4D: Adaptive Radiotherapy & Tomotherapy

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Radiation Oncology Workflow

- Image Patient
- Simulation
- Immobilization
- Target and Structure Definition
- Forward Planning
  - Treatment setup
  - Dose computation
- Inverse Planning
  - Define Objectives
  - Optimize
- Plan Analysis
- Delivery System QA
- Dose Accuracy
- Export to Delivery System
- Pre-Verify Dose/Position
- Pretreatment CT Guidance
- Modify Plan/Patient Position
- Deliver Treatment
- Verify and Monitor Delivery
- Export for Population
- Adaptive Analysis

Planning

4D Components

Delivery
Where is the greatest uncertainty now?

**Treatment Uncertainties**

- Target
- Biology
- Motion
- Setup
- Delivery
- Dosimetry
- Total

**IMRT Improved Delivery Uncertainty**
4D Radiotherapy Adaptation Considerations

**Patient**
- Fractionation
- Tumor Response
- On-line Imaging (Spirometry)
- Portal Images
- Dose Verification

**Physician**
- Radiobiology
- Target Re-Assessment
- Organ Motion
- Setup Error
- 4D Dose Eval

**Plan Modification**
4D Approaches - Frequency

• **Multi-Fraction - Weeks**
  – Monitor course of treatment and modify plan at intervals of multiple treatment fractions

• **Inter-Fraction - Day**
  – “Plan of the Day” treatments
  – Prostate, Head and Neck

• **Intra-Fraction - Seconds**
  – Use 4D images to generate plans that adapt to breathing cycle during treatment
  – Lung
4D Breathing
4D Treatment Planning

- Is it possible to daily re-plan?
  - 3D Conformal? IMRT?
- Is it practical to manage all the accumulated data offline and periodically re-plan?
- Are breathhold techniques acceptable or do we require dynamic motion compensation in our delivery?
- Is the incremental clinical benefit worth the cost?
- Can the process be made efficient enough for the busy clinic?
- Could we increase time per fraction and reduce the number of fractions to improve delivery?
  - Biology?
  - Reimbursement?
4D Component Organization

**4D Image Processing**
- Deformable Registration
- Model Based Segmentation
- Organ Propagation
- 4D Visualization

**4D Data Management**
- Time Series Volume Data
- Record of Treatment Delivery
- Time Series Portal Images

**4D Evaluation**
- Organ Motion Analysis
- Setup Error Assessment
- 4D Dose Evaluation
- Radiobiological Assessment

**4D Treatment Planning**
- Geometric Uncertainty Planning
- Adaptive Plan Modification
- Automatic Re-planning (3D, IMRT)
- Intra-fraction Motion Planning
Determine translation (and rotations)
Respiratory Gating
*Model-based image segmentation is a work in progress*
BREAST EXAMPLE (Model-Based Image Segmentation*)

*Model-based image segmentation is a work in progress
Summary

- 4D RT concepts represent a challenging new step for radiation oncology
- Various image processing tools show promise in automating the image segmentation process to identify organ motion
- Data management and automated analysis are required to enable adequate monitoring of the course of treatment
- Molecular imaging may play a strong role in assessing tumor response to therapy
- Economical benefit may be realized in the trade-off between geometrical vs. radiobiological sparing of normal tissues with reduced the number of fractions, and daily re-planning