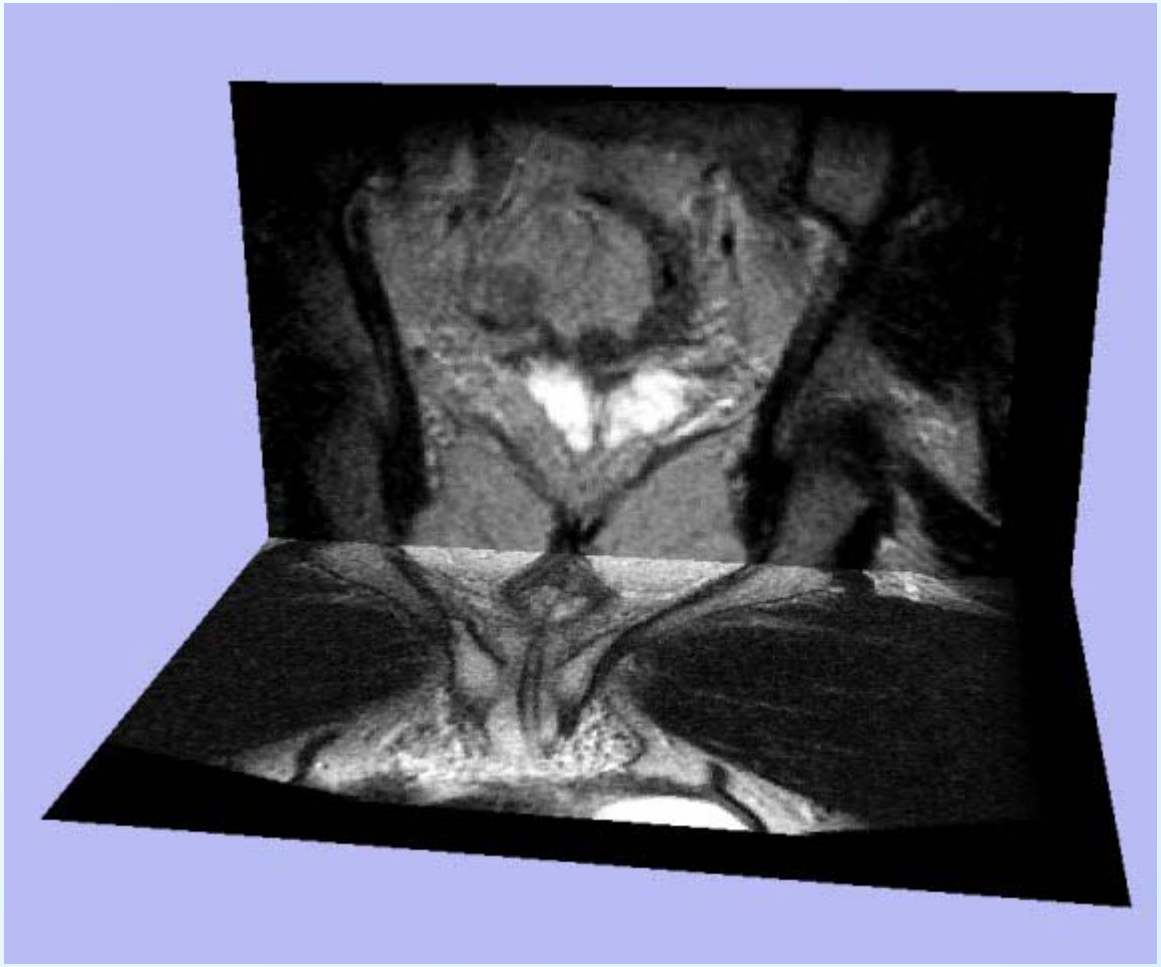


Image Fusion and Visualization

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.

MR guided biopsy-3D slicer



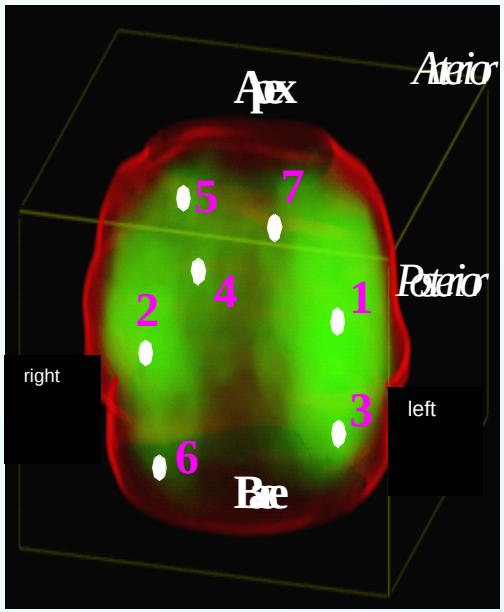
MR guided brachytherapy: Clinical validation / outcomes

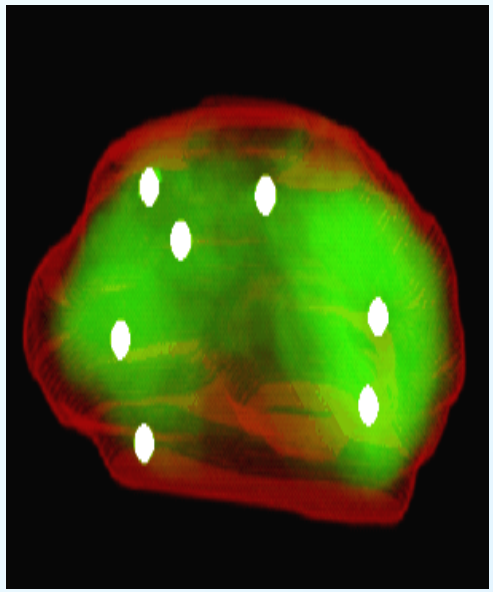
- *Outcomes. Albert et al Cancer (2003)*
  - Grade 3 rectal bleeding 8% vs 30% (combined)
  - 4yr freedom from Radiation cystitis: 100 vs 95%
  - No urethral strictures or TURP to date
- *Cancer control D'Amico et al (2003)*
  - 93% 5 yr PSA control, similar to a surgically managed population over the same time frame
- *QOL: Szot et al RSNA 2004*
  - *Significant improvement over US in both GU and sexual function*

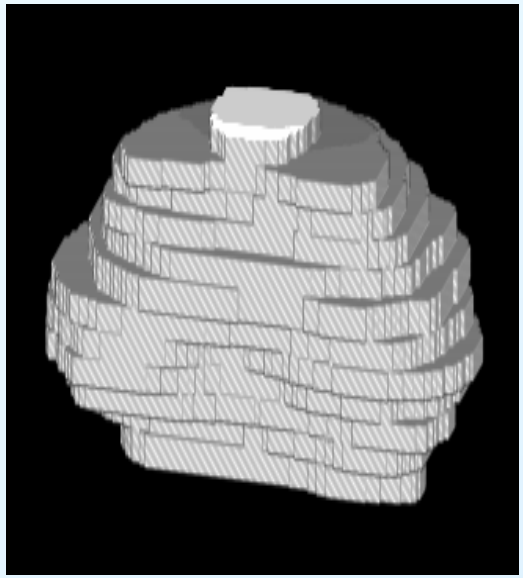
Validation methods

- Pre-clinical
  - IGT technology-imaging system , guidance and monitoring techniques-organ/disease specific
- IGT Procedural
  - Image registration & segmentation
    - *DICE*-Statistical analysis of registration matching
    - *Staple*-analysis of expert and automated methods
  - Procedure Feasibility
    - Safe and effective
- Treatment specific -Cancer specific goals
  - Patient safety, toxicity profiles, Cancer control-long and short term outcomes

Optimized biopsy project







Probability of cancer occurrence shown in green (left) and its adaptation (middle) to a stack of segmented intra-operative MR images obtained at the BWH (right). Optimal biopsy sites are transferred to the patient's space.

* NIH R01 PI: Davatzikos et al

Template-based Needle Insertion

MRI-guided Prostate Biopsy

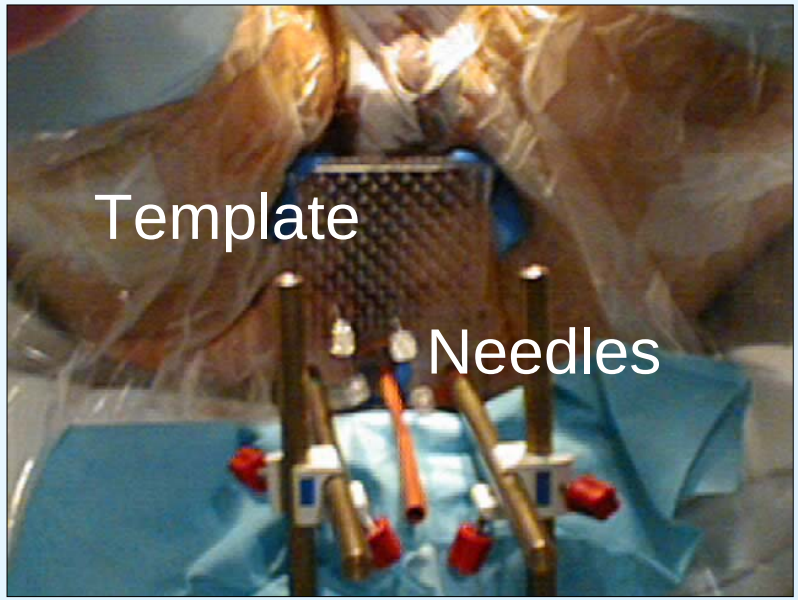
- High cancer yield by targeted sampling [So-2005],
- Accuracy matters.

<u>Unresolved issue</u>

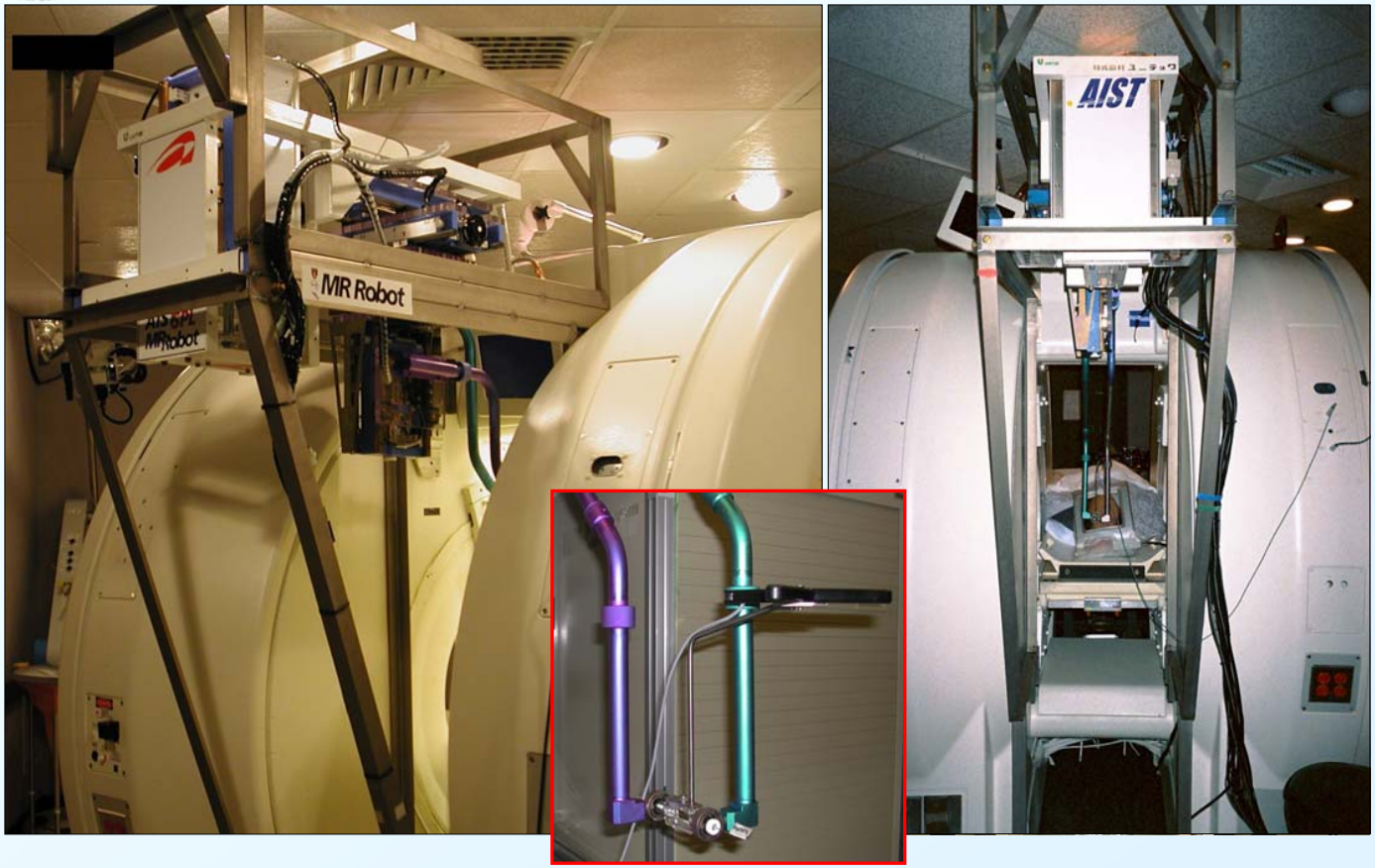
Inaccuracy (avg. 6.9mm) due to grid template,
Extensive accuracy analysis needed
Accurate target sampling

Proposal

Clinical accuracy assessment with mechanical needle-guiding device.



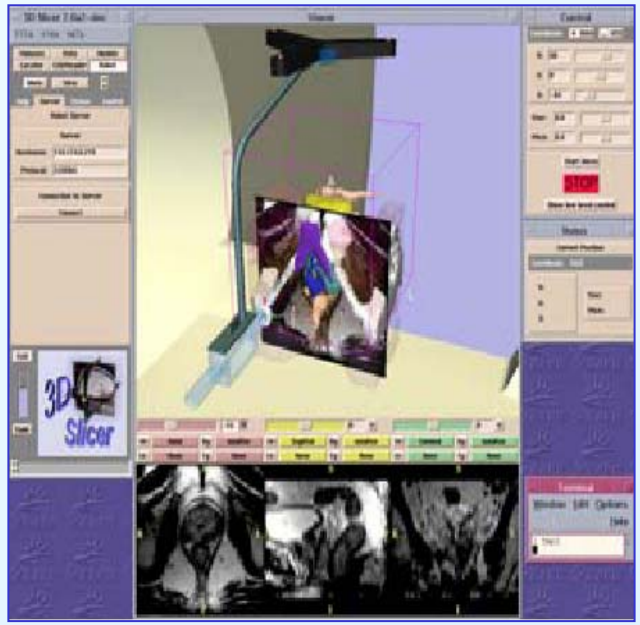
MRI-Compatible Needle Positioning Device



Chinzei K, Warfield SK, Hata N, Tempany CMC, Jolesz FA and Kikinis R (2003) "Planning, simulation and assistance with intraoperative MRI." Minimally Invasive Therapy & Allied Technologies 12(1-2): 59-64.

Challenges

- MR-compatibility
  - Non-ferromagnetic material
  - Ultrasonic motor
  - Optical sensors
- Software Integration
  - Planning
  - Motion control
  - Imaging control



Chinzei K, Hata N, Jolesz FA and Kikinis R (2000).
MR compatible surgical assist robot: System integration and preliminary feasibility study. Medical Image Computing and Computer-Assisted Intervention. MICCAI. 1935: 921-930.

