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
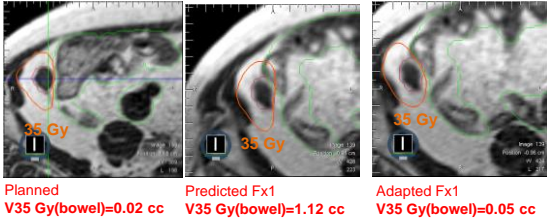
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Division of Medical Physics

Disclosures

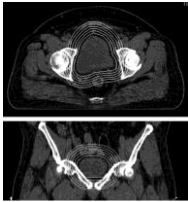• Consulting fees from ViewRay for machine testing

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• "*Adaptive radiation therapy is a closed-loop radiation treatment process where the treatment plan can be modified using a systematic feedback of measurements.*" Yan, Di, et al. "Adaptive radiation therapy." *Physics in medicine and biology* 42.1 (1997): 123.

• 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.

[1] Burridge, Nichola, et al. *International Journal of Radiation Oncology* Biology* Physics* 66.3 (2006): 892-897.
[2] Gill, Suki, et al. *Radiotherapy and Oncology* 107.2 (2013): 165-170.
[3] Heijkoop, Sabrina T., et al. *International Journal of Radiation Oncology* Biology* Physics* 90.3 (2014): 673-679.

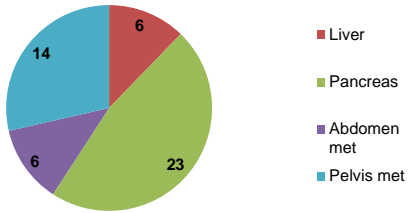Murthy, Vedang, et al. *Radiotherapy and Oncology* 99.1 (2011): 55-60.

MRI Guided Plan of the Day Selection - UCLA
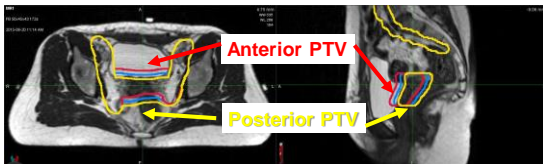
Challenges:
- Who decides which plan matches the daily anatomy best?
- How easily can you change plans with the system?
- Intra-fraction motion

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

- Liver
- Pancreas
- Abdomen met
- Pelvis met

Since April 2016, all our abdominal and pelvic SBRT on ViewRay are evaluated for adaptive on a per-fraction basis.

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

- Deformable contour propagation: saves time but editing still needed.
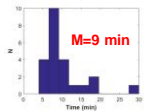
- Review of edited contours by second expert is mandatory.
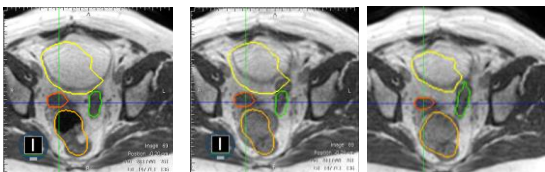
Treatment plan (Fx1)   **Fx2 - rigidly propagated**   **Fx2 – deformed**
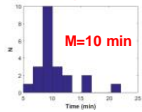
Contouring: Don't waste time on useless precision
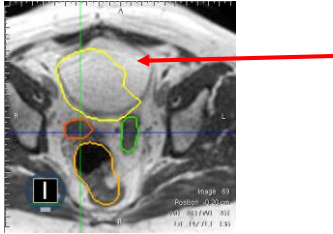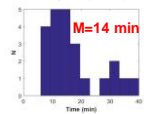

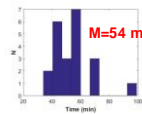## Timing measurements

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.
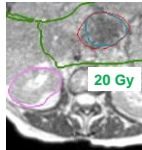

How to plan like your plan will be adapted
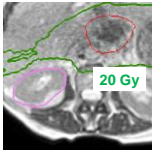
Initial plan: kidney far away and not getting much dose, so not included in optimization.
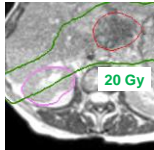
Re-optimized plan: still far away, but not weighted and optimizer happens to puts a beam through it.

