Robotically Assisted Prostate Therapies Under CT Guidance

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Outline

• Vision & mission
• Surgical CAD/CAM paradigm
• Localized therapy
• Prostate brachytherapy
• Percutaneous robots for prostate
• Experiments & results
• Lessons learned
• Future work
The glory goes to...

- ERC: multi-institution & multi-disciplinary NSF funded center
  - Johns Hopkins University + Medical Institutions
  - MIT AI Lab + Brigham & Women’s Hospital
  - CMU + Shadyside Hospital
- Johns Hopkins University
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- Students
  - Alex Patriciu, Robert Susil, Richard Wiard, Feras Mousilli, Brian Handly, Dan Elgort, Andrew Bzostek, Rajesh Kumar
Surgical CAD/CAM Paradigm

Pre-op = CAD
MODELING & PLANNING

Intra-op = CAM
UPDATE PLAN
Robot assisted placement

Statistical Atlas
- Anatomy
- Deformation
- Physiology
- Pathology
- Dosimetry

UPDATE MODEL
Imaging & sensing

Post-op = TQM

Engineering goals

• Implement Surgical CAD-CAM paradigm in the context of percutaneous (needle-based) systems

• Create modular, factorable systems with a basic architecture that (to a reasonable extent) is invariant to imaging modality, target organ, and procedural details
Why Prostate?

We can make a huge difference

– 200,000 new prostate cancer per year
– 1,000,000 biopsies per year
– BPH: 11,000,000 current cases
– 25% of males has prostate condition
  • PC, BPH, Prostatitis (chronic testicular and pelvic pain)
• Seems to be doable
• Drives core research
• Pre-existing experience
• Strong clinical support
• Industrial participation
Prostate diseases and treatments

- **Adenocarcinoma**
  - Prostatectomy - resection
  - External beam – high energy X-ray
  - Braceytherapy – implanted radioactive sources
  - Experimental local therapies
    - Thermal (RF, Magnetic, HiFu, US, cryosurgery)
    - Gene therapy

- **BPH**
  - TURP
  - Thermal (RF, HiFu)

- **Biopsy**
  - Sextant + targeted
Target procedures

• Transperineal procedures under
  – US guidance w/ Burdette Medical Systems under Phase I/II SBIR
  – CT guidance at JHU Urology
  – MRI at JHU Urology
  – Open MRI at BWH (in collaboration)

• Branch out to transrectal & transurethral procedures
Gold standard

- TRUS
- Template
- Manual insertion

(Burdette’s Interplant®)
Transrectal US guided brachytherapy

Enlarged diagram of catheters filled with radioactive Iodine-125 or Palladium-103

- Spacer
- Radioactive seed
Transrectal Ultrasound Probe, Template, and Stepper
In OR Patient Position and Setup
Transrectal Ultrasound of the Prostate
Prostate Implant PrePlan

Obtain axial ultrasound images of the prostate from apex to base in 5 mm increments.

Base 0 mm 5 mm 10 mm 15 mm
20 mm 25 mm 30 mm Apex 35 mm
Defining Regions of Interest
Isodoses and Selection of Seed Loading
The Brachytherapy Pre-Plan
Before insertion

(Burdette’s interplant®)
Urethral Sparing
Prescription Dose Coverage
3D Volume Visualization: Seeds
3D Volume Visualization: Seeds
Dose Volume Histograms (DVH)

- Urethral (100%)
- Prostate (94%)
- Rectal (38%)
Traditional vs. Intraoperative Brachytherapy
Result: Implanted prostate
Transverse CT Slice with Dose
Orthogonal CT Views with Dose Overlay
Mess after insertion
Why robotic assistance

- No template
  - Arbitrary entry & angle
  - No pubic arch interference (?)
  - Faster & easier setup/calibration
- Encoded robot
  - Track needles and seeds
  - Real-time optimization on per needle/seed basis
  - Full intraop dosimetry (calculation & measurement)
  - Less re-insertions (?)
- Less or no dose to crew
- Electronic procedure logs
Basic robot configuration

- Needle guide/driver – 1DOF
- Remote Center of Motion (RCM) Robot – 2DOF
- Cartesian (XYZ) motion stage – 3DOF
RCM robot & needle driver
Pre-clinical prototype system

- 7-DOF passive arm
- Needle injector with mounted stereotactic fiducials
- Joysticks and safety switches
- Locking arm
- 2-DOF Remote Center of Motion robot
- 1-DOF needle injector with mounted stereotactic fiducials
- Amplifier box
- Table side robot mount
Schematic drawing of the prototype system

- Surgeon
- Planning & control computer
- DICOM images
- CT table
- Robot
- Patient
- CT gantry
- CT computer & DICOM server
CT-guided biopsy
When the guinea pig chickens out...
Instrumented full-body phantom
Close-up view of needle insertion
Needle driver & stereotactic adapter

CT slice
Stereotactic CT-guidance & targeting
Recent cadaver experiment
Inside the gantry
Targeting
Path planning in the 3D Slicer system
Needle insertion
Results

• In air:
  – Total systemic error < 1.5 mm
  – Directional error < 1 deg
• In cadaver:
  – Directional error ~ 2 deg
  – Needle stopped short
  – Organ shift ~ 5 mm
  – Transmission slippage ~2-3 mm

(Note: diamond needle tip, not loaded, prostate was not pinned, skin was incised)
Lessons learned

- Procedure seems to be doable in scanner
- Robot is sufficiently small, strong and dexterous
- Needle bending was lot less than expected (but do not expect to incise live patients)
- Organ shift → pin down the prostate
- Slippage → redesign transmission
- Setup/take down time is minimal
- All we learned is valid for
  - US guided system
  - Other CT guided procedures
Future work

• Short term:
  • IRB for CT guided biopsy
  • US guided system w/ Burdette Medical Systems
  • Clinical trial in CT guided kidney ablation
  • Neurorad interventions (nerve root, facet joint)

• Midterm:
  • Steerable needle & wrist

• Long term:
  • Smart needle
  • One stop shopping
  • Full blown atlas & TQM
The robotic system easily deployable in prostate, spine, and abdominal treatments
Spinning needle driver (CAD drawing)

- Aluminum outer package
- Non backlash transmission
- Bi-directional translation motor
- Bi-directional rotation motor
- Variable diameter, Independently controlled rotation and translation
- Remote Center Motion (RCM) robot to aim needle
- Radiolucent fixed arm
- Radiolucent translating arm
- Bi-directional rotation motor
- Aluminum outer package
Spinning needle driver prototype
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