ART on an MR-Linac: Effective and safe implementation of an online adaptive workflow

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Learning Objectives

1. Understand the steps of a clinical MR-guided ART workflow
2. Appreciate the challenges and risks of online ART

Outline

1. Why MRgRT for ART
2. Step of adaptive workflow
3. Day-to-day challenges of on-line ART

The ability to adapt a treatment plan online in response to daily anatomic or disease change is a powerful tool in modern radiotherapy. MR-guided ART can enable target dose escalation and/or dose reduction to critical structures.
Why MRgRT for ART?
- Superior soft tissue contrast of MR is the (not so secret sauce) to recognize its full potential
  - see targets and avoid OARs.

- MRgRT is great for abdomen and pelvis: organ filling and positional variability are main sources
  - of uncertainty and dose limitation.

MRgRT @ UW Madison > 400 patients treated since 9/2014

Why treat Pancreas with MRg ART?
- Pancreas is one of the most treated sites for MRgRT.
- Excellent soft tissue visualization with MRI
- Surrounded by dose sensitive GI organs
- Daily anatomic changes due to organ filling and motion
- Therefore: Ideal candidate for on-line ART

- The case I will use to illustrate workflow is being treated
  - on a pancreas stereotactic MRI-guided Adaptive RT trial
  - 10 Gy x 5.

Clinical Objectives
- PTVopt: Ideal, but often violates OAR constraints;
  - Dmean = 9.9 Gy
  - V90.95 Rx = 60-90%
Outline

What is needed to implement and perform MR guided ART?

1. Why MRgRT for ART
2. Step of adaptive workflow
3. Day-to-day challenges of on-line ART?

What is needed to perform MRg ART safely and efficiently?

- Daily pre-treatment MRI imaging
- Deformable Image Registration (DIR)
- Contouring workflow
- Accelerated re-planning/optimization/dose computation
- Patient specific pre-treatment quality assurance
- Treatment ("Gated")

All put together with well thought-out clinical workflow

* Not required, but gating or other motion management is key for state of the art abdominal SBRT

Dedicated ART Team:
Dosimetrist, RTT, Physicists and MD
Short (25 sec) volumetric scan for initial position, manually register, rigid copy contours and send shifts to couch. MD/physics review (1)

(Really small shifts, we are not always that close)

Positioning
Deformation and electron density
Contouring
Predict dose and plan re-optimization
Plan quality evaluation
Treatment

Electron density view of current image

Density override example

Todays MRI

Assigned electron density based on initial CT data.

However today that gas bubble is not there so the contour ToWater was edit to fill in this area.
7/7/20

Tracking structure in green (3 mm boundary in red)

Positioning
Deformation and electron density
Contouring
Predict dose and plan re-optimization
Plan quality evaluation
Treatment

Focus Edits in 4 cm Ring (from PTV) and Apply “Rules”

• First step: Predict dose
• MD/Physics review (2)
• Review contours and evaluate need for adoption
• Evaluate Original vs Predicted Dose (on today’s anatomy)
• In this fraction, all OAR were met (underdose) contour but opt_PTV is under covered.

Bohoudi et al. 2017
• Beam angles are not edited
• Costa functions/weights are sometimes tweaked
• Re-optimize and MC calc. ~ 3 min
Delivery QA

• Final plan review (D/H, IDL and objectives) & print TPO, ART plan pdf and adaptive checklist
• QA – Monte Carlo based independent calculation from DICOM RT PLAN

<table>
<thead>
<tr>
<th>Metric</th>
<th>Original Plan</th>
<th>Adapted Plan</th>
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<tbody>
<tr>
<td>MU/Fraction</td>
<td>3.84</td>
<td>4.32</td>
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<tr>
<td>MU/Prescribed Dose</td>
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<td>Total number of segments</td>
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<td>Dose comparison</td>
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<tr>
<td>Dose pass rate</td>
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</tr>
</tbody>
</table>

3. Aperture/fluence difference per beam

Positioning
Deformation and electron density
Contouring
Predict dose and plan re-optimization
Plan quality evaluation
Treatment

Beam ON: Tracking structure in bounds
Beam OFF (target out of bound)

12 angle Step and Shoot IMRT

Post Treatment

• Post treatment documentation
• Review plan / checks
• Reset delivery calendar – we usually treat subsequent fractions with original plan (A0)
Outline

 Sounds swell, when can we start?

1. Why MRgRT for ART
2. Step of adaptive workflow
3. Day-to-day challenges of on-line ART?

Day-to-day challenges of on-line ART

• Patient selection
  • Can be in bore 30 min -2 hrs. (1hr is average)
  • Comfort (claustrophobia, arm position, bladder filling, gated breathing sequence, etc.)
• Internal motion while re-contouring, adapting, evaluating...
• Availability of MD and physics coverage at treatment unit
  • Important roles, random times with short notice
  • Any delay adds to patient time on table
  • Page MD and assign physicist to machine
• Experienced and dedicated therapists are required
  • Very interactive during treatment (compared to other modalities)
  • Trained for OAR contouring and coaching through the gating breathing sequence

Day-to-day challenges of on-line ART ...

• Software limitations
  • Bugs – crash during ART you may lose contours
  • Deformation is less than stellar for abdominal organs
  • Editing contours is time consuming – focus near tumor
  • Optimization and dose computation time
• Finally, not all adaptive plans are acceptable – it’s important to appreciate the limits of the system and process.
Tumor moved a lot. Initially anterior to liver. Adapted plan was unacceptable.

All Adaptive Plans Are Not Clinically Acceptable

The ability to adapt a treatment plan online in response to daily anatomic or disease change is a powerful tool in modern RT.

- Slow down
- Establish clear, well-documented workflows with checklists
- Train and communicate within the ART Team.

Thank you

- Drs. John Bayouth and Poonam Yadav – UW ViewRay Physics leads who developed a darn great ART program on our serial number 2 system!
- Dr. Kate Mittauer – Miami Cancer Institute – teaching me the importance of “getting my reps” for the ART workflow.
- Dr. Laurence Lee – Teaching us all our small bowels from large, and how to find a duodenum in a haystack of bowel loops and vessels.
- The phenomenal UW ViewRay team:
  - RTT: Dan, Dusty, Emilee, Jason, Jess K, Jess S Kaliee, Jason and Susie
  - MD: Dr. Bassetti
  - FSE: Nick
## References

- Boldrini et al. Online adaptive magnetic resonance-guided radiotherapy for pancreatic cancer: state of the art, pearls and pitfalls. Radiation Oncology 14 (71) 2019
- Corrado et al. MR-guidance in clinical reality: current treatment challenges and future perspectives, Radiation Oncology 14 (92) 2019