Personnel

Engineering Faculty/Staff:

BWH:
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- N. Aucoin

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CISST ERC:
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- G. Fichtinger
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- A. Deguet
- C. Davatzikos

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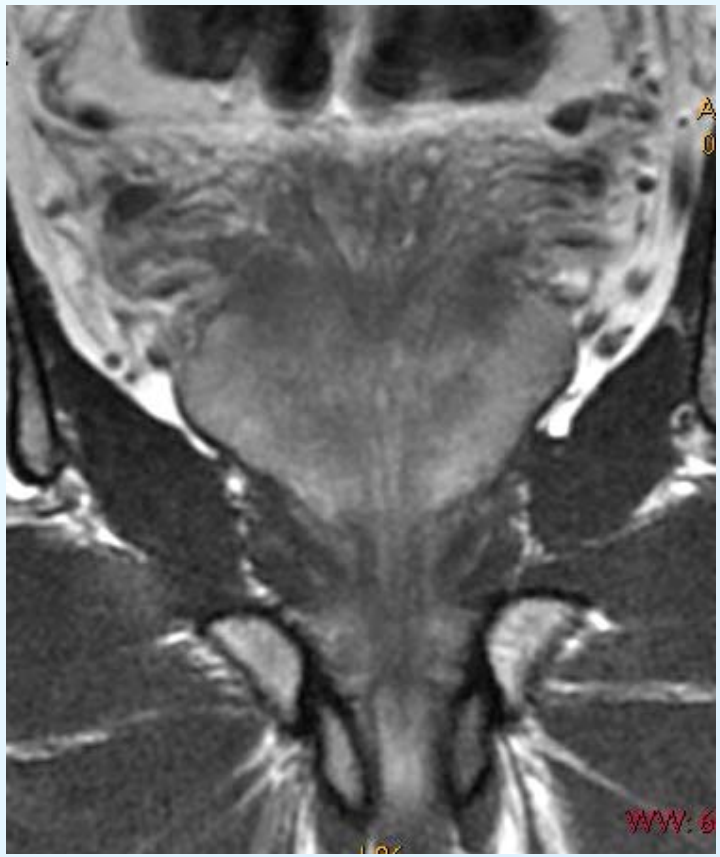
- A. D'Amico MD PhD

Consultants:
- S. Pieper (*Isomics Inc.*)
- M. McKenna (*Small Design Firm*)

Why 3T ? Prostate Imaging



14FOV, 4mm, 3:18 acq
5000/160 etl 16 torso array; ↓refocused pulse FA

Bob Lenkinsky & Neil Rofsky

A STATISTICAL COMPARISON OF MULTI-PARAMETRIC MR FOR PROSTATE CANCER

Ian Chan, Steven Haker, Robert Mulkern, Kelly Zou, Jianqing Zhang, Stephan Maier, William Wells, Robert Cormack, Ron Kikinis,

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Brigham and Women's Hospital Surgical Planning Laboratory

Harvard Medical School

MIT Laboratory for Computer Science

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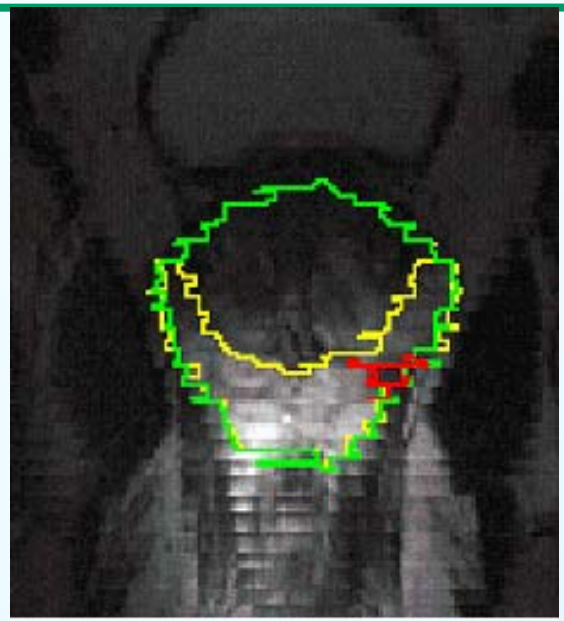
1. Evaluate Line Scan Diffusion Imaging and T2mapping Imaging

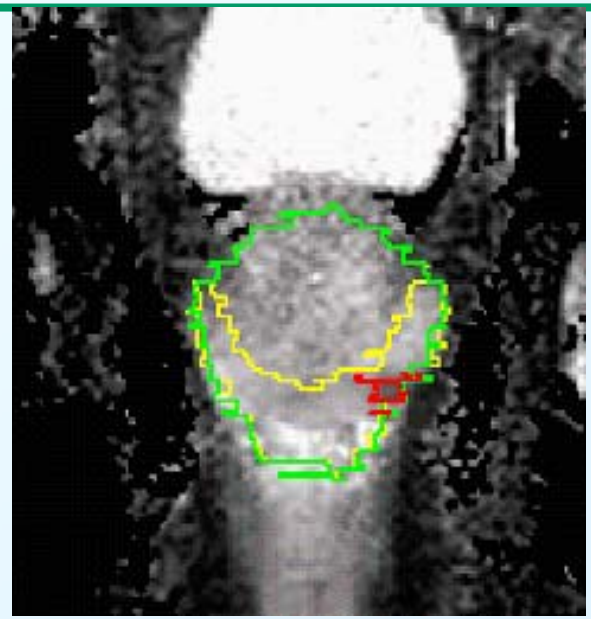
2. To extract the textural and anatomical features in these images

3. To combine all the information statistically and for clinicians to visualize the results

Results: Sample Multi-parametric Dataset

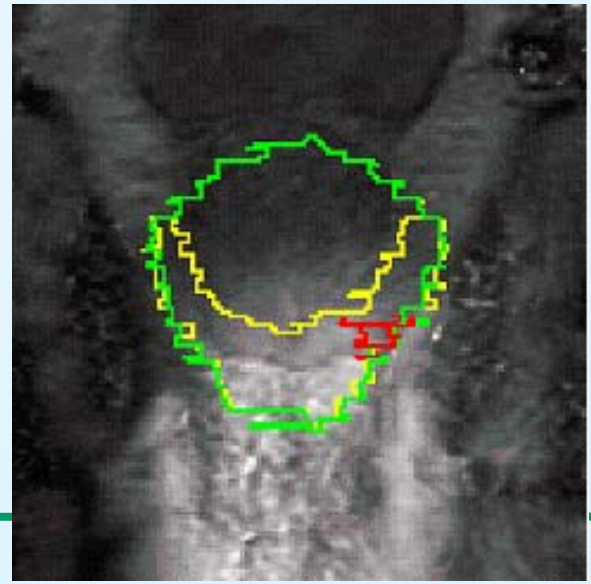
T2 Weighted (resampled)





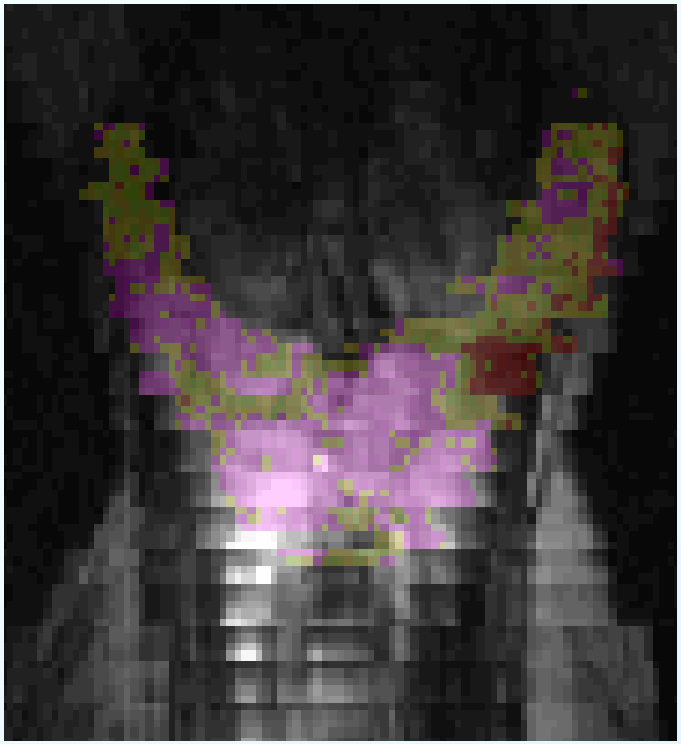
Apparent Diffusion Coefficient Map

T2map from T2 mapping



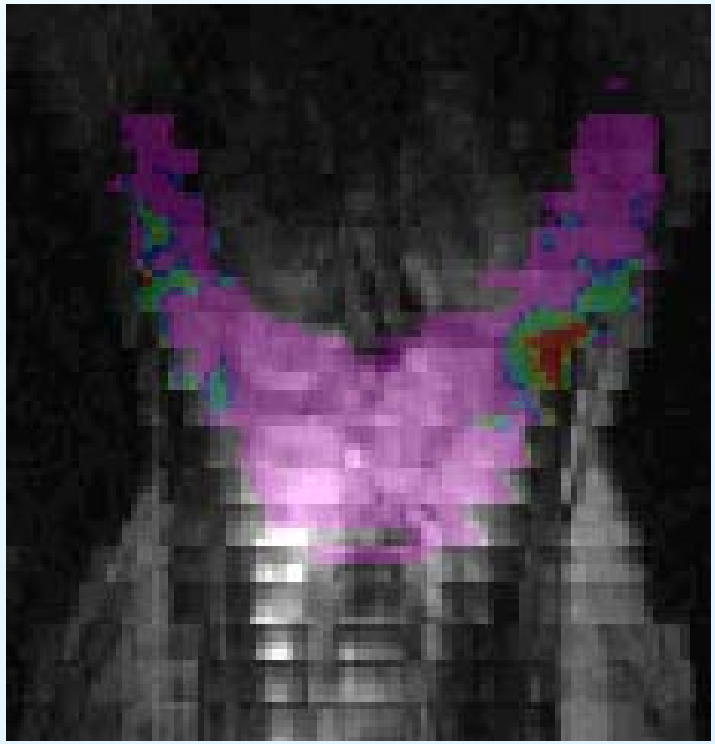
Proton Density from T2 mapping

Results: Summary Statistical Map



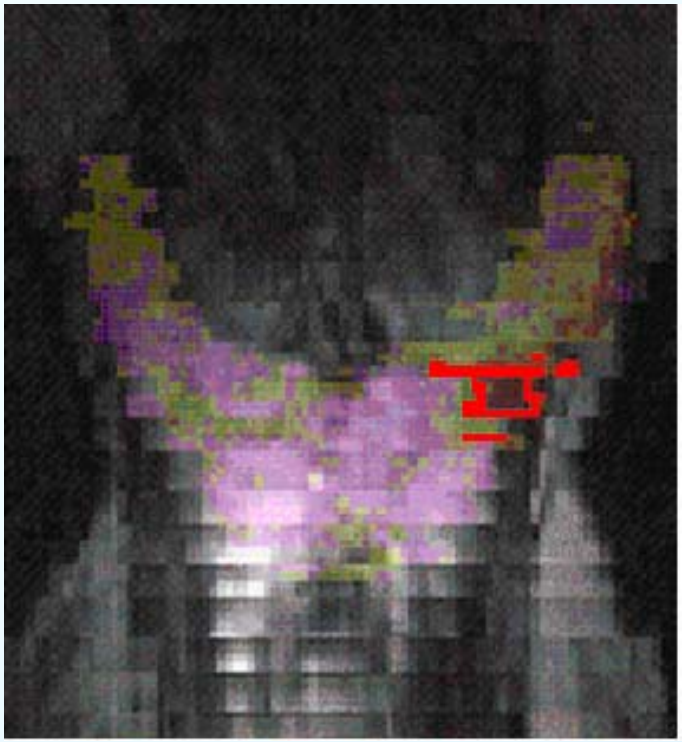
Fisher Linear Discriminant

allCM + DCT features



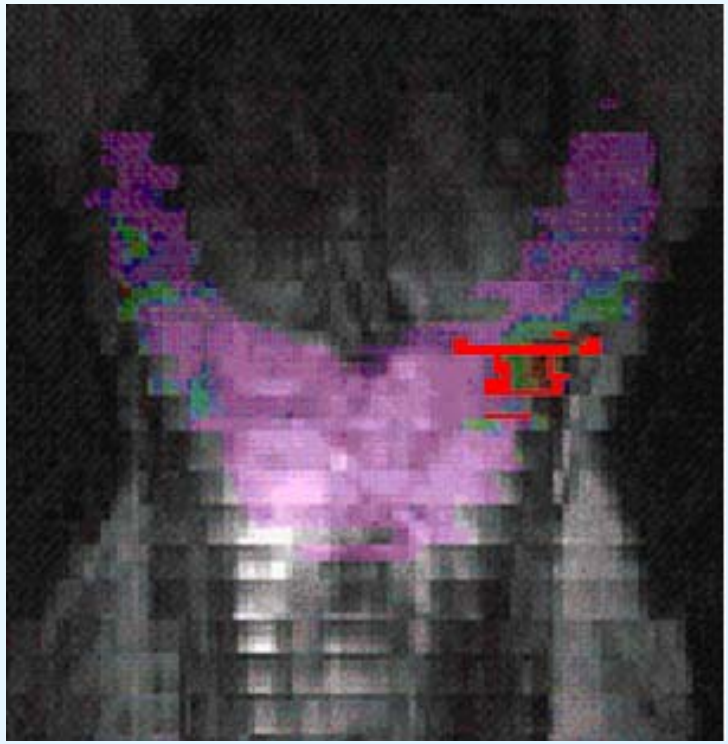
Support Vector Machine

Basic 4 + anatomy features



Fisher Linear Discriminant

allCM + DCT features



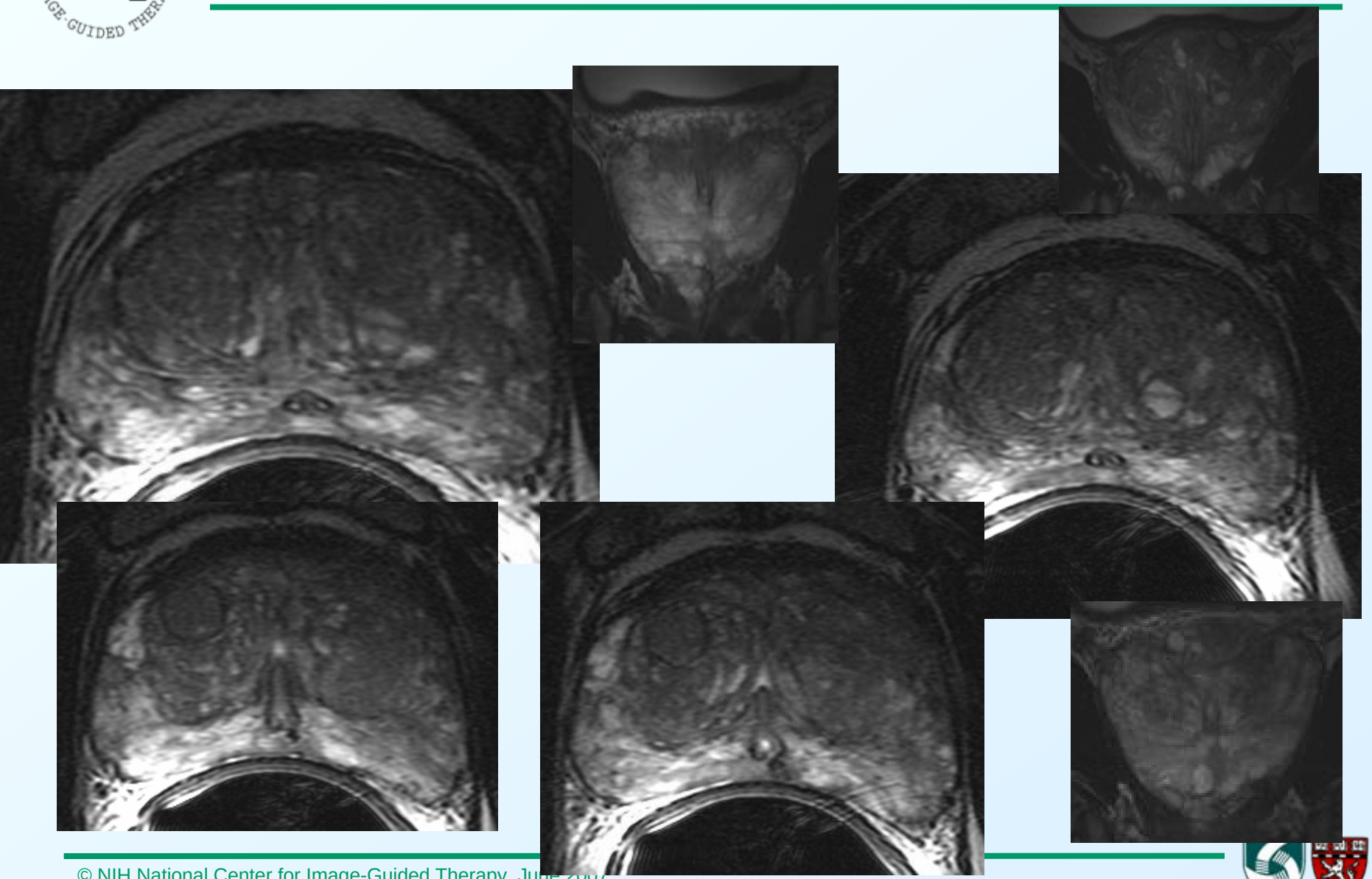
Support Vector Machine

Basic 4 + anatomy features

Results: ROC area statistics

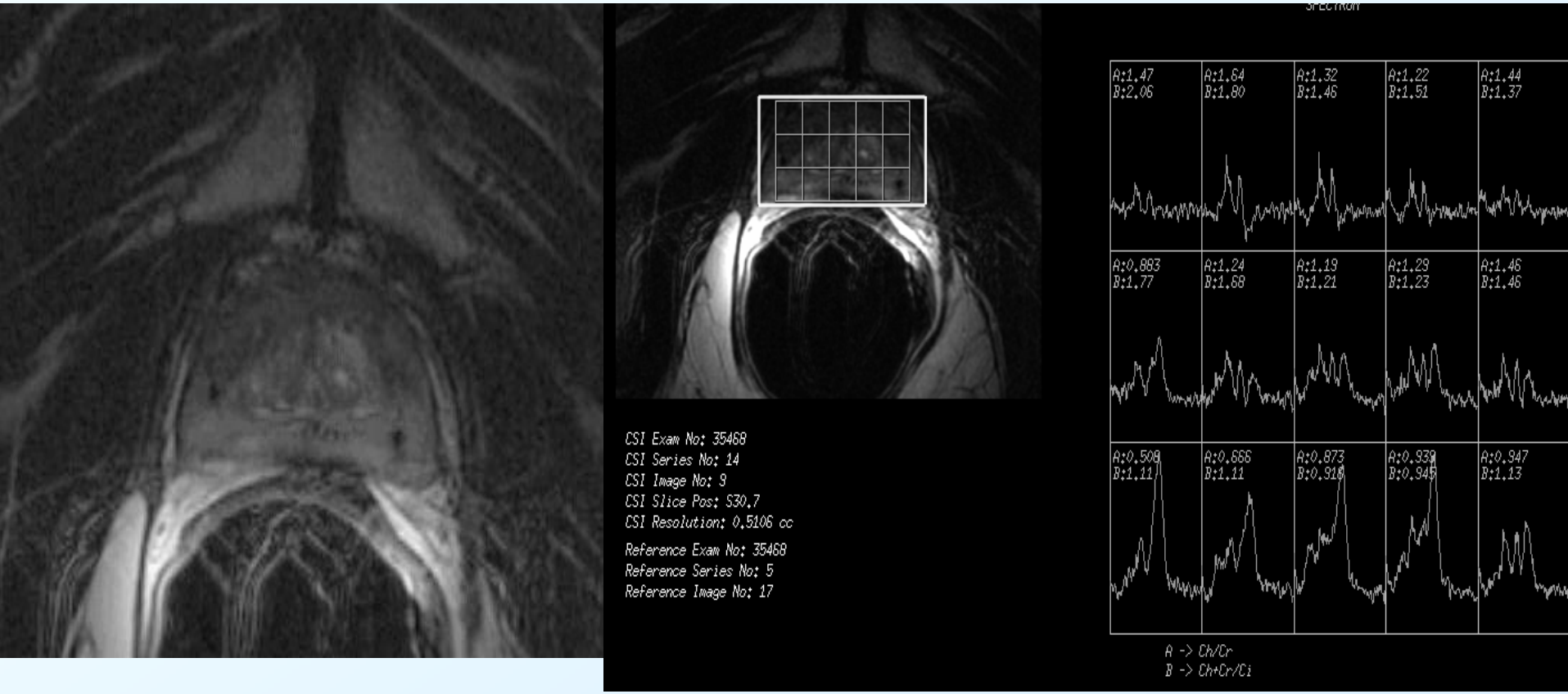
Classifier	Features	ROC area: μ (σ)
Single-channel classifier	T2W	0.599 (0.146)
	ADC	0.533 (0.114)
	PD	0.521 (0.165)
	T2Map	0.562 (0.058)
Multi-channel FLD	basic 4	0.620 (0.089)
	basic 4 + anatomy	0.729 (0.058)
	all CM	0.825 (0.056)
	all DCT	0.791 (0.043)
	all CM + DCT	*0.839 (0.064)*
Multi-channel SVM	basic 4	0.635 (0.079)
	basic 4 + anatomy	0.761 (0.043)
	all CM	no convergence
	all DCT	no convergence
	all CM + DCT	no convergence

