Image Guidance Techniques Related to Radiation Oncology

Robert Cormack
Department of Radiation Oncology
DFCI/ BWH Cancer Center
Outline

- Radiation Oncology
- Imaging
- Diagnosis: Visual
- Treatment
  - Brachytherapy: Visual -> Adaptive
  - External Beam: Visual -> Adaptive
- Evaluation
  - Brachytherapy: Multimodal Registration
  - External Beam: Deformable Registration
- Future
Radiation Oncology

- Radiation damages cells
- Cancerous cells are less able to repair radiation damage
- Two approaches
  - Single shot tumoricidal dose
  - Fractionated treatment: 10-40 treatments allowing preferential repair of normal tissue
- Constraints
  - Neighboring sensitive structures
  - Uncertain target definition
  - Uncertain target location
Radiation Oncology

- **External Beam: LINAC**
  - Non invasive/non distorting
  - Treatment at a distance
- **Process**
  - Film
  - Choose beams
  - Plan dose
  - Delivered planned beams
- **Single to many fractions**
- **Patient (target) not tied to source of radiation**

- **Brachytherapy**
  - Isotope on or in target
  - Inherently distorting
- **Process**
  - Place applicator
  - Film
  - Determine source placement
  - Place isotope as planned
- **Single or few fractions**
- **Radiation source more or less connected with target**
Imaging in Radiation Oncology

- Diagnosis
- Localize target: CT MR PET for planning: dose evaluation
- Find patient/target at treatment time: Port films, diagnostic X-ray, US, RF
- Evaluate treatment
  - Geometric/dosimetric
  - Response
- Already image intensive
Limits to Radiation

- Target uncertainty: margins
- Daily applicator placement
- Daily location uncertainty: margins
- Margins: Increasing radiation fields increases volume of normal tissue that is irradiated
- IMAGE GUIDANCE: The use of imaging (3D or 2D) to reduce margins or improve dosimetric evaluation of procedure
Imaging (CT, MR, PET.....)

• Physician already knows what to expect
  – Increased resolution
  – “Penetrating vision”
• Visualizes what the eye cannot
  – CT: contrast enhancement
  – MR: Tissue types
  – PET: Metabolism
  – US, Film, RF, IR
• “Why did somebody put a CT in the OR?”
Prostate Cancer

• Most common malignancy for US males
• PSA offers early detection
• Local treatment (surg or BRT) for confined disease vs XRT + systemic for nonconfined
• Pathology required
• Progresses slowly: side effects must be tolerated for a long time
Prostate

- Small ~10’s of cc
- Deep 10-20 cm from surface
- Mobile
- Neighbor to sensitive structures: bladder, urethra, rectum, NVB
- Dangerous ~300,000 in US alone
- Treated with XRT/BRT
Prostate Cancer

• Detection:
  – Image guided biopsy

• Treatment
  – Permanent prostate implants
  – External beam prostate treatments

• Evaluation
  – Multimodal image guidance: post implant dosimeter using registered images
  – Cumulative dose distributions over time
Prostate Cancer Detection

- Localized disease can be treated
- Early detection difficult
- PSA helpful but not specific
- Tissue biopsy required for diagnosis
- US Susceptible to false negatives
- Disease starts in PZ
MRI for Detection

- “Why did somebody put an MR in the OR?”
- Biopsy needed to confirm suspicions
- MR excellent for distinguishing soft tissues in the pelvis
- Interventional MR allows visualization of biopsy
- MR Visualizes PZ
Signa SP Guided Biopsy

- Imaging locates region of interest
- Optical calibration of template
- Calculated coordinates and trajectory
- Image verifies needle placement before sampling
- Targets suspicious vs sextant.
- Image provides verification of needle placement
Biopsy Summary

• Imaging allows verification of needle placement before tissue is sampled
• Interventional MR can visualize suspicious regions
Prostate Cancer Treatment

- Biopsy leads to treatment
- Localized disease suited to localized treatment
- Surgery (gold standard): high morbidity
- External beam radiation non invasive but dose limited appropriate for nonlocalized disease
- Brachytherapy (~100 sources)
  - Minimally invasive
  - Highly conformal
  - Requires image guidance
Rad Onc Image Guided Prostate Treatments

- MR (US) Permanent I125 prostate implants
- Image guidance of external beam (XRT) treatments CT (US, Film): daily treatment setup
- Dose cannot be imaged unlike resection, Cryo, HIFU
Prostate Brachytherapy

- Dose prostate
- Spare rectum, urethra and bladder
- ~100 tiny sources delivered by needle through transperineal approach
- Misplacement may cause insufficient dose
  - Imaging used to capture configuration of the implant
  - Dose calculated from data acquired from images
Image Guided Prostate Brachytherapy

