Online Adaptive MR-Guided RT: Workflow and Clinical Implementation

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Disclosures

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Learning Objectives

- To understand the difficulties, challenges and available technologies for online adaptive RT.
- To understand how to implement online adaptive therapy in a clinical environment and to understand the workflow and resources required.
- To understand the limitations and sources of uncertainty in the online adaptive process

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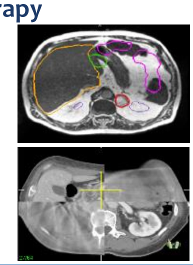
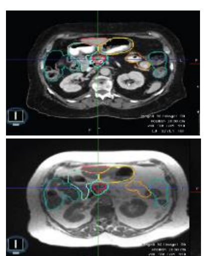
Rationale for adaptive radiotherapy

- Anatomical changes
  - Tumor response
  - Change in normal anatomy
  - Weight gain / loss
- Systematic changes in patient setup and positioning relative to initial simulation
- Inter-fraction variations in shape / size of the target (bladder, cervix, …)
- Variations in position and proximity of OARs relative to the target



Plan adaptation strategies

- Treatment adaptation strategies and the tools required depend on what type of anatomical change we want to correct for
  - Weight change (offline)
  - Tumor response (offline)
  - Variation in shape / size (online)
  - Variation in OAR proximity to target (online)



Online Adaptive Workflow

Imaging → Contouring → Dose calculation → Planning and Evaluation → Patient QA

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Online Adaptive Workflow

Imaging → Contouring → Dose calculation → Planning and Evaluation → Patient QA

- In-room CT
- MR
- CBCT
- …

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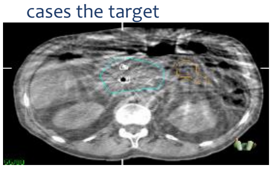
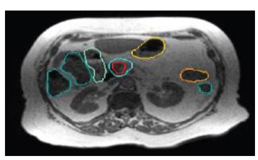
Volumetric imaging for plan adaptation

- In-room CT, MR, CBCT
- Soft-tissue contrast for delineation of OARs and in some cases the target





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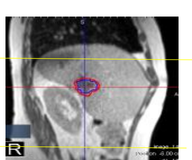
Volumetric imaging for plan adaptation

- Large field of view
  - Encompass all regions where contouring is required
  - Allow for inclusion of patient's external surface for dose calculation



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Online Adaptive Workflow

Imaging → Contouring → Dose calculation → Planning and Evaluation → Patient QA

Imaging	Contouring
In-room CT	Fully manual
MR	Registration
CBCT	Auto-segmentation
…	

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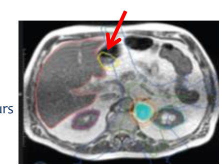
Contouring for online adaptation

- Planning image (CT / MR) are registered to the daily image after initial localization to the target
  - Rigid
  - deformable
  - Atlas based auto-segmentation
- Uncertainties in automatically generated contours
  - No deformable registration is perfect
  - Manually edit the contours if needed
  - Does not fix the deformation vector field



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Online Adaptive Workflow

Imaging → Contouring → Dose calculation → Planning and Evaluation → Patient QA

Imaging	Contouring	Dose calculation
In-room CT	Fully manual	Electron density
MR	Registration	
CBCT	Auto-segmentation	
…		

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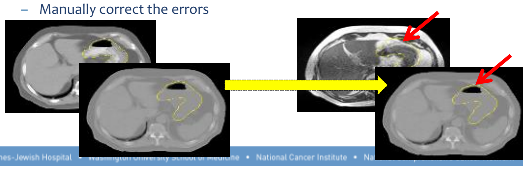
Electron density map for dose calculation

- In-room CT
- CBCT – Some corrections needed
- MR – Transfer from original plan
  - The errors in deformation will propagate to the electron density map
  - Manually correct the errors



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Online Adaptive Workflow

Imaging	Contouring	Dose calculation	Planning and Evaluation	Patient QA
In-room CT MR CBCT …	Fully manual Registration Auto-segmentation	Electron density	Full reoptimization Adjusting the aperture Plan library	

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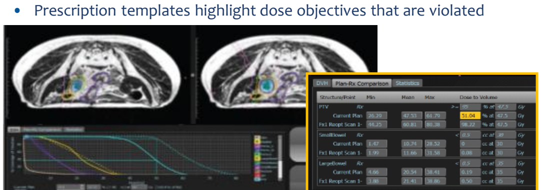
Dose prediction