3T endorectal coil MRI

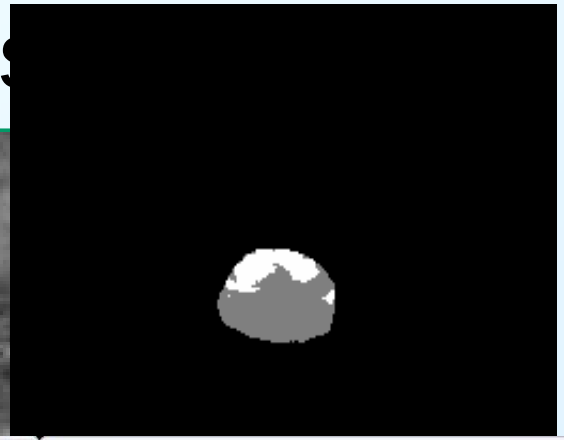


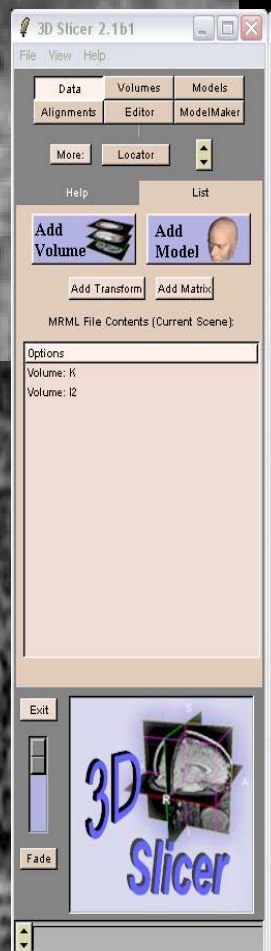
Bob Lenkinsky & Neil Rofsky

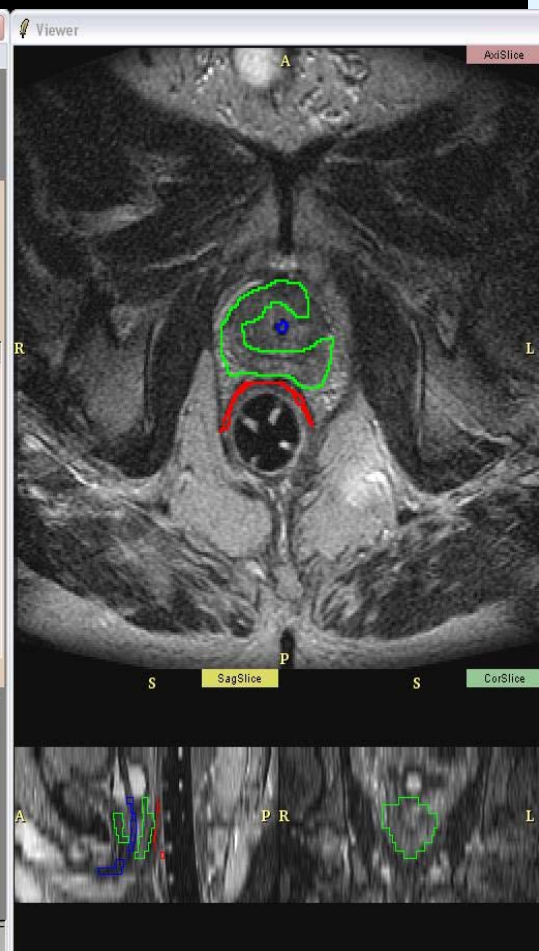
Recent case: Rising PSA 4 years after brachytherapy



MR/MRSI guided biops
0.5







Dx
Adenocarcinoma
Anterior TZ

Intra-operative MRI at BWH

- Craniotomy=699
- Brain biopsy=180
- LASER ablation=9
- Transsphenoidal pituitary adenoma resection
- Total=918

Conclusions and Future Directions

- Multi-modality image fusion
- Intra-operative functional testing annotation
- Develop paradigms which work well for patients with neurologic deficits
- Integrate fMRI with DTI and other imaging modalities
- Improve ability to predict post-operative outcomes and avoid neurologic injury
- Correlate fMRI signal with neuronal activity

Research Interactions between NA-MIC, NAC, BIRN

BIRN

Focus: infrastructure, data, data distribution
e.g. Provides shared image databases and high speed network/computing for NA-MIC & NAC

Data

Requirements, testing, tools

NA-MIC

Focus: algorithms, engineering, general software tools
e.g. Analysis of tensor and non-tensor diffusion data at three algorithm groups (UNC, Utah, MGH) , hosted on BIRN servers from four clinical sites (Dartmouth, Harvard, UCI, U of Toronto)

Data repositories and access

Advances in medical image computing

NAC

Focus: specific applications, custom software tools
e.g. Tensor analysis for pioneering diffusion technology from BWH

National Level Science

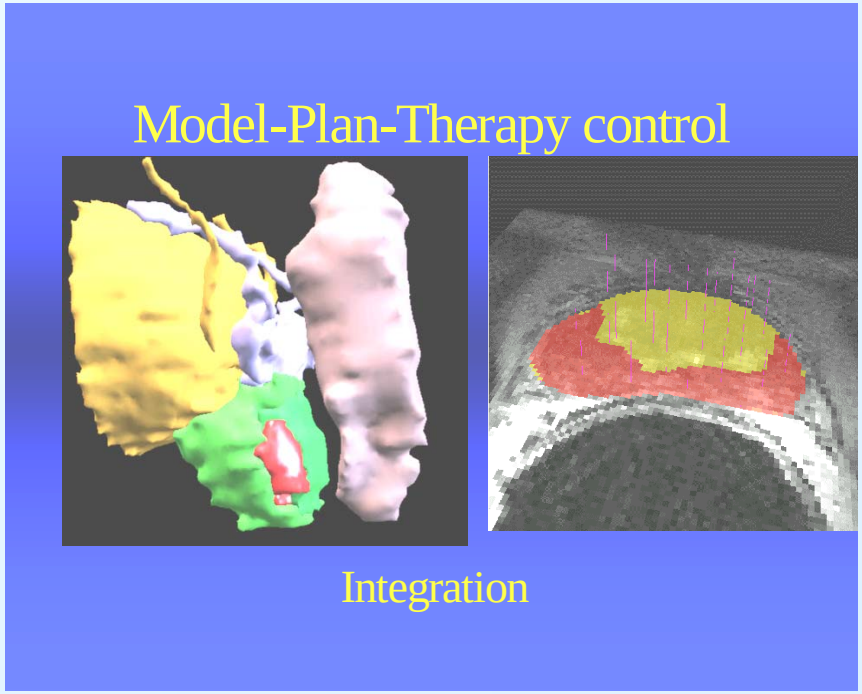
National Level Outreach

Local Level Science

National Level Outreach

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

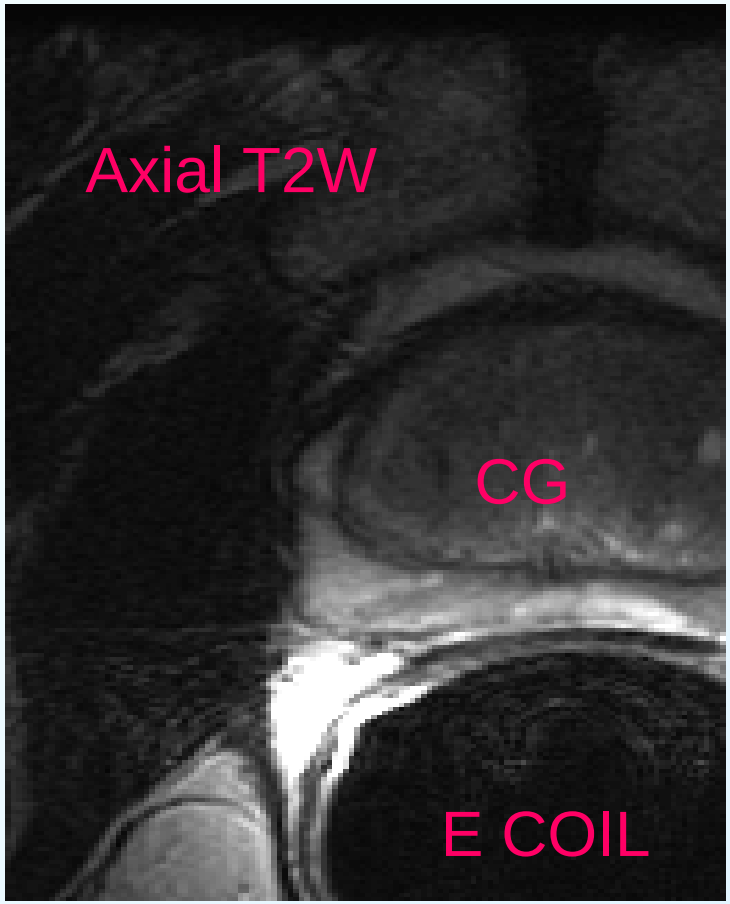


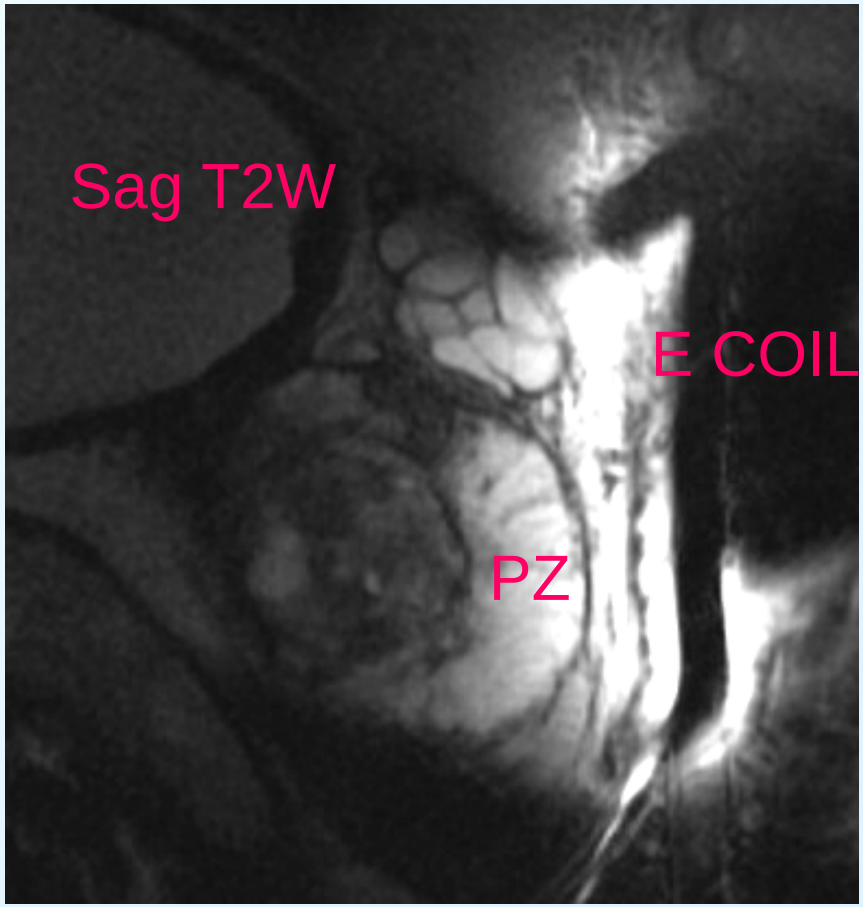
Registration

Staging/Treatment prostate cancer

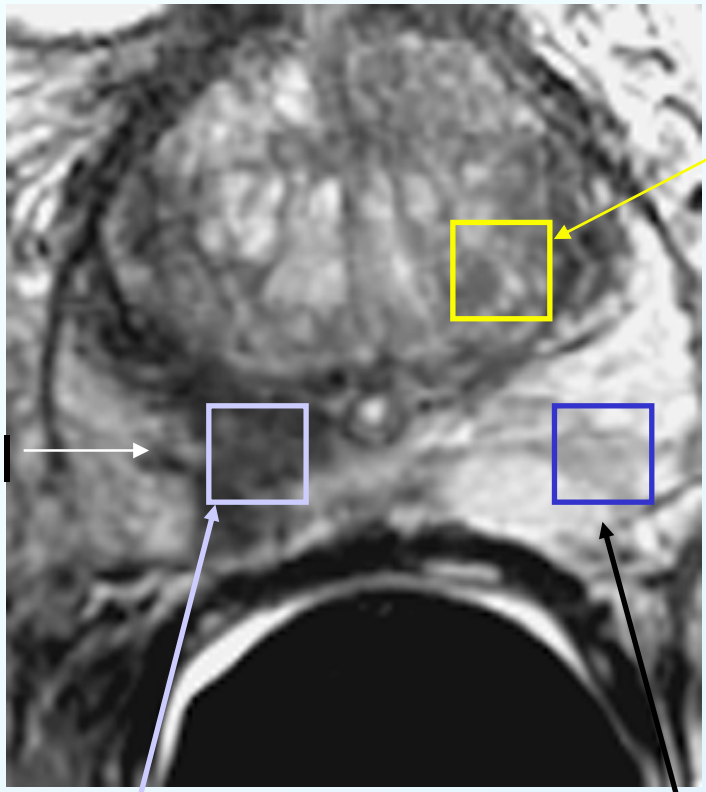
- T1/T2 intra-glandular tumors
  - Treatment-goal-local cure
    - Radical prostatectomy
    - XRT
    - Implant
    - Watchful waiting
- T3 Extra-glandular
  - Through capsule
  - Into seminal vesicles
    - Treatment-Radiation+/- Total androgen suppression

Normal prostate MR Appearance



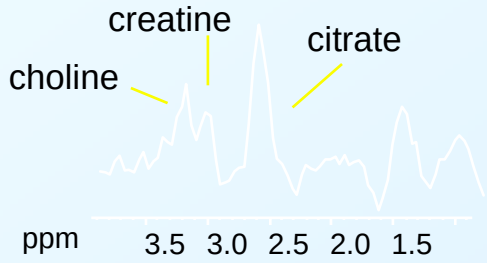


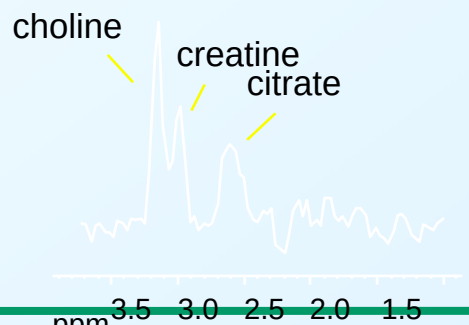
MRSI: Metabolic Identification of Cancer



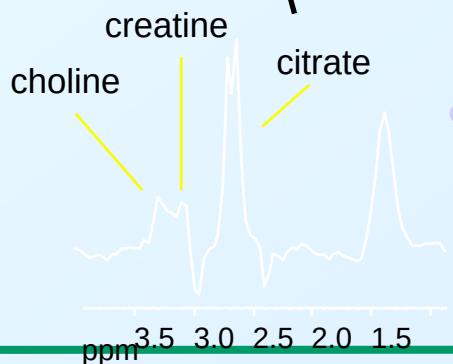
Peripheral Zone (68% of cancers)

