Anatomical Adaptive Radiation Therapy

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Anatomical Variability - Sources

- Musculoskeletal (articulation / swallowing)
- Motion (breathing, peristalsis, heartbeat)
- Disease progression / response
  - Primary
  - Secondary (pleural effusion)
- Other – immobilization / applicator

Collapsed Lung

Organ motion

Multifactorial – breathing and response

Tumor Growth / Response
Anatomical Variability - Considerations

- Rigid / non-rigid
- Time scale
- Pattern
- Magnitude
- Affected tissues
Anatomical Variability during RT

Geometric variability => target volume size

Geometric variability => uncertainty in normal tissue dose

Higher precision => less toxicity, better local control

Better estimates of delivered dose => better outcome models
Adaptive Radiation Therapy

- Imaging
- Planning
- Treatment
- Assessment (Imaging)

Quantify geometric variability
Correct what we can at time of treatment
Adapt the treatment plan to changes during therapy
Enabling Technologies for Adaptive RT

Onboard Imaging

Decision Making

Replanning
Timescales of Adaptive RT

- Offline
- Online
- Realtime
Timescales of Adaptive RT - Offline

Treatments continue while adaptive process performed outside of treatment space
Timescales of Adaptive RT - Online

Adaptive process performed while patient is on the treatment table, immediately prior to treatment
Adaptive process performed while patient is on the treatment table, continually during treatment
Timescales of Adaptive RT

**Offline**
- Economical
- Manages slow or singular changes
- Can use diagnostic images
- Can’t manage daily change
- Typically more manual

**Online**
- Semi-automated toolset
- Typically single integrated system
- Most variabilities
- Risk of anatomical changes during / after replan
- Additional QA burden
- Requires intrafraction motion management

**Realtime**
- Most responsive to high frequency changes
- Most direct, no need to model / manage other sources
- Requires most automation
- Less commercial availability
- Highest QA burden
Clinical Trials – Adaptive RT

Bladder Cancer – Hybrid Online/Offline – Meijer Radiother Oncol 2012

NSCLC – Tvilum Acta Oncol 2015

Cervical Cancer / IGABT EMBRACE-II

Seppenwoolde Radiother Oncol 2019
Phase I Trial - Stereotactic MR-Guided Online Adaptive RT (SMART)

- 20 patients with unresectable primary or oligometastatic disease of the liver (n = 10) & non-liver (n=10) abdomen planned for SBRT
- Prescription: 50Gy/5fx with SMART approach
- Isotoxicity approach, with dose escalation (or de-escalation) based on hard OAR constraints
- Breath hold or gating – managed by realtime cine MR

Henke Radiother Oncol 2018, Rudra Cancer Medicine 2019
Phase I Trial - Stereotactic MR-Guided Online Adaptive RT (SMART)

- 83% (79/95) fx adapted—all patients had $\geq 1$
- Primarily (70/95 fx) to protect OARs after interf-x motion
- 100% of OAR violations resolved with adaptive planning
- No **Grade 3+ toxicity** at median 11.8 mo f/u. Expected up to 30% based on prior reports accounting for motion (Hoyer, et al. 2005)

_Henke Radiother Oncol 2018, Rudra Cancer Medicine 2019_
• 48 prostate cancer patients
• 88% patients > 1 correction
• CTV D98% within 5% with realtime IGRT
• No grade 3 toxicity
• Multi-vendor!
Adaptive RT – Needs Assessment

- Trials, trials trials!
- Automation and QA of automation
- Robust workflow models
- Training programs
- Tools for managing complex, multifactorial variability
Summary

• Anatomical variability can be managed in part by adaptive radiation therapy.

• Different types of adaptive RT for different time scales of variability.

• Work remains to produce clinical evidence, develop workflow and robustness, and manage complex changes.