- DVHs can be evaluated for the new contours
- Prescription templates highlight dose objectives that are violated



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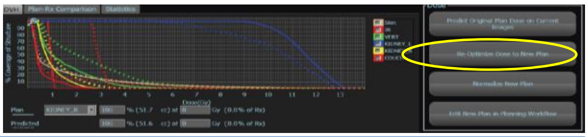
Plan Re-optimization

- Reoptimization with same beam angles and original set of optimization objectives
  - Preserving the beam angles of the original plan can simplify QA
  - Robustness of the original set of objectives is important



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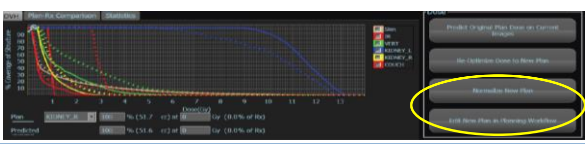
Plan Re-optimization

- Plan normalization – Normalize to cc or % of any structure
- Planning tools should be accessible in case modifications to the objectives are needed.



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Plan Evaluation and QA

- Final plan is evaluated and approved by the physician
- Export for QA - Images, structure set, RED, dose, and beam parameters

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Online Adaptive Workflow

Imaging	Contouring	Dose calculation	Planning and Evaluation	Patient QA
In-room CT	Fully manual	Electron density	Full reoptimization	Measurement
MR	Registration		Adjusting the aperture	Secondary calculation
CBCT	Auto-segmentation		Plan library	
…				

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Patient QA

- Primary limitation in proceeding to treatment is QA
  - We cannot take the patient off the table to do phantom measurements.

Patient-specific QA for IMRT should be performed using software rather than hardware methods

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Is patient specific phantom measurement necessary?

Argument against measurement

- Measurement inaccuracies
- Insensitivity of the QA devices
- Measurements cannot separate the source of the error

Argument for measurement

- Measurement is the only way to test deliverability of the plan
- Measurement can save us from catastrophic errors

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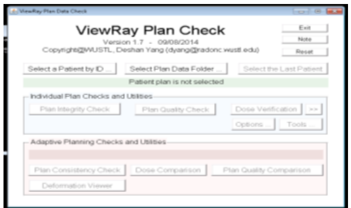
Independent plan evaluation prior to delivery

- Independent Monte Carlo dose calculation
- Plan consistency check:
  - Gantry angles
  - Number of segments
  - Beam on times
  - Fluence calculation
  - Structure volumes
- Contour QA (in progress)
  - Boolean operations
  - Margin expansions



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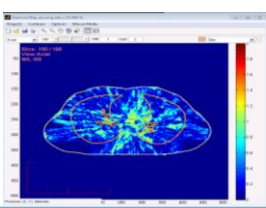
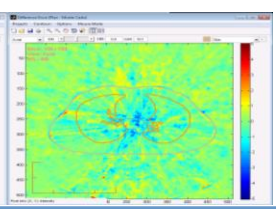
Independent plan evaluation prior to delivery

- 3D gamma calculation over the full volume with 3%, 3 mm criteria





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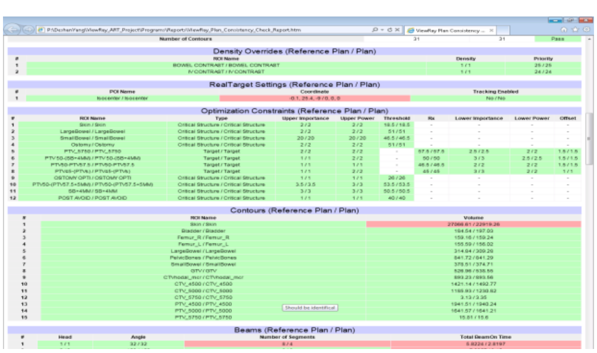
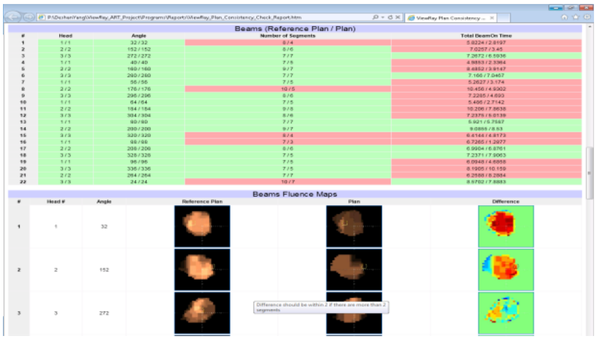
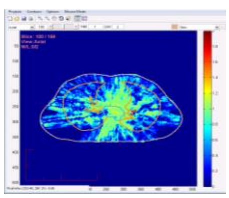