BPH





Cancer



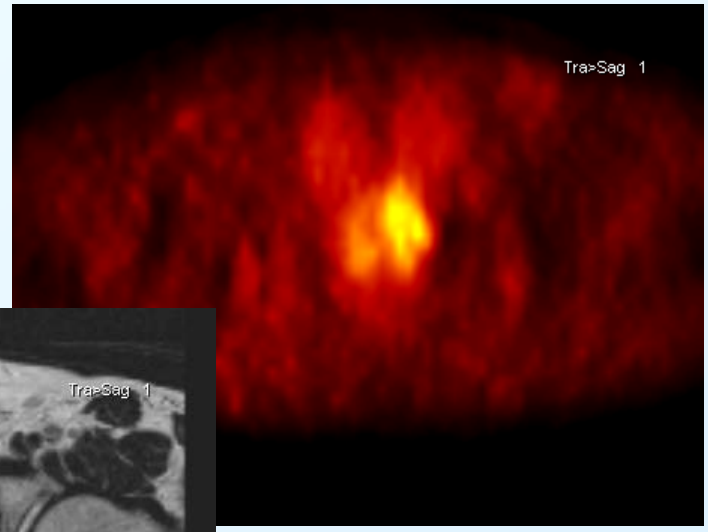
Peripheral Zone

Prostate Cancer

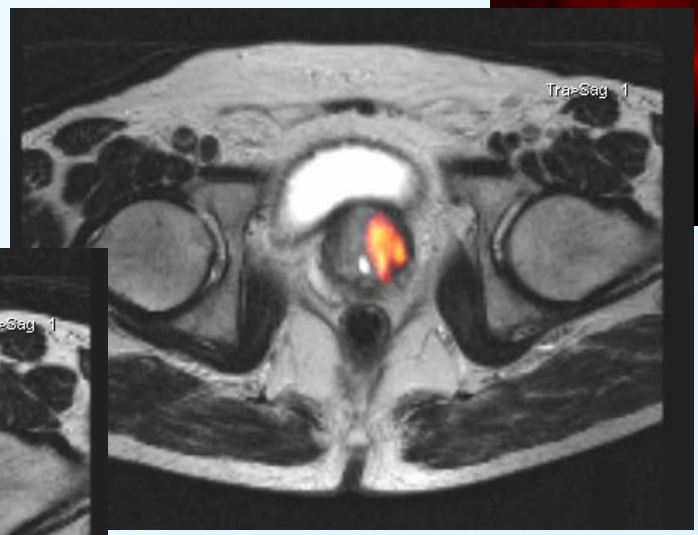
Metabolically (MRSI)

- Increased Choline - due to increased cellular proliferation, cell density changes and membrane changes
- Decreased Citrate - Citrate production and secretion is a specialized function lost with the evolution of cancer

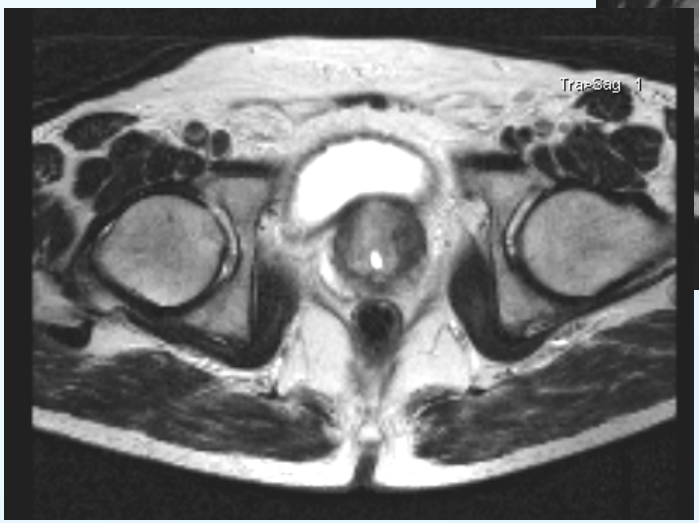
[^{11}C] Choline PET/MRI



FUSION



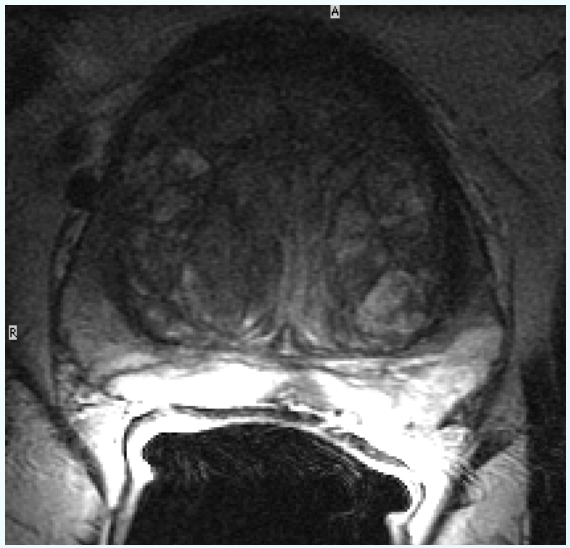
MRI

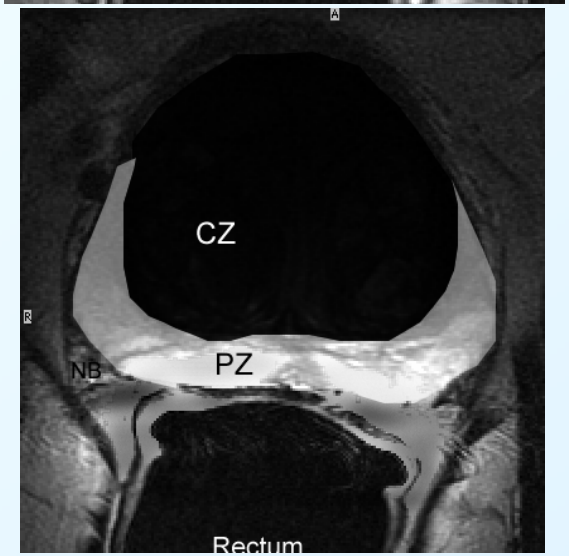


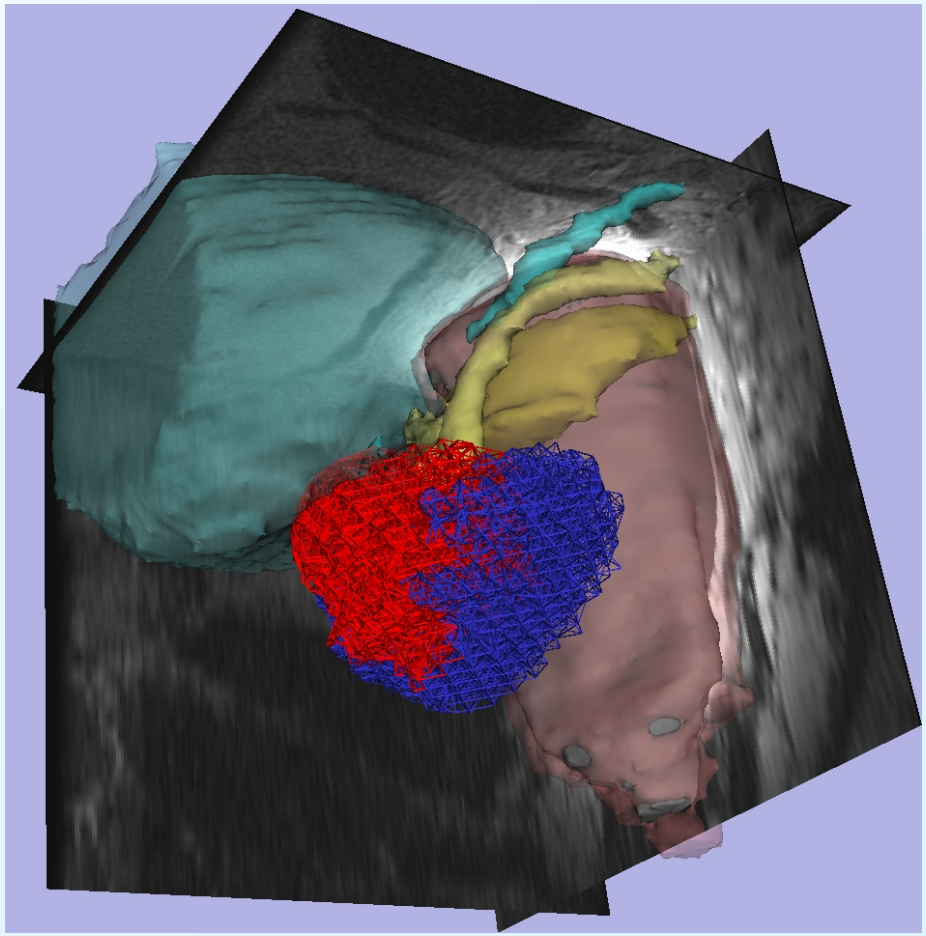
PET

Courtesy of J. Czernin, MD Ahmanson Biological Imaging Center, David Geffen School of Medicine at UCLA

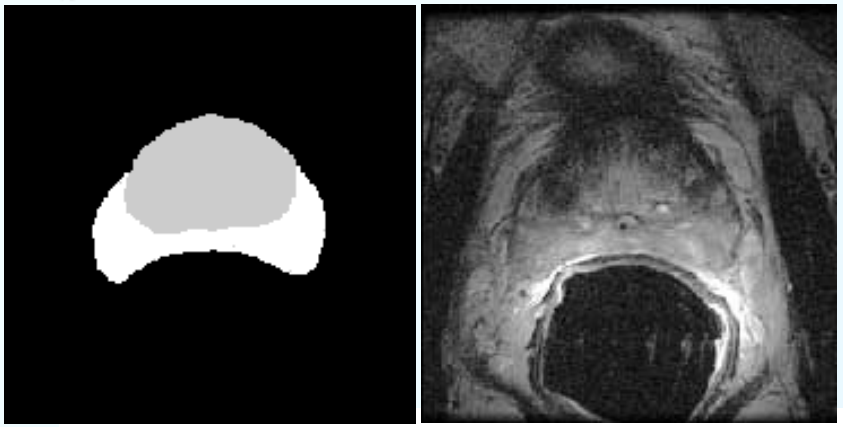
Registration and Segmentation



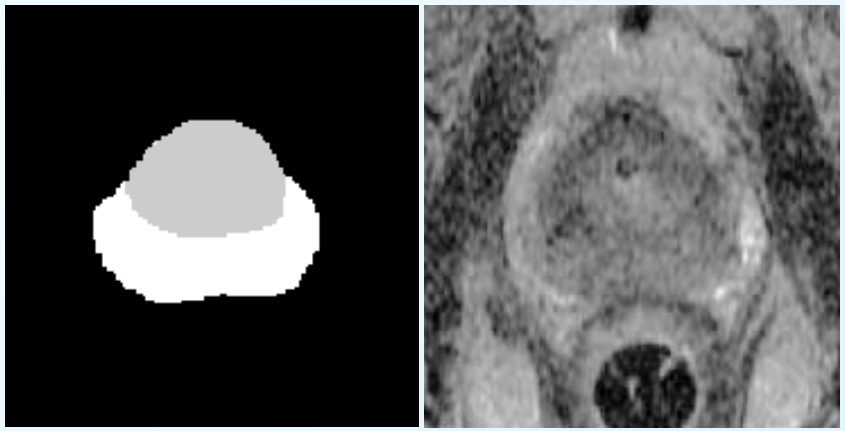




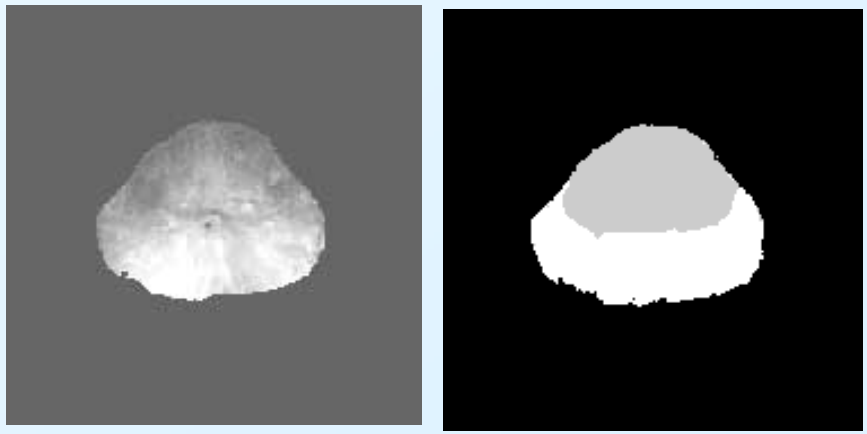
Finite Element Registration



Pre-operative 1.5T T2 FSE



Intra-operative 0.5T



Deformed pre-op T2 FSE

The Basic Problem

- New MR imaging parameters and high field strengths hold promise for increased sensitivity and specificity in cancer detection.

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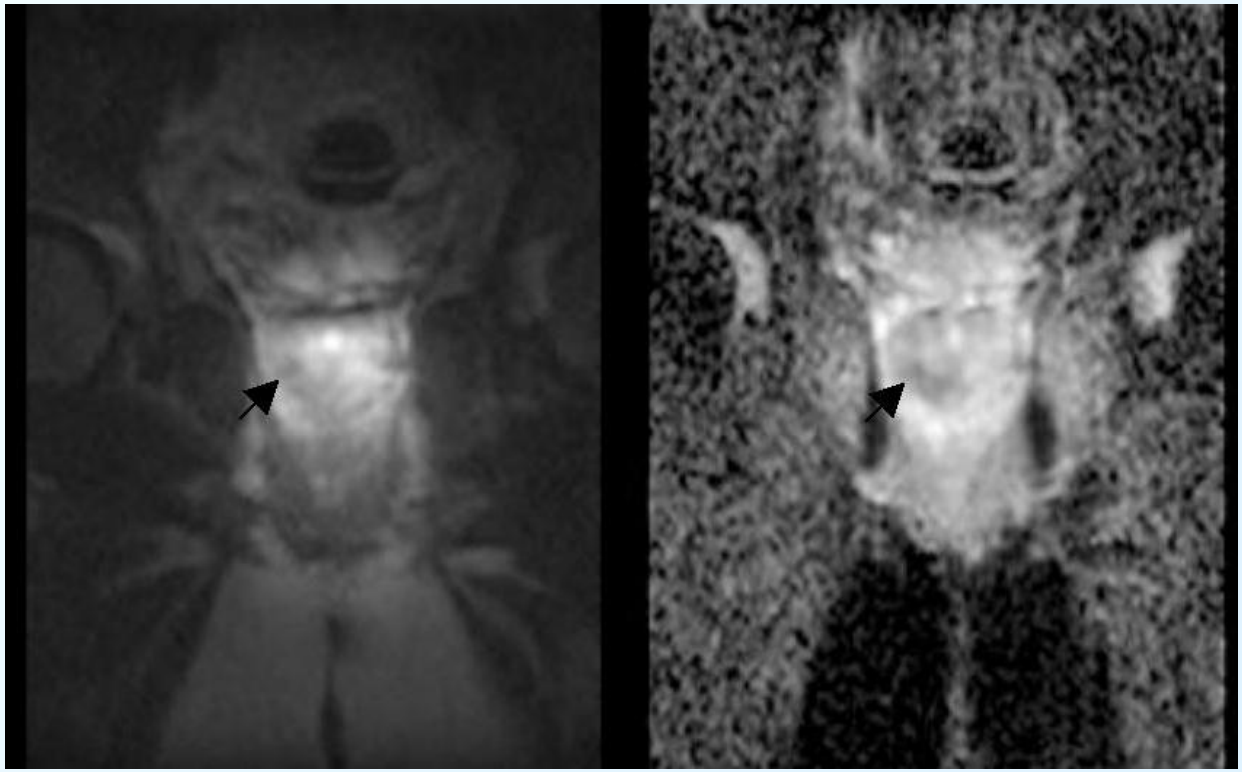
- New MR imaging parameters and high field strengths hold promise for increased sensitivity and specificity in cancer detection.
- Relatively poor ultrasound image quality makes intra-operative segmentation difficult.
- Ultrasound does not have comparable tissue characterization abilities of MR.
- Solution: *Image registration*, which allows all pre-operative imaging to be used for targeted therapy.

Promise: New MR Acquisitions

T2-Weighted Imaging Diffusion Imaging

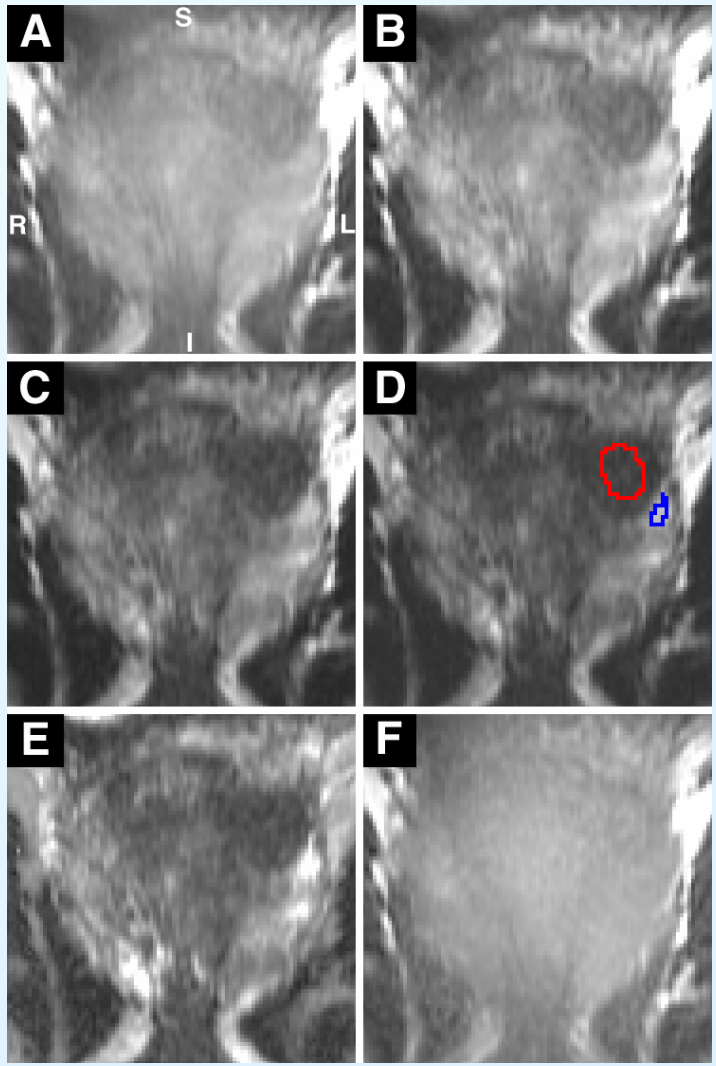


Haker, ISMRM 2005

Promising new imaging techniques are not readily available in the operating room.