- **Traditional:**
  - TRUS study and plan
  - TRUS implant
  - CT evaluation

- **In-OR planning**
  - Image, plan treat (removed repositioning)
  - Adapt treatment plan as sources placed

- **Needles seen, not seeds or radiation**
Adaptive Brachytherapy

- MR Tracks individual needles
- Dosimetry software calculates dose from configuration
- Dosimetric feedback during procedure
- No one image summarizes procedure
- Cumulative effect calculated from data extracted from images
- Treatment inferred
Image Guided External Beam Treatments

• Planning
  – “Simulate”
  – Find prostate
  – Choose beams
  – Lasers + Tattoos

• Treatment
  – Position: Lasers + Tattoos
  – Adjust
  – Treat
Image Guided Treatment Planning

- CT finds prostate
- Beams are chosen in software
- Lasers + Tattoos
- Traditional beams: large margins
- IMRT produces offers sparing with conformal dose distributions
- “Why did somebody put an OR around the CTSim?”
XRT Treatment Delivery

• Portal films
  – See bony anatomy
  – No prostate visualization
  – Location of prostate inferred (balloon helps)
  – Patient adjusted accordingly

• Similarity
  – Guide needle to biopsy
  – Place prostate in fields

• Can only deal with rigid transformations
• Cannot adjust to what you cannot see

Lateral Port Film
XRT Pretreatment CT

- "What is that CT doing in the LINAC bunker?"
- MDACC CT on rails
- Allows CT scan of patient immediately before treatment
- Scan localized prostate
- Shifts correct for day to day motion
- Can only deal with rigid transformations
Adaptive XRT

- Traditional: shift target back into
- Shape changes are problematic
- ART Adapt fields to daily position & shape
- No visualization of the radiation
- Complex with static fields
- ?Possible? with IMRT
Treatment Summary

- Imaging can guide delivery of treatment either BRT or XRT
- Allows correction of misplacement or daily positional shifts
- Allows opportunity to adapt treatment based on RT imaging
  - Adaptive in-OR treatment planning
  - Adaptive fields on LINAC
Need for Additional Imaging

- Imaging at time of treatment differs from optimal imaging used for diagnosis/staging
  - Low field MR vs 3T +- MRS
  - Portal films vs CT or PET or MR soft tissue
- Imaging may introduce variable distortions: endorectal coil, TRUS
- Need a means to combine data sets
Brachytherapy Follow-up

- Need to evaluate success of implant
- CT finds seeds easily
- MR soft tissue resolution
- Merged image set
Post Brachytherapy Image Registration

- Difficult soft tissue registration
- No natural landmarks
- Post implant: ~100 fiducials
- Merged dataset offers anatomy, dose and indication of uncertainty
- Rigid transformations well understood
Deformable/Dynamic Registration

- Intraoperative imaging may not provide desired information
- Guidance: US, Film, CT
- Information: PET, MRI, MRS ...
- Guidance and Information may be in different geometries
Example: Improved Registrations

• Brachytherapy/Biopsy
• Interventional MR
  – Low field 0.5 T
  – Deformed anatomy
• MRS, Diffusion MR
  – High field
  – Different anatomy
• XRT: LINAC
• CT Planning
• Sub volume identification
  – MRS
  – PET
• CT on rails: cumulative DVH

• Goal: Warp high quality images into interventional coordinate system
Tools

- Biomechanical model
- Match surfaces
  - Modality to modality
  - Day to day
- Elastic model deforms internal points from one scan to another
Current Validations

- Brain (slow)
- Bladder (less slow)
- Prostate (sufficient for biopsy)
  - MR guided (0.5T obturator)
  - Diagnostic fused (1.5 w ERC) T2 + Diffusion + MRS
  - PZ to PZ match for validation
Applications

- Brachytherapy/Biopsy
  - Better targeting based on diagnostic imaging
  - MR guidance in US setting
  - Cumulative doses in fractionated settings

- XRT
  - Better targeting by incorporating MRI/PET
  - Calculate dose based on daily position
Evaluation Summary

- Registrations can bring more information to an image guided procedure
- Deformable registrations overcome constraints of imaging geometry
- Significant user interaction
Image Guidance

- Imaging has allowed us to see beyond what is visible to the eye
- Radiographic tool guidance
- Quantitative procedure guidance
- Quantitative adjustment to daily changes
- Multimodal evaluation
- All derived from images at time of procedure
Future

- Moving beyond what is available from the interventional imaging
- Multimodal image guidance requires REAL TIME adaptive techniques
- 4D Imaging
- Gated treatments

Image guided OR: CT/PET, 3T MR, Fluoro