MRI-Guided On-line Adaptive Radiotherapy
– The UCLA Physics Experience

James Lamb, Nzhde Agazaryan, Minsong Cao, Mitch Kamrava, Percy Lee, Daniel Low, David Thomas, Yingli Yang
Department of Radiation Oncology

Disclosures

• Consulting fees from ViewRay for machine testing


• On-line adaptive: measure something about the patient while he/she is on the table and modify the delivery.
  • Change the treatment plan
  • Select plan of the day from a plan library, based on best match to the current daily anatomy
On-line plan change: re-optimization

Planned
V35 Gy(bowel)=0.02 cc
Predicted Fx1
V35 Gy(bowel)=1.12 cc
Adapted Fx1
V35 Gy(bowel)=0.05 cc

On-line plan of the day selection

- Studied for bladder [1], prostate [2], and cervical cancer [3].
- Established clinical use in bladder cancer.


MRI Guided Plan of the Day Selection - UCLA

Challenges:
- Who decides which plan matches the daily anatomy best?
- How easily can you change plans with the system?
- Intra-fraction motion
Since April 2016, all our abdominal and pelvic SBRT on ViewRay are evaluated for adaptive on a per-fraction basis.

### On-line Adaptive Fractions Treated on UCLA ViewRay 2015-2016 (N=45)

- Liver: 14
- Pancreas: 6
- Abdomen met: 23
- Pelvis met: 5

#### Quality considerations

- Keep the time under control
- Get the best dosimetry possible
- Avoid (or catch and correct) human error made more likely by time pressure

#### Treatment plan (Fx1)

- Fx2 - rigidly propagated
- Fx2 - deformed

- Deformable contour propagation: saves time but editing still needed.
- Review of edited contours by second expert is mandatory.

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<thead>
<tr>
<th>Liver</th>
<th>Pancreas</th>
<th>Abdomen met</th>
<th>Pelvis met</th>
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</thead>
<tbody>
<tr>
<td>14</td>
<td>6</td>
<td>23</td>
<td>5</td>
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Contouring: Don’t waste time on useless precision

Timing measurements

- Time to room pt. and acquire image: M=9 min
- Time for adaptive re-contour: M=10 min
- Time for adjust plan plus QA: M=14 min
- Total time until beam-on: M=54 min

Things that make the time blow up

- Physician or physicist didn’t respond promptly to pages.
- Physicist or physician unfamiliar with tools.
- Contoured more anatomy than needed.
- Made a mistake in contouring, noticed it in plan evaluation, and had to go back and correct.
- Needed to make in depth plan modification.
How to plan like your plan will be adapted

- Avoid derived optimization structures if possible.
- Use the conformality constraint.
- Put optimization weights on all structures coplanar with the target, even if far away.

Initial plan: kidney far away and not getting much dose, so not included in optimization.

Re-optimized plan: still far away, but not weighted and optimizer happens to puts a beam through it.

Edited optimization: Fixed the problem but added time and complexity.

QA Tools: What do we need to check?

- Will the delivered dose match the planned dose?
  - For off-line planning we do IMRT QA
  - For on-line adaptive planning: recalculate plan using an independent Monte Carlo dose calculation engine (provided by ViewRay)

- Did we make a mistake in planning due to the time pressure?
  - Contour and dosimetry consistency checks
On-line Adaptive – WUSTL QA Tools

On-line Adaptive – UCLA QA Tools

Project lead at UCLA: David Thomas, PhD

Acknowledgements:
- Zeus MC support: Tony Apicella / ViewRay
- 3D Gamma code: Mark Geurts / UW

UCLA Consistency checks – Bixel-Minutes Example

MLC segment

17 x1 cm² elements
X 18 seconds
= 5.1 bixel-minutes

Ratio of sum of bixel-minutes in the adaptive and the initial plans (histogram of 40 adapted fractions)
Consistency checks

- Adapted target volume relative to initial volume.

Communication is critical: Templated document

For covering physician:
critical constraints

For covering planner:optimization structures and booleans

End-to-End Tests for QA and Training

Motion phantom: move the plunger and adapt.
On-line imaging is the foundation of on-line adaptive planning CT (Fx1 - CBCT (Novalis Tx)) and on-line MRI.

On-line re-optimization

Physicist’s wish list and future directions

- Fast and user friendly interface to choose “Plan of the Day”
- Adaptive optimizer that runs multiple plans in parallel with a range of critical structure weights, lets the user choose which one he/she likes best.
- Decision support tool for physicians to evaluate a full adaptive course.

Predicted 
V35 Gy(bowel)=0.73 cc

Adapted 
V35 Gy(bowel)=0.05 cc
Summary

- On-line adaptive is a new paradigm; analogous to surgery
- QA of technical factors still important
- QA of human factors and workflow increasing in importance
- Further development of workflow and tools needed to bring the benefits of on-line adaptive to more patients.

Thank you!
On-line adaptive clinical workflow

Outline
- Introduction to the ViewRay system
- UCLA adaptive case statistics
- Adaptive case studies
- QA tools
- Timing
- Adaptive commissioning
- Physicist’s wish list and other final thoughts

Motion Management
- free-breathing with monitoring
- free-breathing with gating
- breath-hold treatment
  - Inhale
  - Exhale
Introduction to the ViewRay system

MRI components:
- Split superconductor MRI (0.345 T)
- 50cm FOV with 70cm bore size
- Imaging isocenter coincident with RT system isocenter
- High resolution 3D MRI images in 25s-172s
- Real time cine MRI image (4 frames/s)

UCLA ViewRay Project Timeline
- June 2014: Acceptance tests
- July – October 2014: Commissioning
- October 27th, 2014: First patient treated
- May 14th, 2015: First gated treatment
- August 7th, 2015: First adaptive treatment
**Patients treated on UCLA ViewRay 2014-2016 (N=181)**

- Head Neck: 30
- Breast: 28
- Thorax: 5
- Extremity: 7
- Liver: 1
- Pancreas: 11
- Stomach: 5
- Abdomen: 22
- Rectum: 15
- Prostate: 35
- Pelvis - Others: 3

**SBRT Patients Treated on UCLA ViewRay 2014-2016 (N=75)**

- Lung: 4
- Liver: 4
- Pancreas: 11
- Abdomen: 15
- Pelvis: 26
- Prostate: 28

**Introduction to the ViewRay system**

RT components:
- 3 headed cobalt system, each 15,000Ci, dose rate around 500cGy/min at 105cm SAD
- 3 independent MLC systems (1cm leaf width, double focus, field size 27.3cm x 27.3cm)
Summary

- Commercially available on-line adaptive has arrived with commercially available MRI-guided RT.
- Other systems likely to follow suit.
- Attention must be paid to QA and process in order to maintain quality and safety.
- Further development of workflow and tools needed to bring the benefits of on-line adaptive to more patients.

Re-optimize the new plan

Volumetric setup image – initial assessment for adaptive
Auto-contouring and manual adjustment

“Predict” – Calculate dose on new anatomy

Online Adaptive Treatment Flow
The value of phantom-based IMRT QA

- Failures with phantom based IMRT QA are associated with:
  - known limitations of dose calculation (DLG)
  - Reproducible machine performance problems.
- Not likely to be caught with Monte Carlo based QA.
- Partly addressed by periodic phantom QA of a standard plan

Off-line Patient Specific QA

- MR-safe/MR-compatible equipment

David Geffen School of Medicine  
RALIATION ONCOLOGY