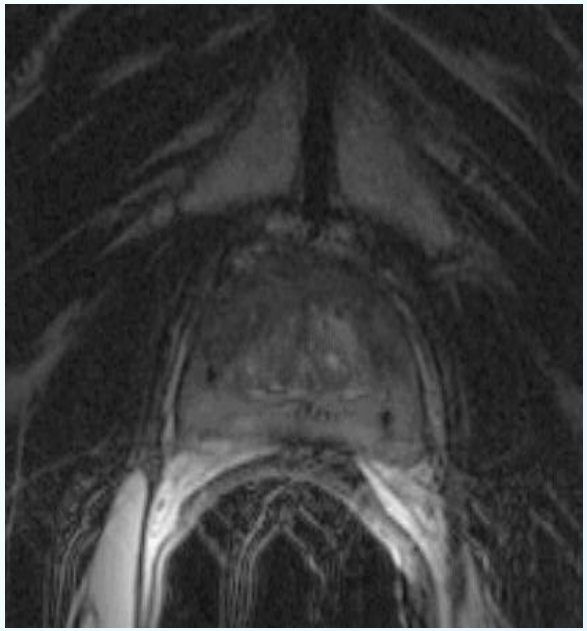
Promise: New MR Acquisitions

"CPMG imaging of the prostate can be performed in reasonable scan times and can provide advantages over T2-weighted fast spin echo imaging alone, including quantitative T2 values for cancer discrimination and proton density maps that may prove useful for parallel imaging schemes."

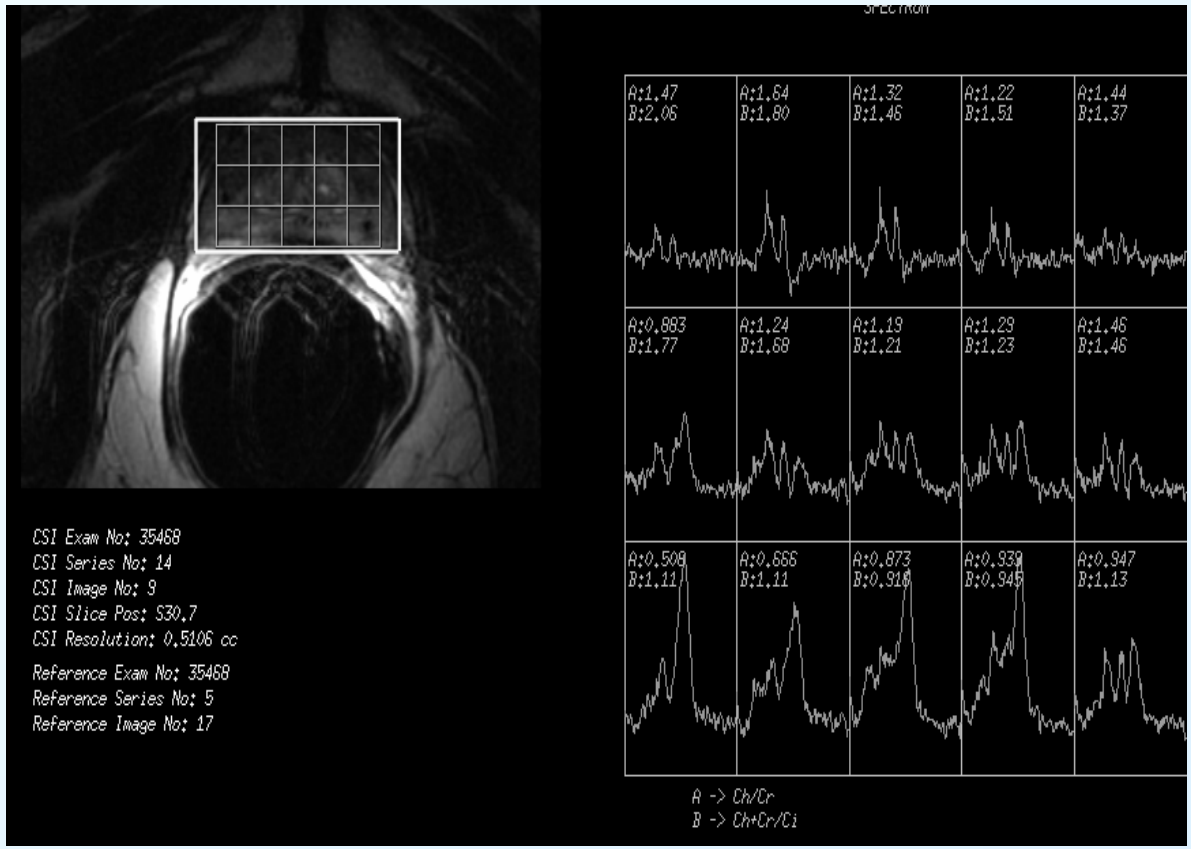


Roebuck et al., in prep.

Promise: New MR Acquisitions



T2-Weighted Imaging

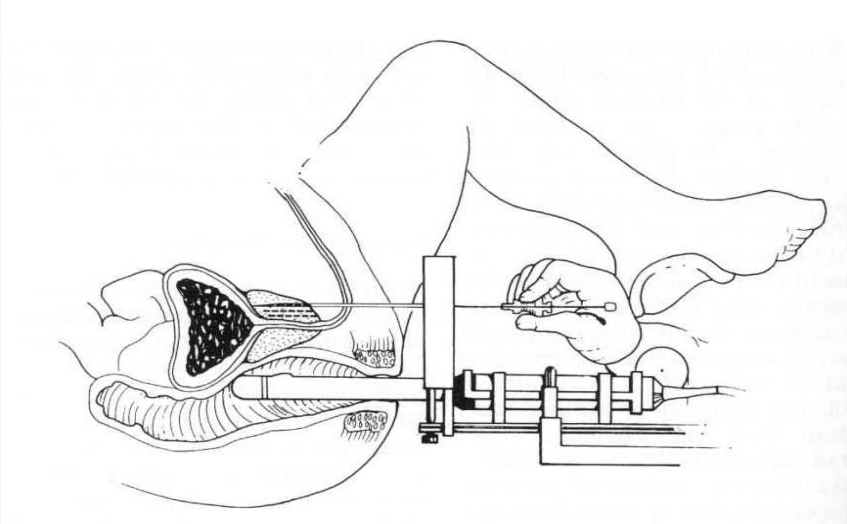


MR-Spectroscopy

MR Spectroscopy yields information on local metabolism

TRUS Guided Brachytherapy

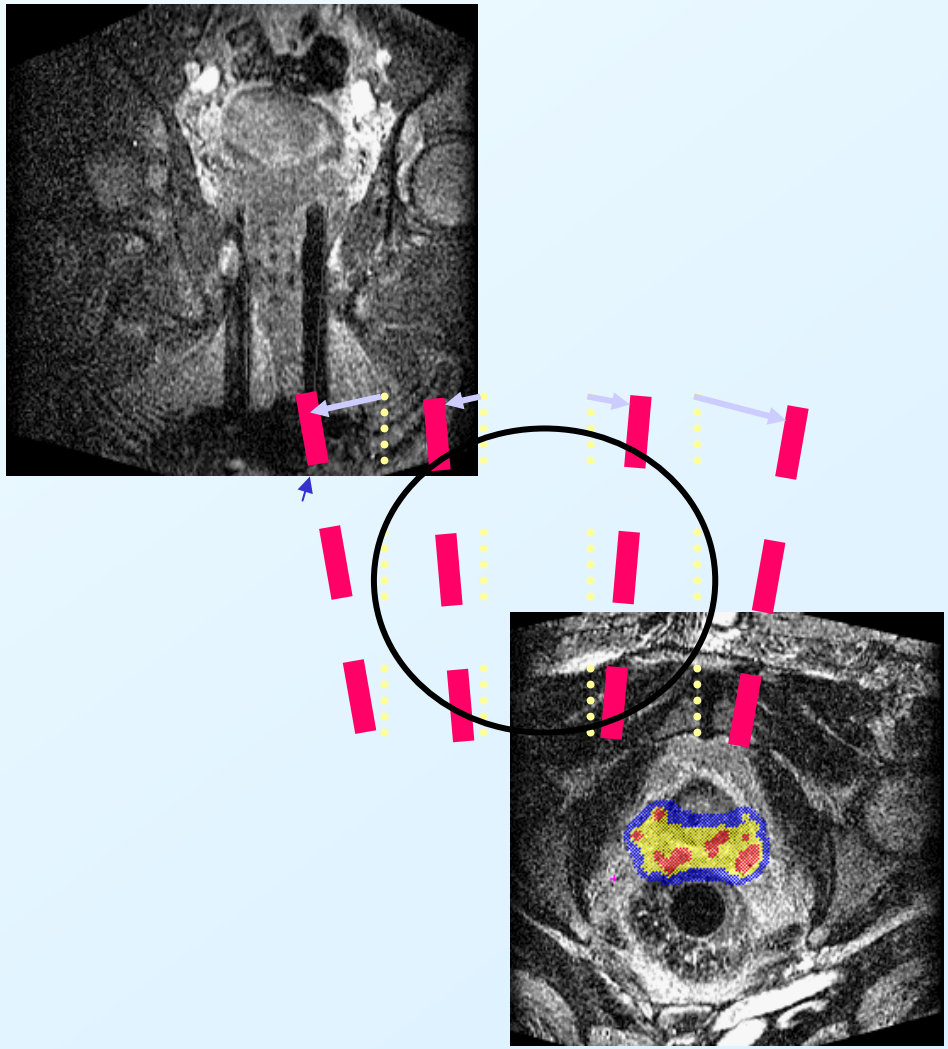
- Irradiation from inside out
- Real time imaging to guide source placement
- Image registration to assist in implant evaluation



- Permanent placement of I125 seeds in the prostate imaging ensures correct placement
- Preplanning and OR Planning

Prior Work: MR Guided Brachytherapy

- MR Tracks individual needles
- Dosimetry software calculates dose from configuration
- Dosimetric feedback during procedure
- Unique procedure/ first implementation of dosimetric feedback ~450 to date



Ultrasound Therapy: Need for Registration

- How can MR imaging be used in the operating room to guide therapy?
  - Limited time
  - Ultrasound has low tissue contrast

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Ultrasound Therapy: Need for Registration

- How can MR imaging be used in the operating room to guide therapy?
  - Limited time
  - Ultrasound has low tissue contrast
- MR Registration may help in segmentation
- Image registration allows us to align pre-operative imaging with intra-operative imaging.
  - Targets may be chosen in pre-operative imaging and used to guide therapy.
  - Pre-operative imaging can be overlaid with intra-operative imaging

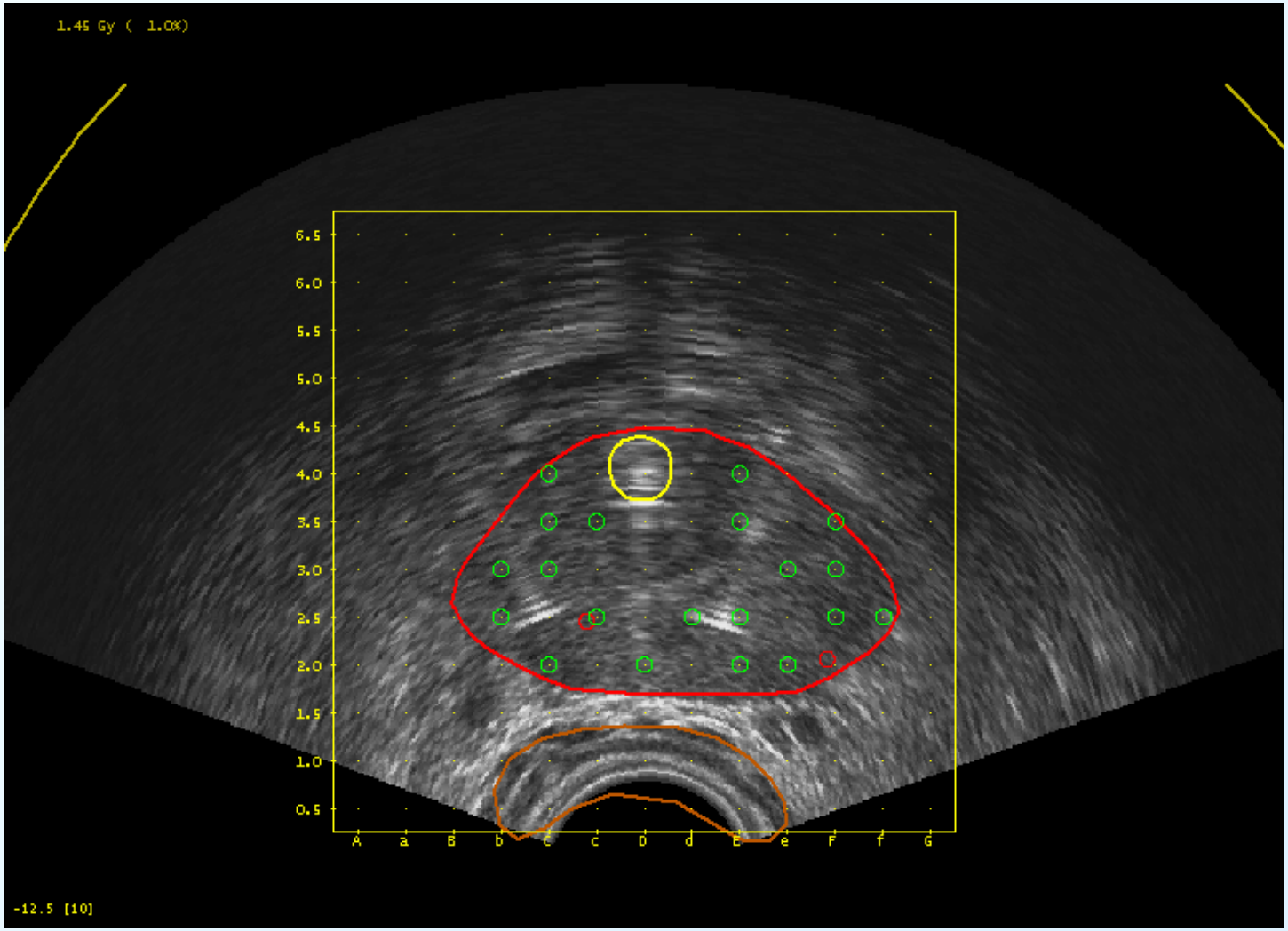
Proposed Method

1. Segment Pre-Operative MR Imaging
2. Select Pre-Operative Targets
3. Segment US imaging in OR
4. Automated registration of MR to US
5. Provide feedback in registration quality to operator
    1. Under/Over segmented regions
    2. Global volume differences
    3. Local deformations required to register
6. If needed, adjust US segmentation and return to 4

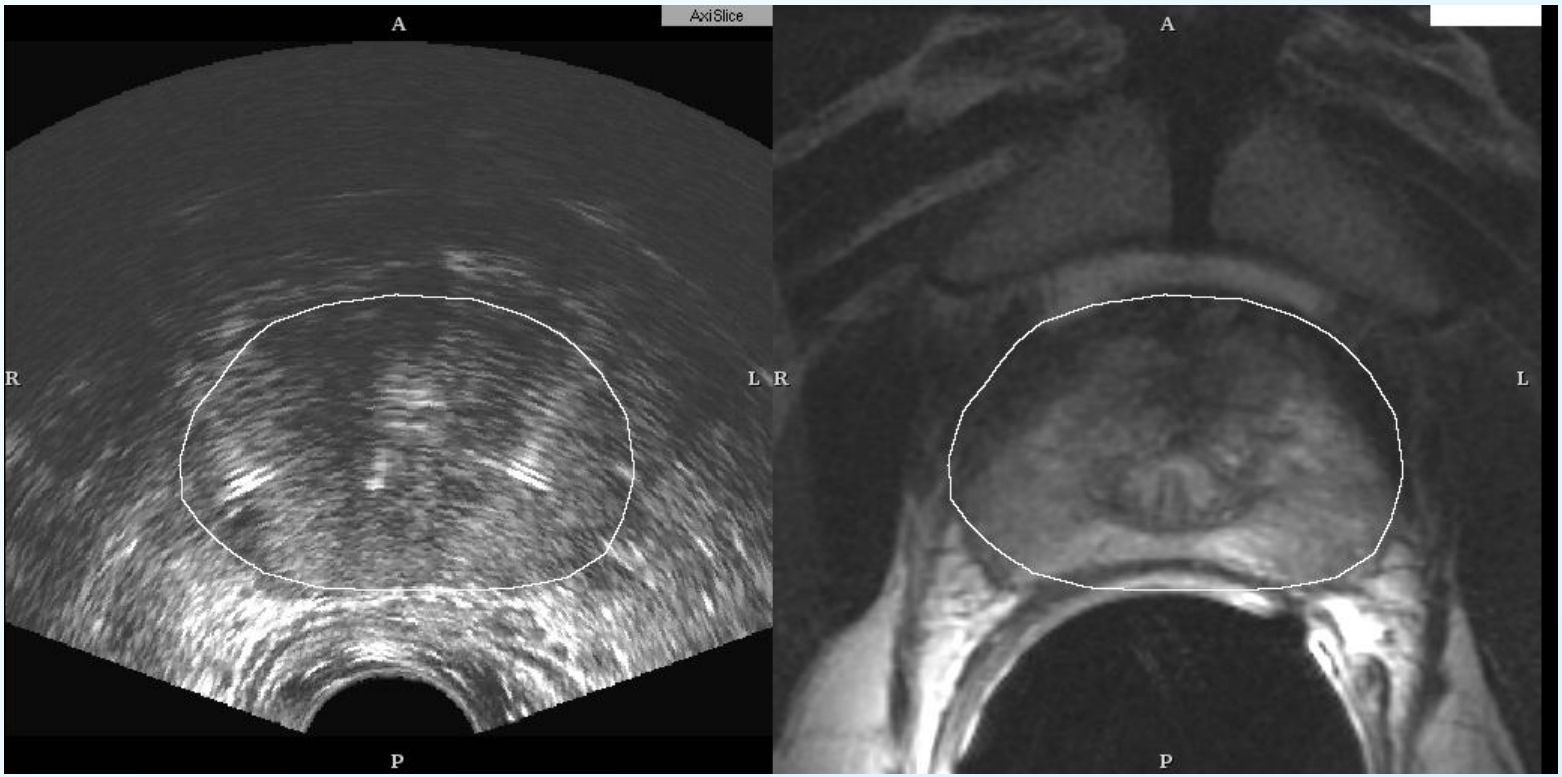
Pilot MRI-Ultrasound Study

- MRI
  - T2 FSE Axial, (TR,TE) = (5200,103) ms
  - 1.5 Tesla, endo-rectal and pelvic phased array coil
  - Reconstructed to 256 x 256 x 32 voxels
  - Voxel size 0.4688 x 0.4688 x 3.5 mm
- Ultrasound
  - Sagittal Radial Sweep
  - Reformatted into axial plane
  - Cropped to 512 x 512 x 21 voxels
  - Voxel size 0.1724 x 0.1724 x 2.5 mm
- N = 4