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
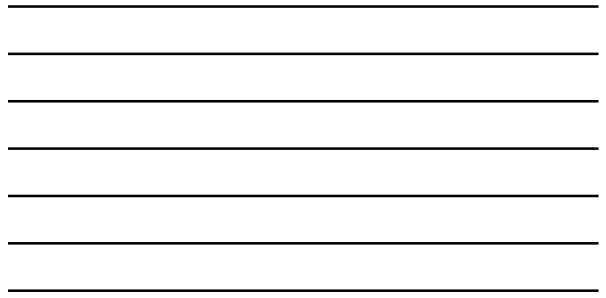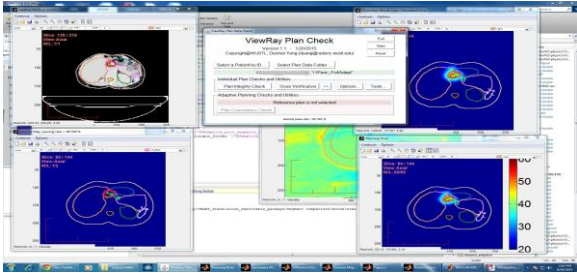
On-line Adaptive – UCLA QA Tools
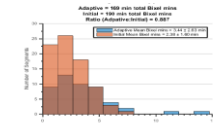
Project lead at UCLA: David Thomas, PhD
Acknowledgements:
- Zeus MC support: Tony Apicella / ViewRay
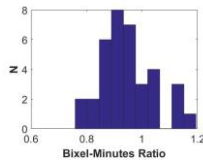- 3D Gamma code: Mark Geurts / UW

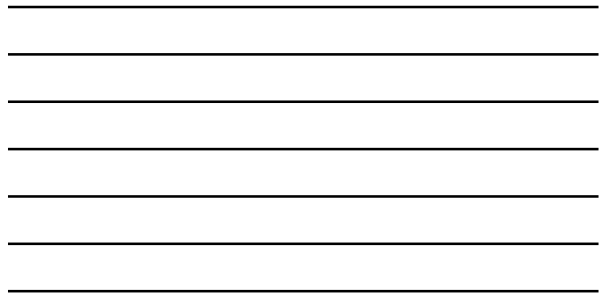## UCLA Consistency checks – Bixel-Minutes Example
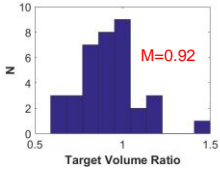
MLC segment

17 1x1 cm^2 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.

M=0.92

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
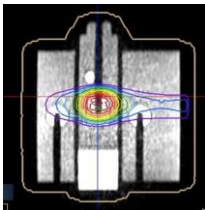
Motion phantom: move the plunger and adapt.

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On-line imaging is the foundation of on-line adaptive

Planning CT

Fx1 - CBCT (Novalis Tx)

Fx 2 On-line MRI

On-line re-optimization

Predicted
V35 Gy(bowel)=0.73 cc

Adapted
V35 Gy(bowel)=0.05 cc
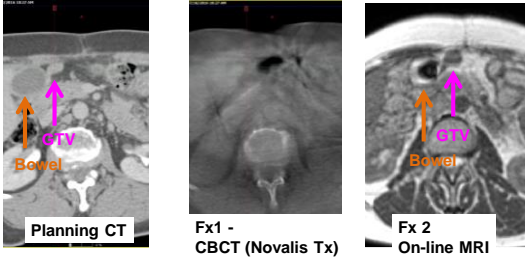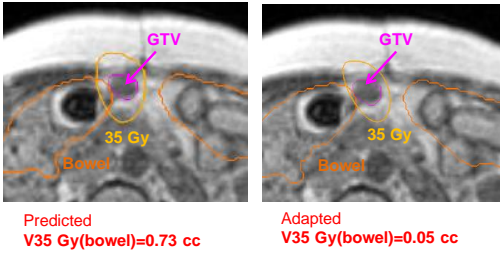
Physicist's wish list and future directions

- 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.