Commissioning the online QA tool

- How do we trust this in place of actual measurements?
  - Dose calculated by this tool was compared to actual patient specific measurements – ArcCheck, ion chamber
  - Sensitivity of the analysis to errors in dose was verified by introducing known errors
    - Introducing a 3% error in dose results in gamma pass rate dropping to 76% from 93%



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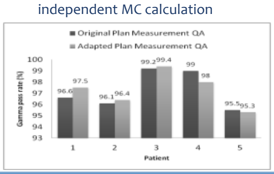
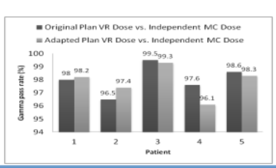
Independent plan evaluation prior to delivery

- Measurement based QA performed results are similar between initial and adapted plans
- Original and adapted plans have similar passing rate when compared to the independent MC calculation





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Contour QA

- Out of 195 adapted fractions, 5 errors or near misses
  - Contouring (3)
    - All were found by the user in post-treatment chart review
  - Density correction (1)
    - Caught by user at time of replanning
  - Beam decay (1)
    - Caught by the online patient-specific QA

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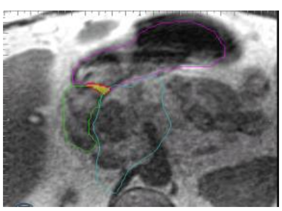
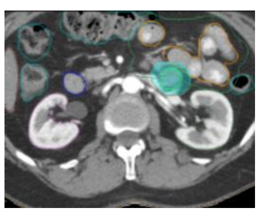
Contour QA





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Time and Resources

- How long does the process take?
  - Volumetric imaging and contour propagation – 2 - 4 minutes
    Contour evaluation and manual edits: 5 to 15 minutes (or more)
  - Dose prediction – 1.5 - 3 minutes
    Manual edits to the electron density: 2 minutes
  - Plan re-optimization – 2 - 4 minutes
    Normalization or modification to the plan parameters: 3 – 5 min

Total time : 20 – 30 minutes

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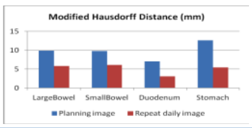
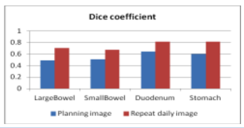
Common challenges in online adaptation

- What happens to the anatomy while we replan?
- Henke et al (MR in RT Symposium, Ann Arbor, June 2016)
  - Repeat images at 45 – 60 minutes after the initial image
  - Evaluated the contours and compared the magnitude of change to the changes observed in between fractions





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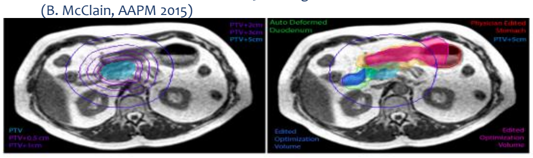
Common challenges in online adaptation

- Contouring continues to be the most time-consuming part of the process
- Understanding the relative geometry of OARs / targets and the beam will allow us to focus manual contour edits to regions that matte
- Contour edits can be limited to a 2 – 5 cm ring around the PTV (B. McClain, AAPM 2015)



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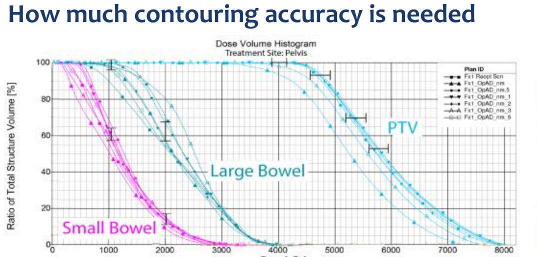
How much contouring accuracy is needed



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Common challenges in online adaptation

- Dose accumulation
  - Uncertainties in deformable registration translate into errors in dose accumulation
    - Regions with high dose gradient are most sensitive
  - Manual correction to the contours does not correct the deformation vector field.
- Daily dose evaluation instead of cumulative dose
  - More conservative approach as it ensures that each fraction meets the specified dose tolerances

Discussion

- Advancements in in-room imaging have enabled the clinical implementation of online adaptive RT.
- Time and resources required at the treatment machine continue to be the limiting factor in a more widespread implementation of these techniques
- Future work should focus on quantifying the sources of uncertainty in order to allow for automation of overall process

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Thank You

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