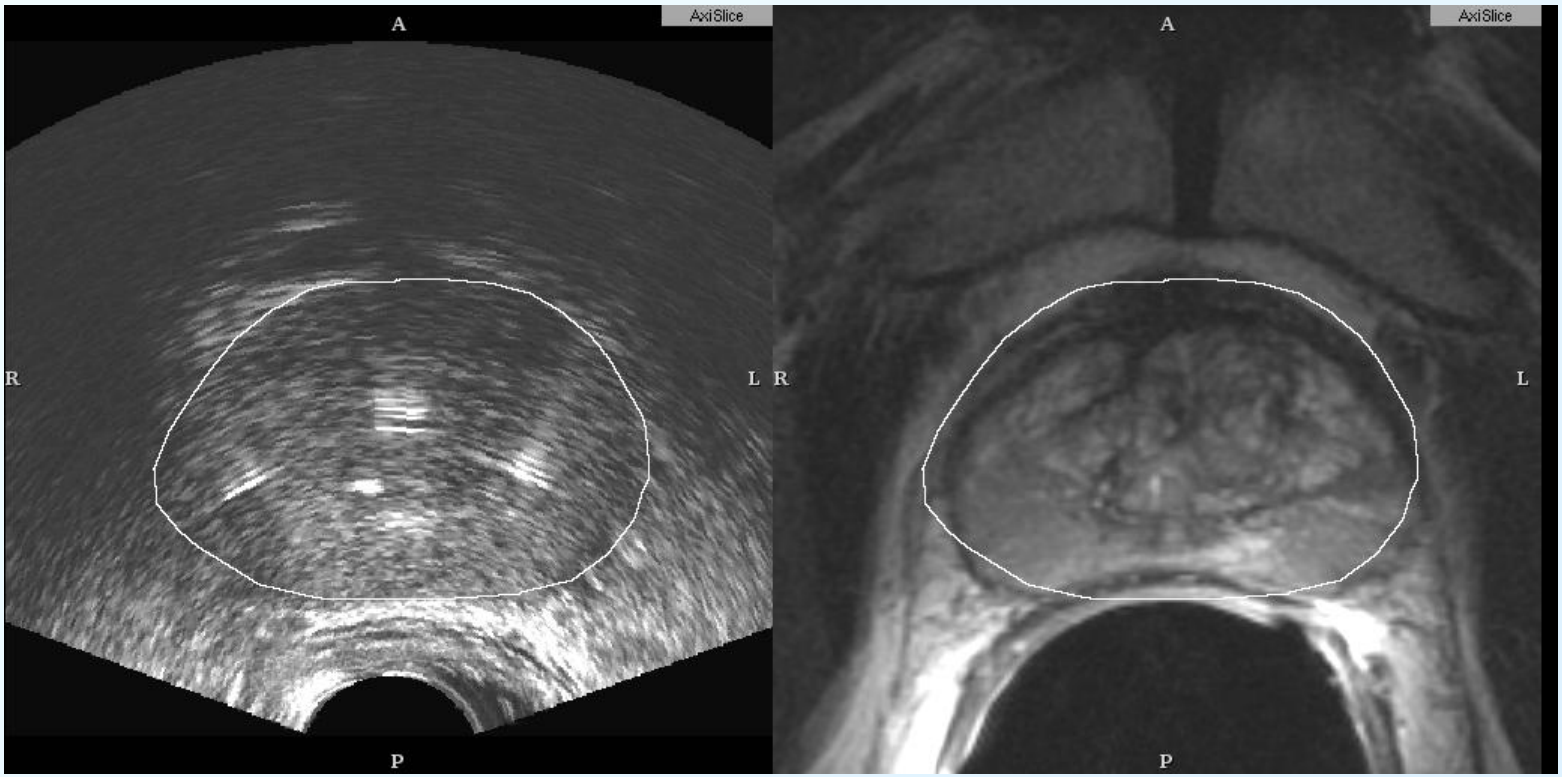
Ultrasound Segmentation



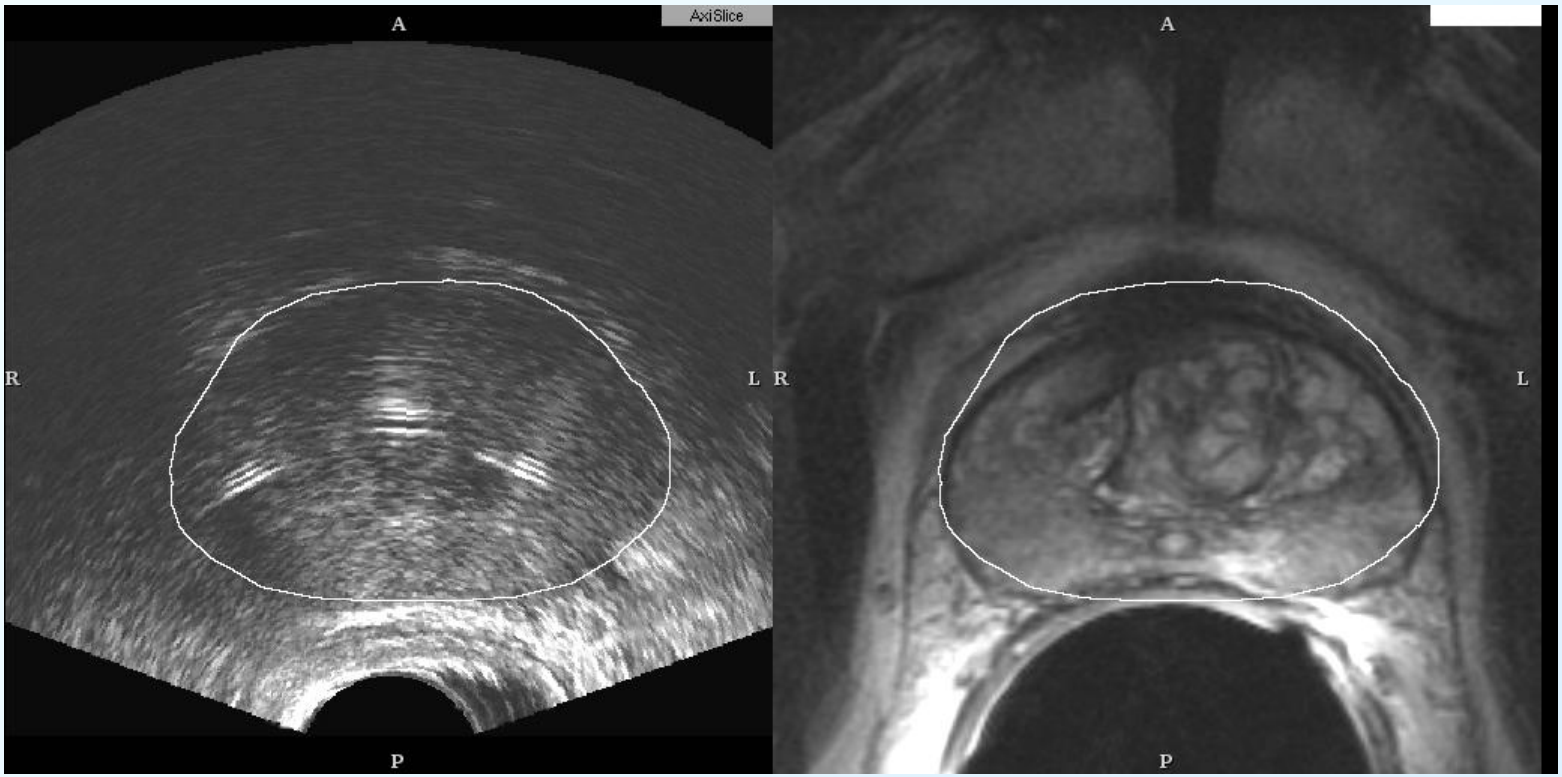
Challenge: US-Guided Prostate Therapy



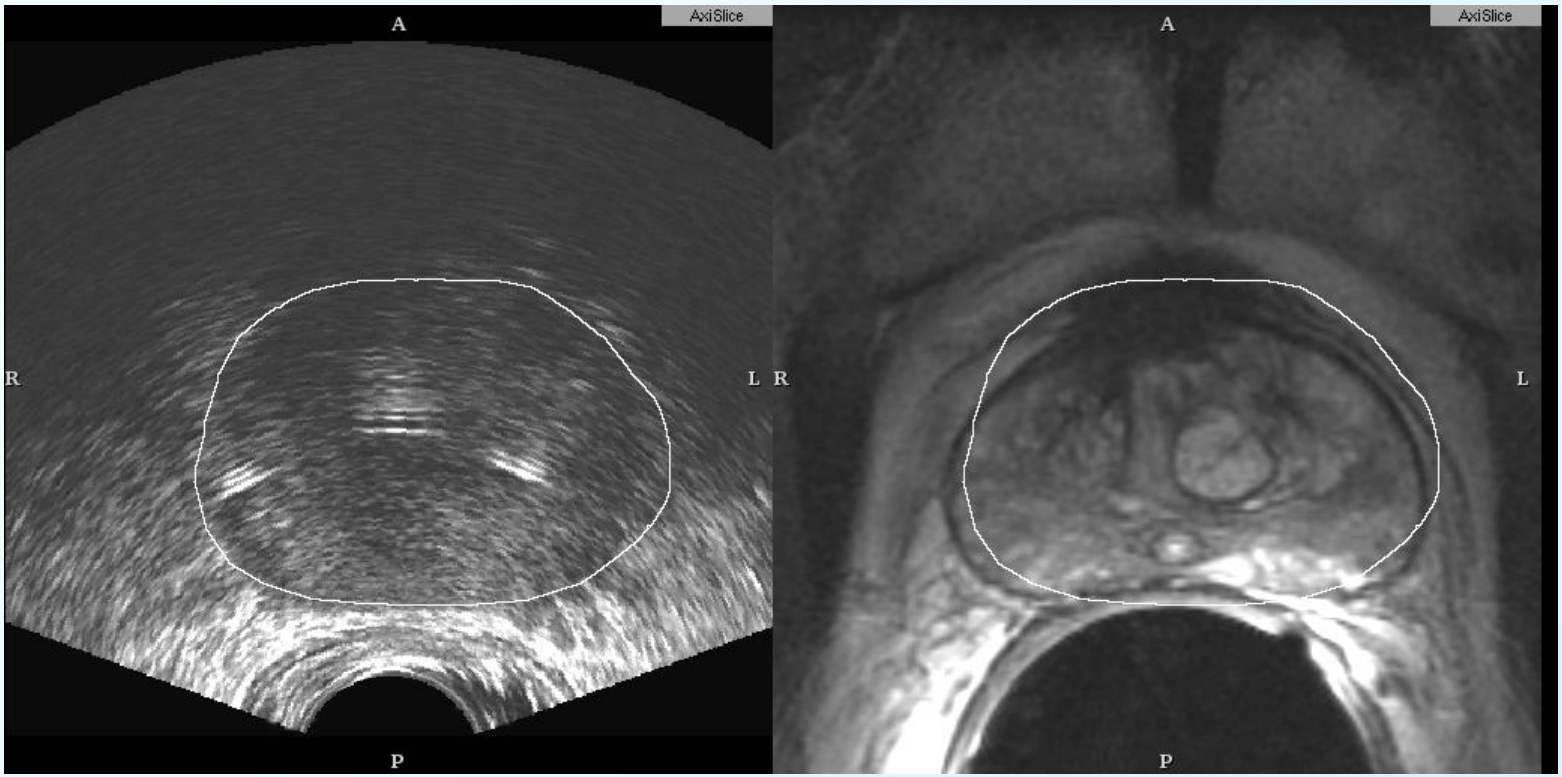
Ultrasound and MR – Side By Side



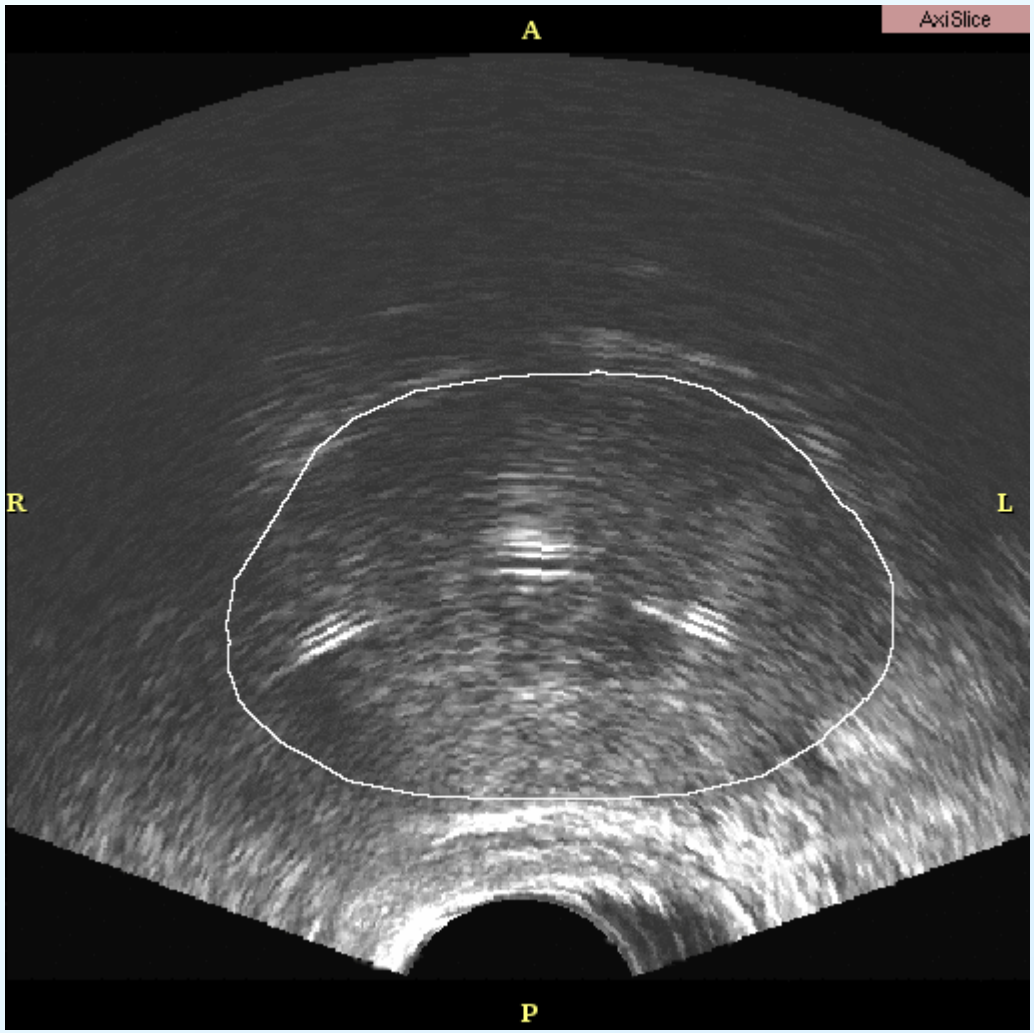
Ultrasound and MR – Side By Side



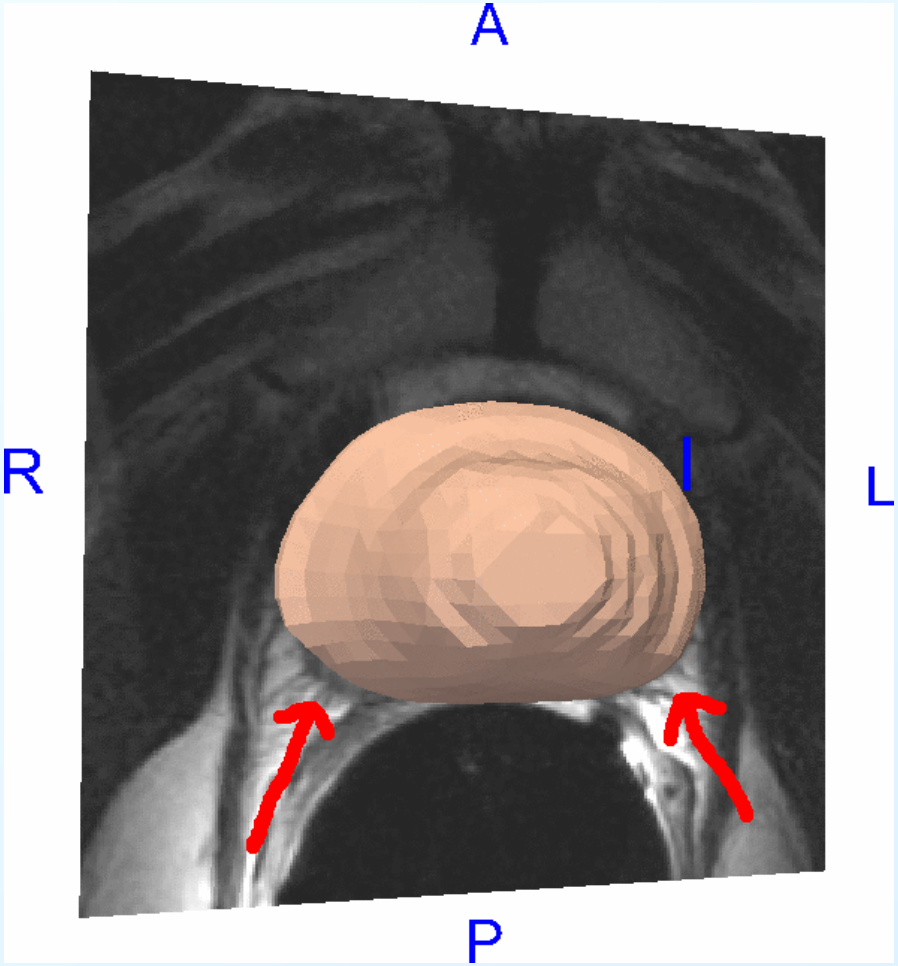
Ultrasound and MR – Side By Side



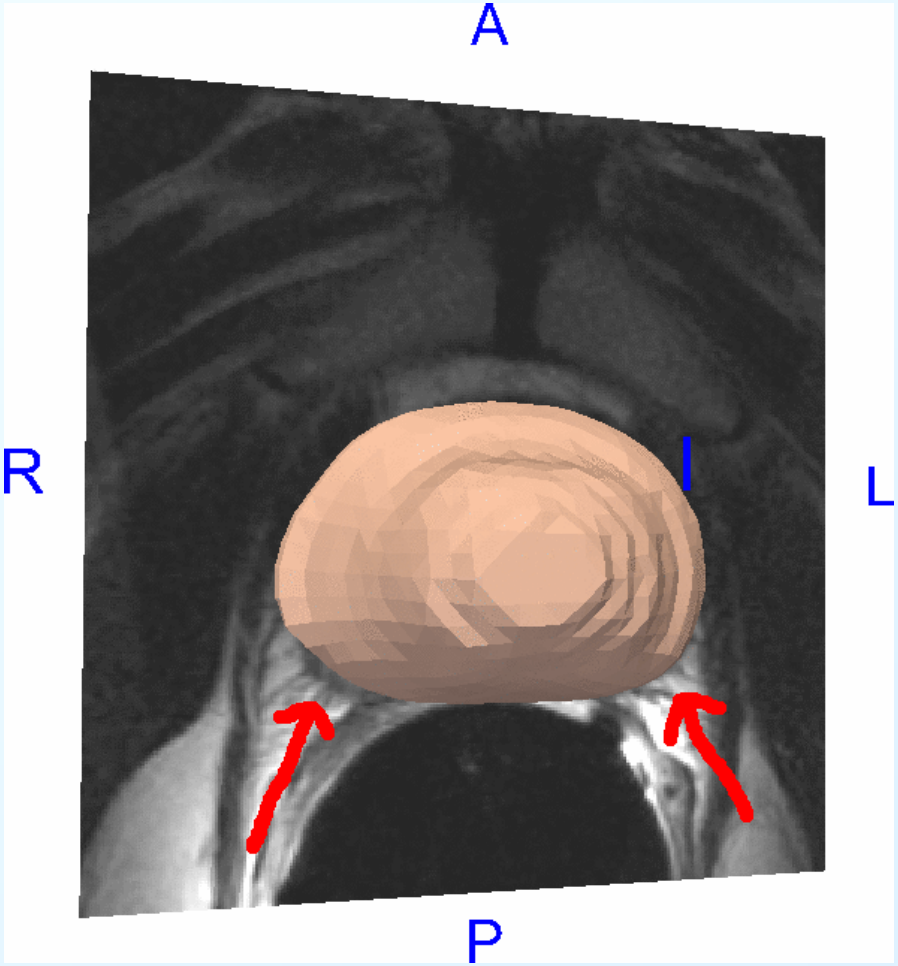
Ultrasound and Registered MR



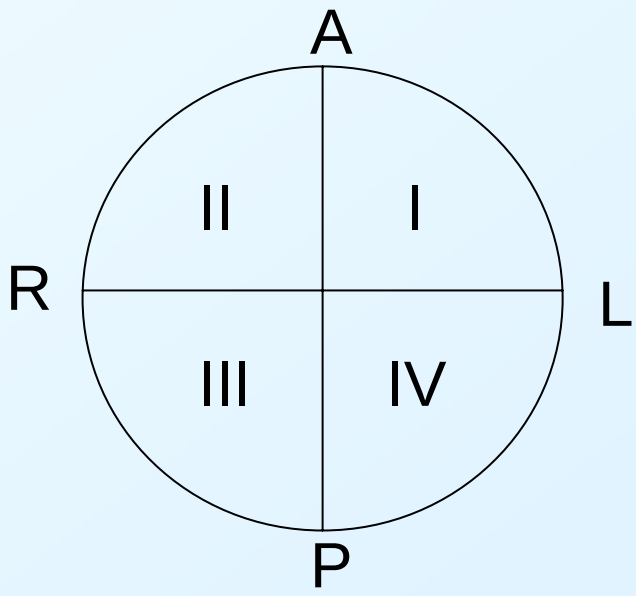
Ultrasound and Registered MR



Ultrasound and Registered MR



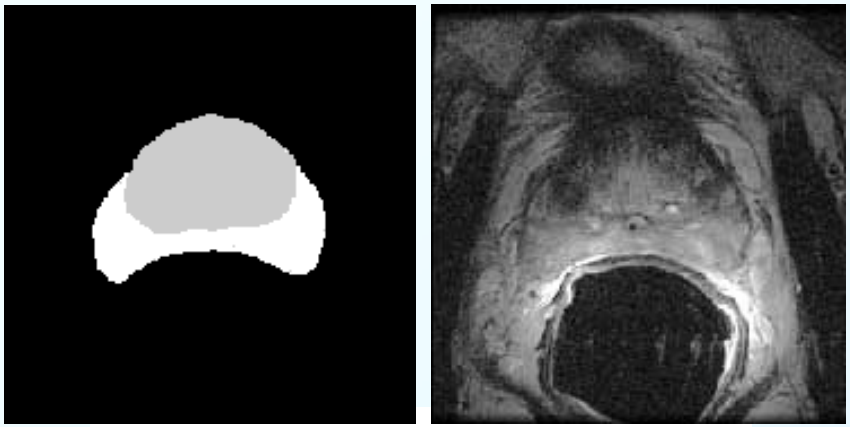
Results



Volume differences (cm^3), total gland and by quadrant.

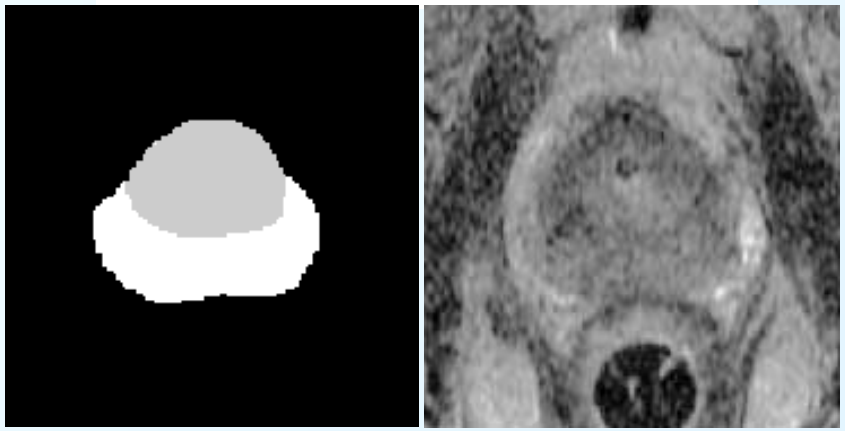
	I	I	I	II	II	II	III	III	III	IV	IV	IV	Tot	Tot	Tot
Case	**MR**	**US**	**Diff**	**MR**	**US**	**Diff**	**MR**	**US**	**Diff**	**MR**	**US**	**Diff**	**MR**	**US**	**Diff**