Summary

- On-line adaptive is a new paradigm; analogous to surgery

- QA of technical factors still important

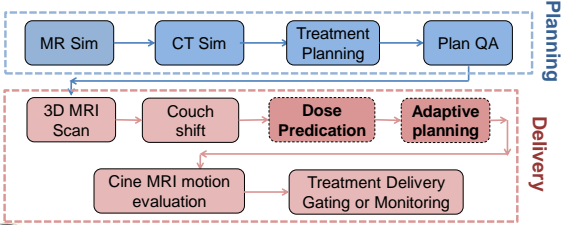- QA of human factors and workflow increasing in importance

- 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

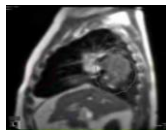- Introduction to the ViewRay system
- UCLA adaptive case statistics
- Adaptive case studies
- QA tools
- Timing
- Adaptive commissioning
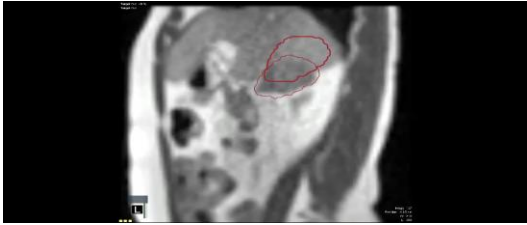- Physicist's wish list and other final thoughts

Motion Management

- free-breathing with monitoring
- free-breathing with gating
- breath-hold treatment
  - Inhale
  - Exhale

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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
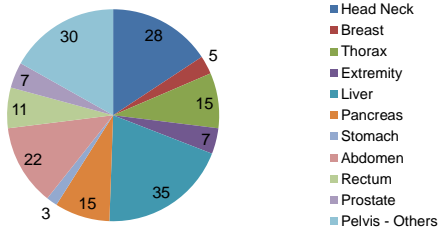- Real time cine MRI image (4 frames/s)

UCLA ViewRay Project Timeline

- June 2014 — Acceptance tests
- July – October 2014 — Commissioning
- October 27th, 2014 — First patient treated
- May 14th, 2015 — First gated treatment
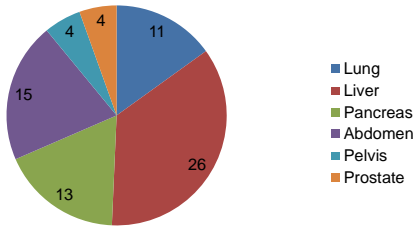- August 7th, 2015 — First adaptive treatment

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Patients treated on UCLA ViewRay 2014-2016 (N=181)

Legend:
- Head Neck
- Breast
- Thorax
- Extremity
- Liver
- Pancreas
- Stomach
- Abdomen
- Rectum
- Prostate
- Pelvis - Others

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

Legend:
- Lung
- Liver
- Pancreas
- Abdomen
- Pelvis
- Prostate

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)
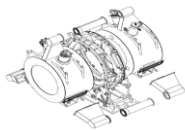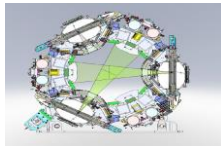
Summary

- 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.
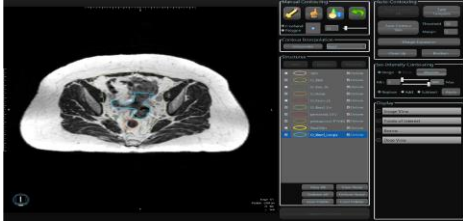
Re-optimize the new plan

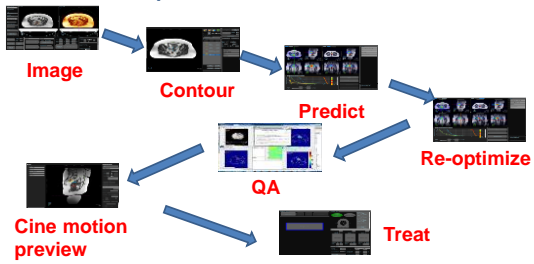## Volumetric setup image – initial assessment for adaptive
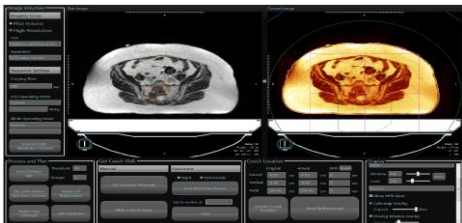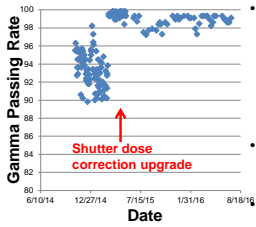
Auto-contouring and manual adjustment

"Predict" – Calculate dose on new anatomy

Online Adaptive Treatment Flow

Image

Contour

Predict

Re-optimize

QA

Cine motion preview

Treat

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

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