Application of Slicer in Prostate Intervention

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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

Treatment monitoring
CALGB/Novartis-STI571

High Performance Computing
Gigabit network / Terabyte storage

MR Robotics

SPL
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

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

© NIH National Center for Image-Guided Therapy, June 2007
Contouring PZ, urethra and rectum

Axial T2W image

Treatment plan
Needle Placement

Needle Insertion

RT Imaging Cor,Sag,Ax

Reposition Needle

Radiologic Evaluation

Yes

Dosimetric Evaluation

Yes

Place Seeds

No

Feedbacks: Anatomic Geometric Dosimetric

Dose Evaluation Plan Modification

Additional Needles Necessary?

Next Needle
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
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

  - 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
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.
Template-based Needle Insertion

MRI-guided Prostate Biopsy

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

Unresolved issue
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

Challenges

- **MR-compatibility**
  - Non-ferromagnetic material
  - Ultrasonic motor
  - Optical sensors

- **Software Integration**
  - Planning
  - Motion control
  - Imaging control

## Personnel

### Engineering Faculty/Staff:

<table>
<thead>
<tr>
<th>BWH:</th>
<th>AIST, Japan:</th>
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<tbody>
<tr>
<td>R. Kikinis</td>
<td>K. Chinzei</td>
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<td>W. Wells</td>
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<td>N. Hata</td>
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<td>S. DiMaio</td>
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<td>D. Kacher</td>
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<td>N. Aucoin</td>
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<th>CISST ERC:</th>
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<td>R. Taylor</td>
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<td>G. Fichtinger</td>
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<td>A. Tanacs</td>
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<td>A. Deguet</td>
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<td>C. Davatzikos</td>
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### Clinicians:

<table>
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<tr>
<th>C. Tempany MD</th>
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<tr>
<td>A. D’Amico MD PhD</td>
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### Consultants:

<table>
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<tr>
<th>S. Pieper (<em>Isomics Inc.</em>)</th>
<th>M. McKenna (<em>Small Design Firm</em>)</th>
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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, Clare Tempany

Brigham and Women’s Hospital Surgical Planning Laboratory
Harvard Medical School
MIT Laboratory for Computer Science

• This work was in part supported by the following NIH grants:

• R01 AG 19513-01, AG 5 P01CA67165-03, 1 R33 CA99015, 1RO1 NS39335-01A1, and R03HS13234-01.
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)
- T2map from T2 mapping
- Apparent Diffusion Coefficient Map
- 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

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<tr>
<th>Classifier</th>
<th>Features</th>
<th>ROC area: μ (σ)</th>
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<td>Single-channel classifier</td>
<td>T2W</td>
<td>0.599 (0.146)</td>
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<td>ADC</td>
<td>0.533 (0.114)</td>
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<td>PD</td>
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<td>0.761 (0.043)</td>
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<td>no convergence</td>
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<tr>
<td></td>
<td>all CM + DCT</td>
<td>no convergence</td>
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3T endorectal coil MRI
Recent case: Rising PSA 4 years after brachytherapy
MR/MRSI guided biopsy
0.5T/3D slicer

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

**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)

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

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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
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

Axial T2W

Sag T2W

CG

E COIL

PZ

E COIL
MRSI: Metabolic Identification of Cancer

Peripheral Zone (68% of cancers)

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
[\textsuperscript{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.
The Basic Problem

• 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.
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- Ultrasound does not have comparable tissue characterization abilities of MR.
The Basic Problem

- 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

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

Haker, ISMRM 2005
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
Ultrasound Therapy: Need for Registration

• How can MR imaging be used in the operating room to guide therapy?
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• MR Registration may help in segmentation
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
## Results

Volume differences (cm³), total gland and by quadrant.

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Registration – Our Method

Pre-operative 1.5T T2

Intra-operative 0.5T

Deformed pre-op T2 FSE

Registration
Surface Matcher – Elastic Model

Pre-Op

Intra-Op
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

Physician Planning Interface

Scanner

Robot

Patient

Coordinates

Digital Images
Phantom Experiments
Phantom Experiments

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

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.