1	9	9	0	10	9	1	12	12	0	12	11	1	42	41	1
2	4	4	0	5	5	0	6	5	1	6	5	1	21	19	2
3	8	5	3	8	5	3	10	7	3	7	5	2	32	22	10
4	9	6	3	10	7	3	13	9	4	13	9	4	45	31	14

Registration – Our Method

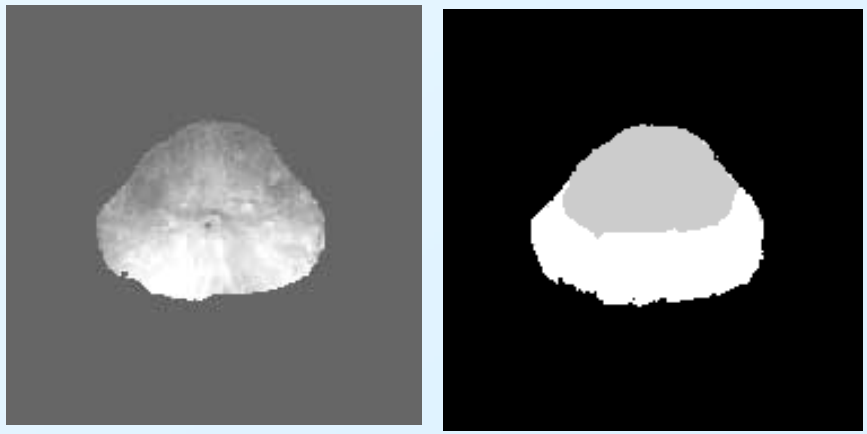


Pre-operative 1.5T T2

Registration

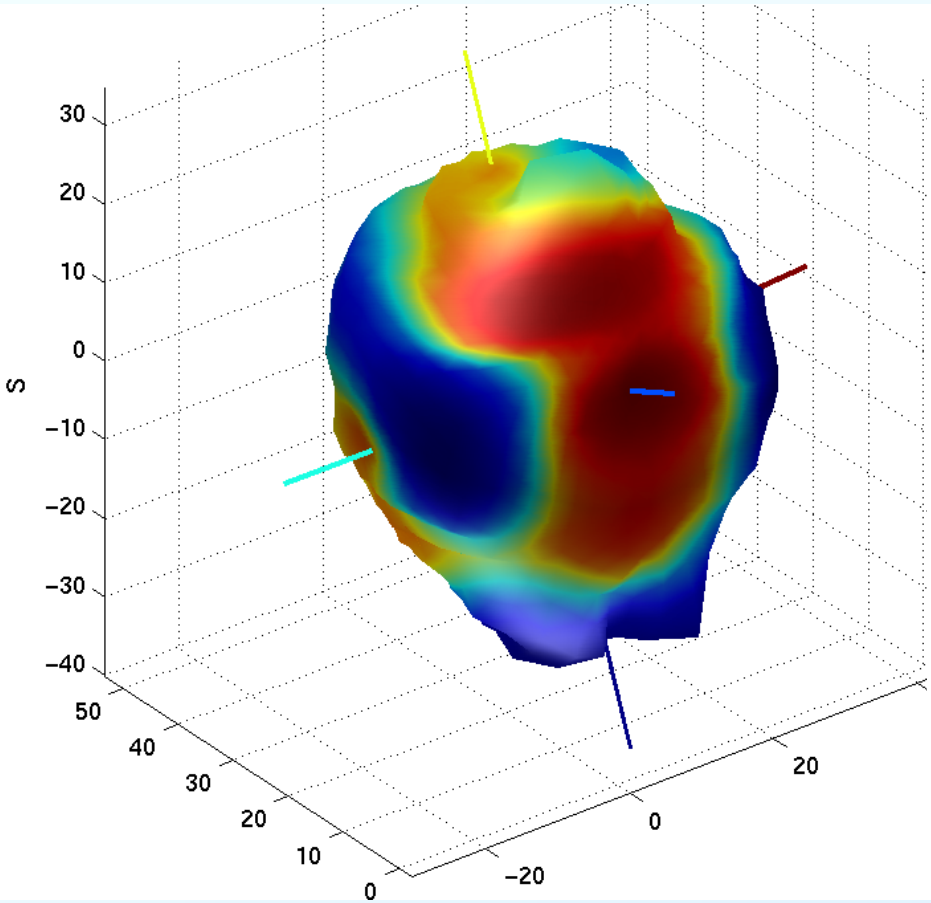


Intra-operative 0.5T

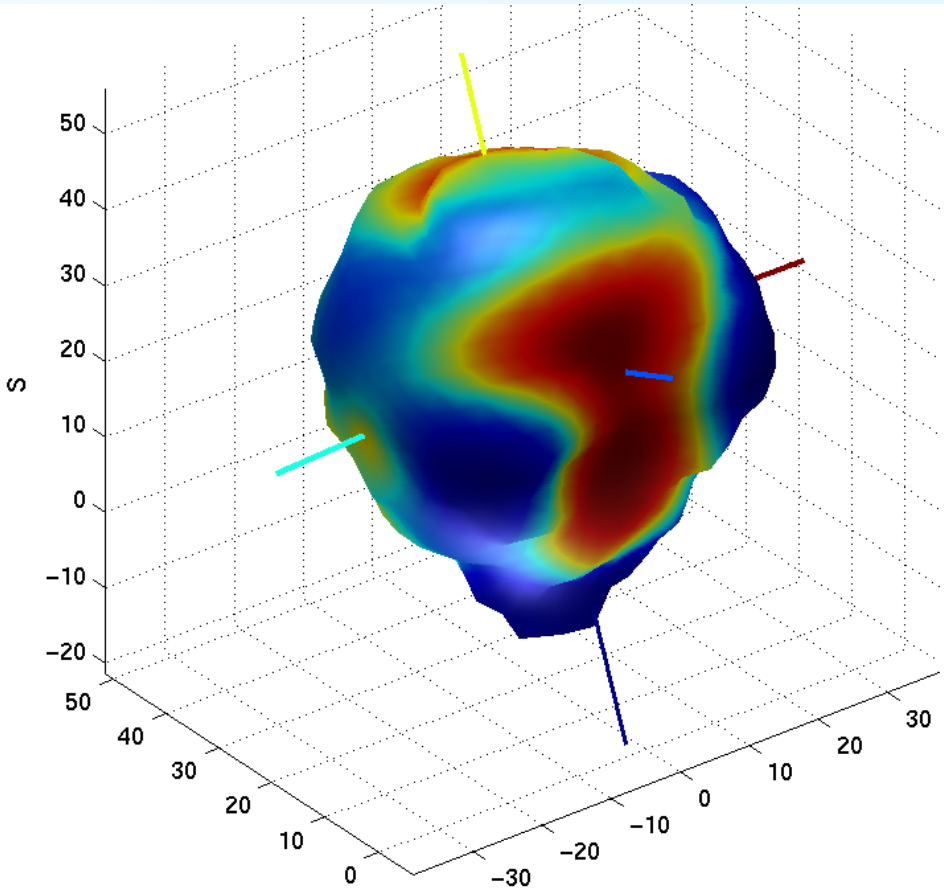


Deformed pre-op T2 FSE

Surface Matcher – Elastic Model

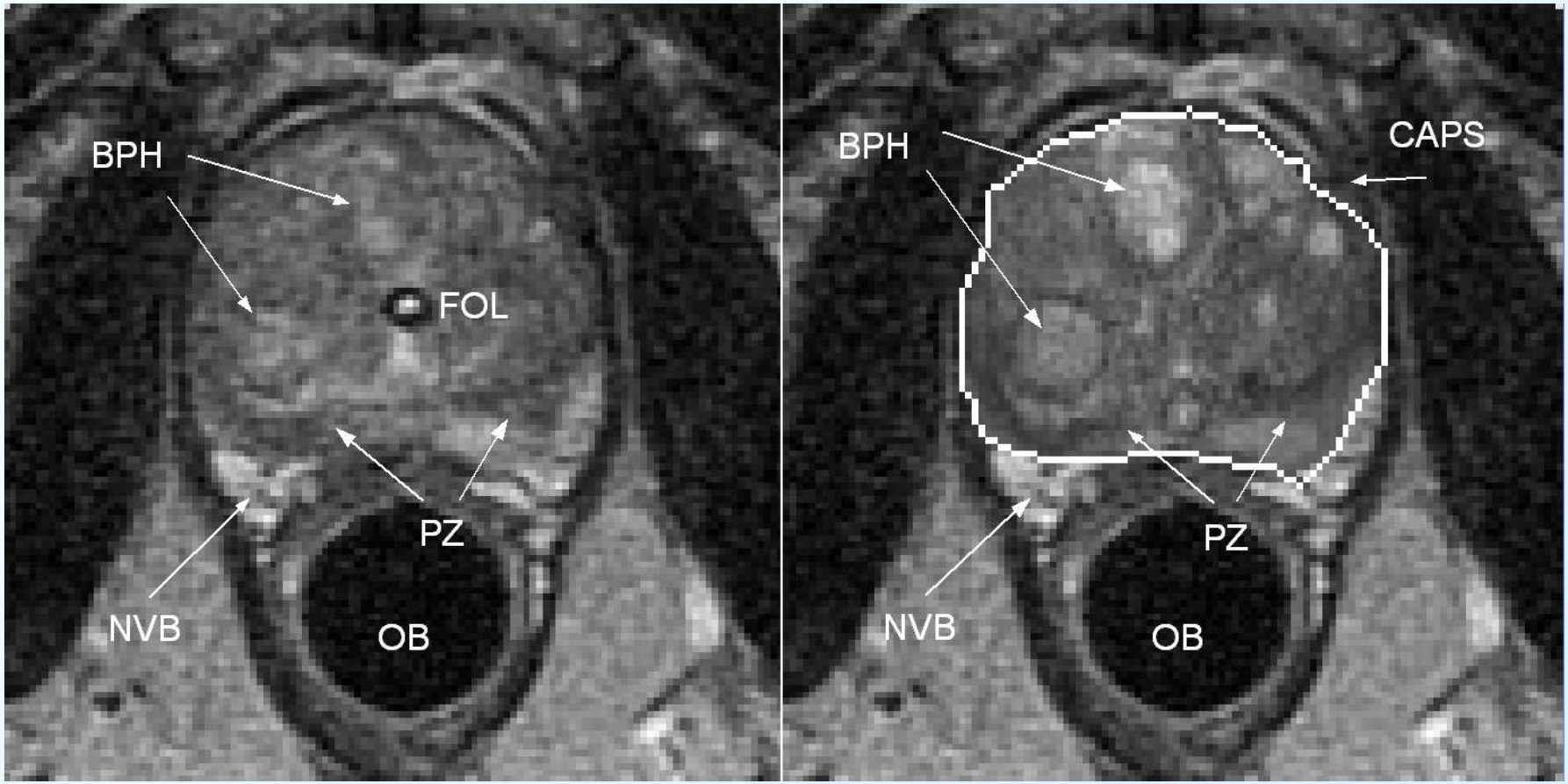


Pre-Op



Intra-Op

Registration – Previous Work



Registration of T2 imaging yields image with greater conspicuity

Conclusion

- Registration allows the best of two worlds
  - Use of high-quality, innovative imaging for segmentation, targeting and guidance
  - Use of real-time imaging to guide needle placement

