New Developments in Radiation Therapy Targeting

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AAPM '07 Learning Objectives

• Understand the presence and variety of interfraction motion present in radiation therapy.
• Develop awareness of novel approaches being proposed to address these issues.

Targeting Uncertainty in RT

• Setup Variation
  – Patient position/geometry differs from planning
  – Commonly inferred by radiography, from skeletal anatomy
  – Not necessarily indicative of target location

• Internal Organ Displacement
  – Tumor and/or normal tissues are positioned differently relative to the skeleton than they were during planning and simulation

• Volume Change and Deformation
  – Geometry of the tumor and/or normal tissues is different from simulation/planning conditions

Respiration-Induced Motion

Normal Breathing
Deep Breathing
Breath-hold Exhale
Breath-hold Inhale
Variability in Respiratory Motion

11 CBCT scans with retrospective 4D CBCT sorting and reconstruction

Prostate Anatomy: Patient Specific Mobility

“Full” Rectum
“Empty” Rectum

Prostate: Probability of Excursion vs. Elapsed Time

POI = Posterior-Mid Prostate
Bladder Filling

1 hr cine MR (sagittal, TRUSP sequence)

Bladder Wall Velocity

TruFISP Sequence, Siemens 1.5T

Therapy-induced Changes: Head and Neck

7 weeks of therapy with weekly MR imaging

Shrinking Target and Normal Structures

Cancer of the Cervix: Therapy-induced Changes

Sagittal Images

Chan, Dimmell et al., PMH
Serial MRI images of a 54 year old woman with a FIGO IB adenosquamous carcinoma of the cervix.

Dose-dependent Volume Changes in Cancer of the Cervix

- Pre-Tx
- 8 Gy
- 20 Gy
- 28 Gy
- 38 Gy
- 48 Gy

Chu, Donnell et al., PMH

4D IGRT and Temporal Scales of Intervention

- Definitely not exclusive processes
- Efficiency and technology will drive the relative use of these scales.
- Need sufficient information in the on-line imaging to indicate the need for off-line re-planning.
- Off-line planning may require additional and different information.

Sensitive, Frequent Imaging

- Greater Contrast to Noise
- Higher Sampling Rates
- Less Ambiguous Signals
  - e.g. Volumetric vs. radiographic vs. fiducials
- Lower Acquisition Penalty
  - Time, Dose

Precise, Responsive Delivery

- Faster Response Times
- Steeper Dose Gradients
- Higher Dose Rates
- Lower Body Doses
- More Degrees of Freedom
- Robustness
IGRT Technologies

- Ultrasound
- KV Radiographic
- Portal Imaging
- Markers

**Implantable Sensors**

- Wireless AC electromagnetic resonant circuit
  - No external lead wires
  - No internal power supply
- Designed for permanent implantation
- Implant prior to therapy
- Positioned in soft tissue in or near treatment target
- Remains inactive until energized by system console
- 1.85 mm x 8 mm for initial prostate application

**Implantable Sensors: Localization System**

Components
1. Wireless Transponders
2. Array
3. Console
4. Infrared Cameras
5. Tracking Station
Examples of behaviors observed in the continuous tracking data: (a) continuous target drift; (b) transient excursion; (c) stable target at baseline; (d) persistent excursion; (e) high-frequency excursions; (f) erratic behavior. Red: vertical, green: longitudinal, blue: lateral, black: vector length.


Comments on Implantable Sensors

- Raises interesting feedback/intervention questions for the therapist at the unit.
  - Beam interruption
- Are these excursions relevant in conventional fractionation? Hypofractionation?
- Is there a sub-group of patients that significantly benefit? E.g. Continuous drift?
Comments on MHI Unit

- Imaging for respiratory motion and adjustable collimation for compensating.
- Volumetric and fluoroscopic functionality.
- Maintained non-coplanar features.
- Large at 3.3 m in diameter

Integrated MRI and Accelerators: a Winning Combination for Future IGRT?

Jan J.W. Lagendijk and Bas W. Raaymakers

Chris Bakker, Elwin Kerkhof, Alexander Raaymakers, Jan Jurjen Haan Schluis, Richard van der Put, Ulf Hanne der Praed, Jan Kiek, Marco van Wellen

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Elekta Oncology Cosway, Kevin Brown

University Medical Center Utrecht
Coil configuration for active shielding (1.5 T)

Comments on Utrecht MR Unit

- Leverages existing MR design.
- Why choose the high (1.5T) field strength?
- How do you achieve repair and maintenance in 1.5 T context.
- General MR questions:
  - Geometric Distortion Corrections (B, chemical shift, susceptibility)
  - Pre-clearance of patients for MR
  - Throughput issues
  - Dosimetry challenges

Novel Linac-MR System for Real-Time ART

- Load shielding for 1.5 cm pole-to-pole: 30 lbs
- Linac: 50 lbs
- Beam stop G-14: 120 lbs
- Max field area 20 x 20 cm at isocenter
Comments on Edmonton MR-guided Accelerator

- Sufficient field strength with 0.2T?
- Significant SAD in Human Scale: ISL->1/3 D_{-reference}
**Comments on Viewray Proposal**

- Feasibility of MR imaging during RT delivery?
  - Cobalt is quite.
- How well does $^{60}$Co perform?
  - Dose rate, conformity

**Summary**

- Precise and accurate radiation delivery continues to be a challenging task.
- Significant advances in IGRT have been made in the past 5 years.
- Increased activity in development of new image-guided megavoltage photon therapy systems.
- Interplay between real-time, adaptive, and response assessment feedback on these systems promises an exciting future for RT.
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