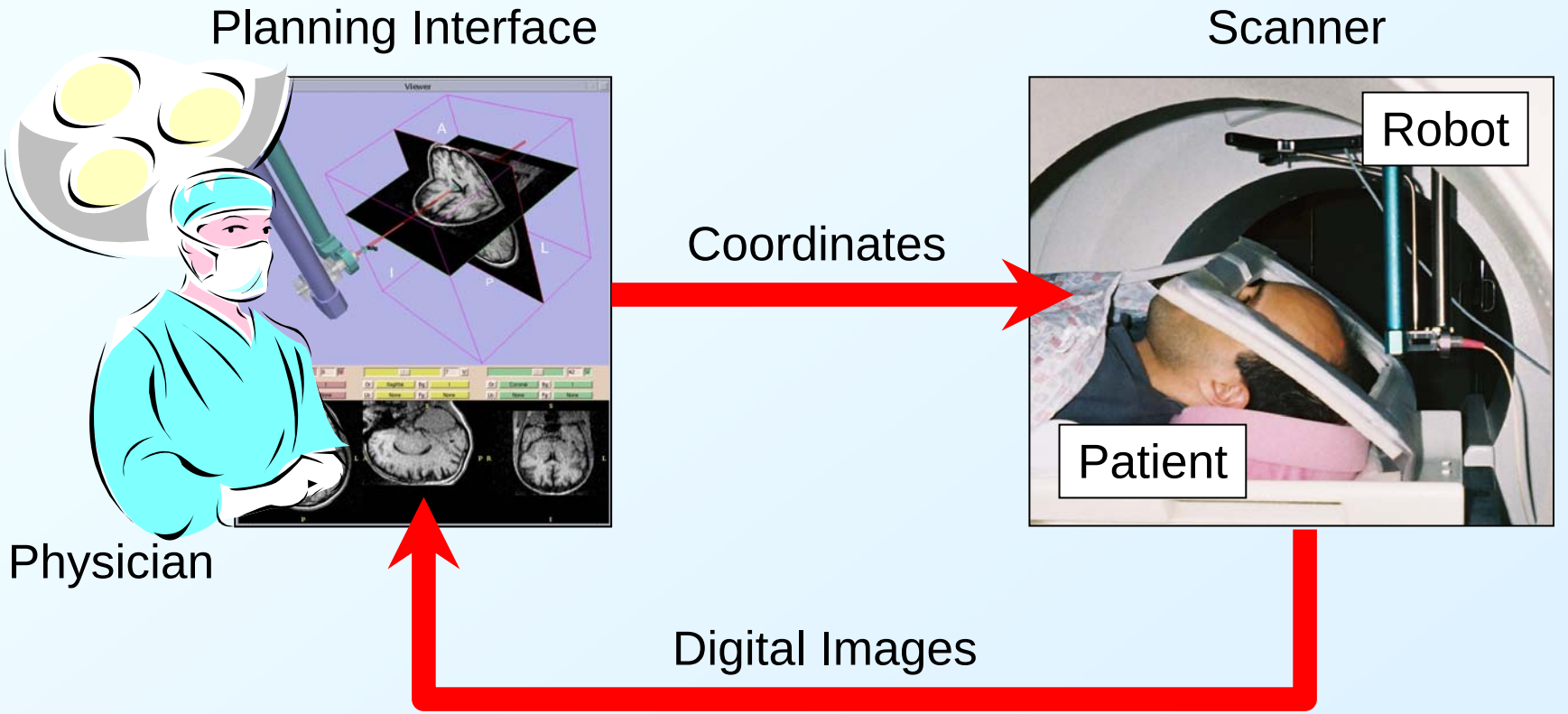
Conclusion

- Registration allows the best of two worlds
  - Use of high-quality, innovative imaging for segmentation, targeting and guidance
  - Use of real-time imaging to guide needle placement

- Registration is practical for operating room use
  - Was regular part of our MR-guided biopsy procedures
  - In-bore display system can provide integrated visual feedback to the doctor.

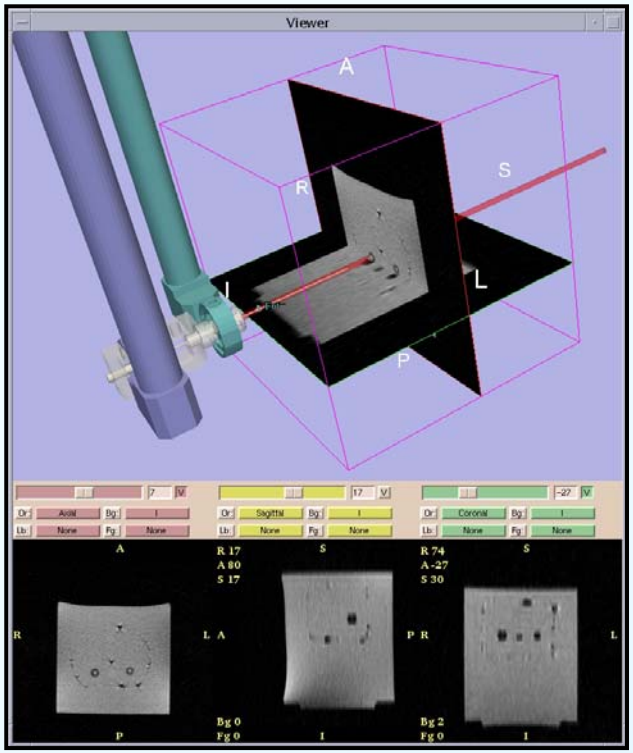
System Integration

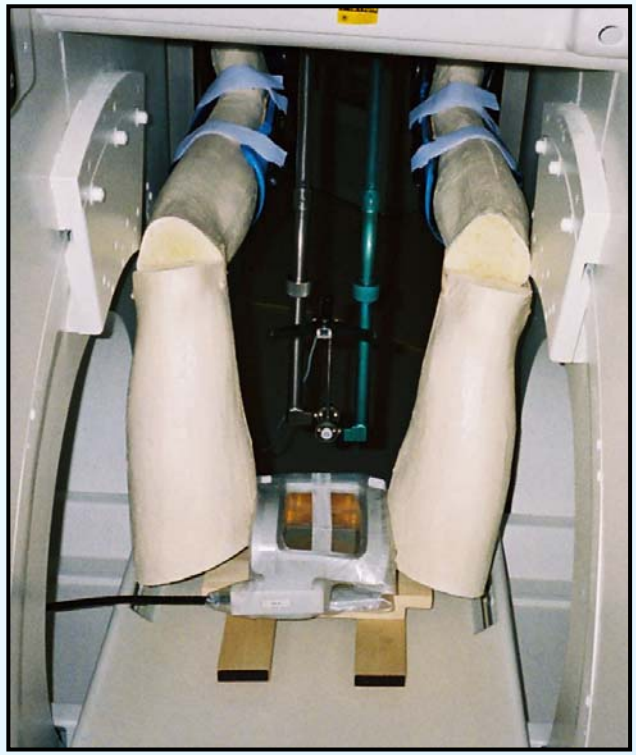
“Point and Click” Surgery

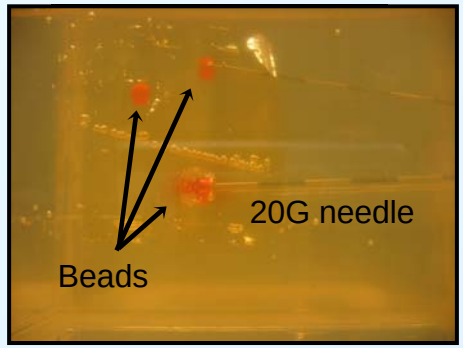


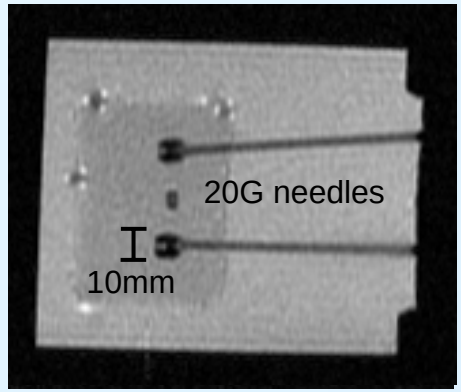
Phantom Experiments

Phantom Experiments





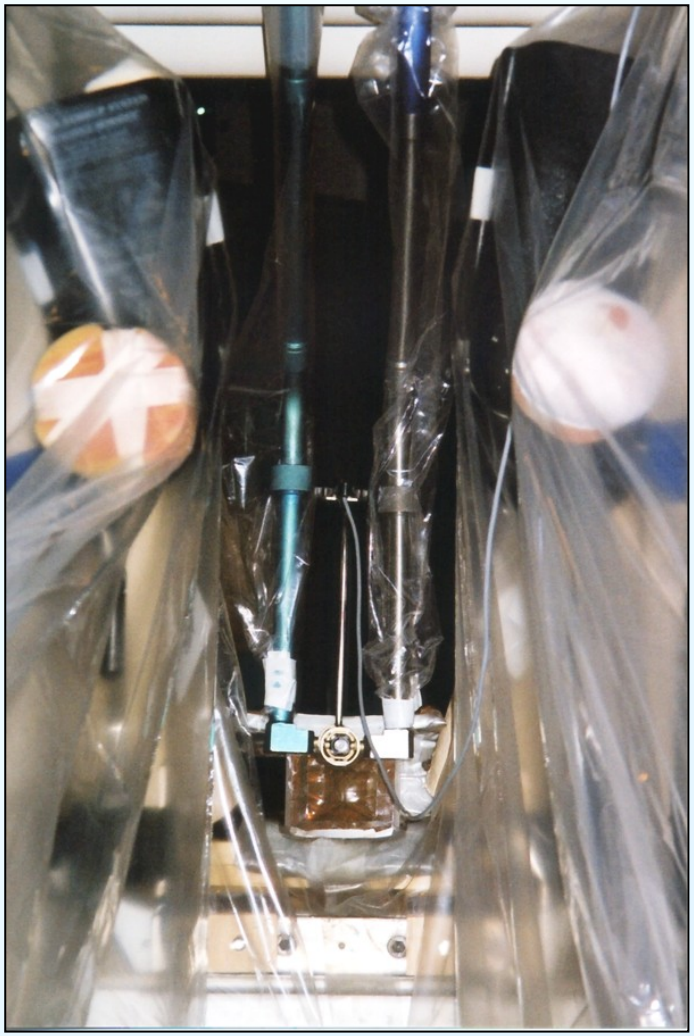


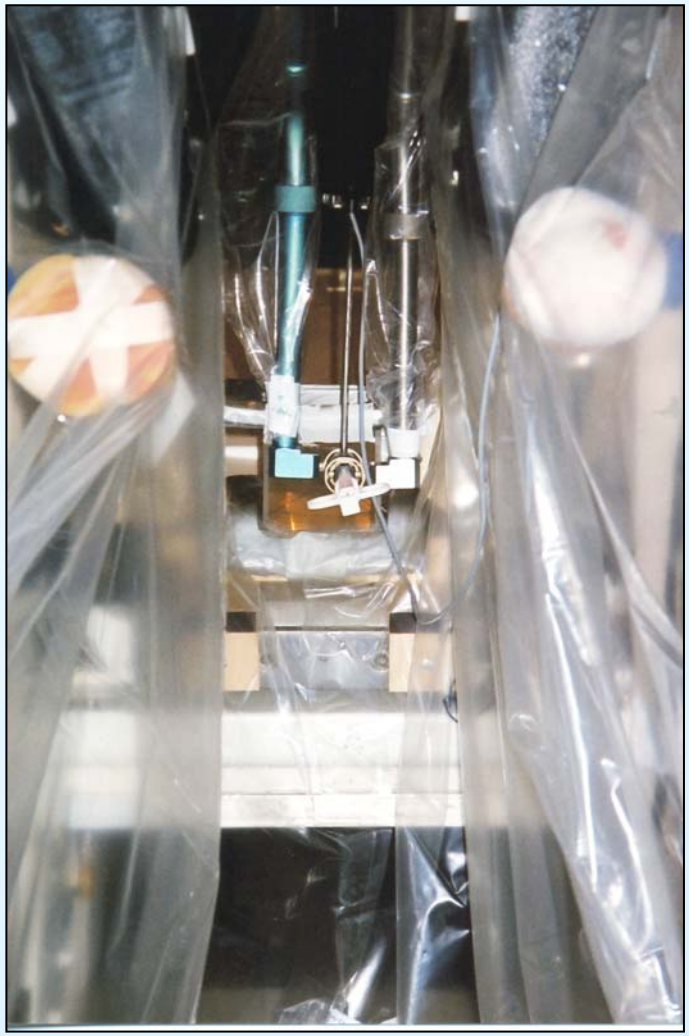


2.0 mm (as opposed to 6.9 mm by template-based insertion)

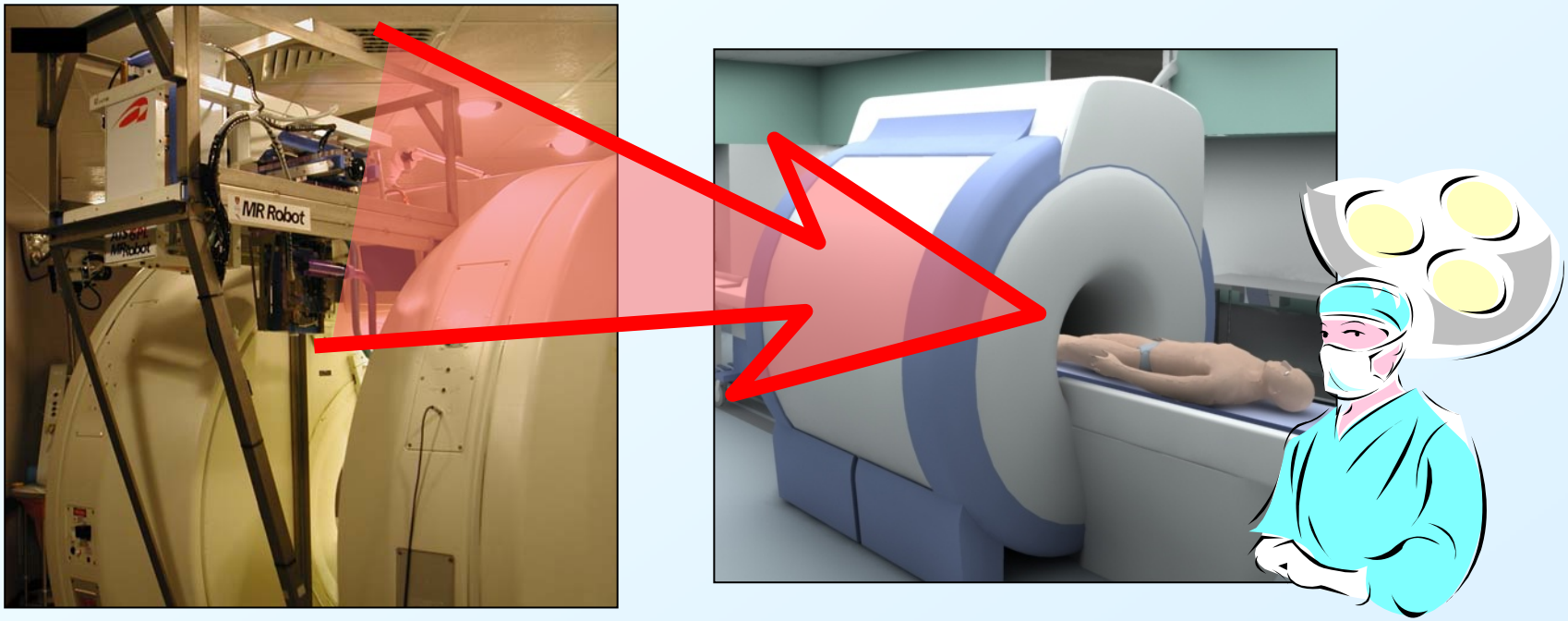
DiMaio SP, Pieper S, Chinzei K., Fichtinger G, Tempany C, and Kikinis R.
"Robot assisted percutaneous intervention in open-MRI."
5th Interventional MRI Symposium, Boston, October 15-16, 2004. Page 155.

Toward Clinical Trial





What about the Future?



Long-term Goal

- 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.