Strategies for Adaptive RT

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Disclosures

• Honoraria and travel grants from ViewRay, Inc.
Learning Objectives

- What is ART?
- What is needed to implement real-time, online ART in the clinic?
- Example from experience

What is ART?

Original definition from D. Yan et al.:

- “Adaptive radiation therapy is a closed-loop radiation treatment process where the treatment plan can be modified using a systematic feedback of measurements.
- Adaptive radiation therapy intends to improve radiation treatment by systematically monitoring treatment variations and incorporating them to re-optimize the treatment plan early on during the course of treatment.
- In this process, field margin and treatment dose can be routinely customized to each individual patient to achieve a safe dose escalation.”


What is ART?

- Frequency varies depending on disease site and type of organ at risk
- Classic examples (in order from slowest to fastest change)
  - Weight changes
  - Tumor shrinkage over course of treatment in head & neck and lung
  - Bowel motion
  - Deformation due to bladder/rectal filling
What is ART?

- Frequency varies depending on disease site and type of organ at risk
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What is ART?

- Plan of the day
  - Upfront estimation of potential changes in relevant anatomy
    - E.g., CT simulation with bladder empty, half-full, and full
  - Evaluation of relevant part of anatomy prior to treatment
  - Selection of appropriate plan
- Real-time, online ART
  - Recognition of all relevant anatomic changes
  - Reoptimization while patient is still on the table
  - Decision support framework for plan selection

Learning Objectives

- What is ART?
- What is needed to implement real-time, online ART in the clinic?
- Example from experience
What is needed for ART?

• High quality imaging
  – CBCT seldom sufficient (currently)

• Fast replanning

• Quality assurance methods

What is needed for ART?

• High quality imaging
  – MRI provides superior soft tissue contrast even at low field strength (0.35 T)
What is needed for ART?

- Fast replanning
  - Registration of image of the day to planning image and underlying electron density
  - Contour transfer – manual or automatic
  - Robust reoptimization
  - Efficient decision mechanism

What is needed for ART?

- Quality assurance methods
  - Do we need to remove patient to do QA?
  - What does FMEA tell us?

Learning Objectives

- What is ART?
- What is needed to implement real-time, online ART in the clinic?
- Example from experience

Washington University MR-IGRT Experience

<table>
<thead>
<tr>
<th>Treatment Type (%)</th>
<th>UM 15%</th>
<th>Short 31%</th>
<th>Upper 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBRT 31%</td>
<td>3%</td>
<td></td>
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</tr>
<tr>
<td>3D 23%</td>
<td></td>
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<tr>
<td>IMRT 46%</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Fractions Treated</th>
<th>4428</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Adapted Fractions</td>
<td>241</td>
</tr>
</tbody>
</table>

| Total Treated Patients  | 335  |
| Total Fractions Prescribed | 398  |
| Total Adapted Fractions | 241  |
Example from Experience:

1. Consultation
   - Evaluate necessity of MR-IGRT and ART
   - Evaluate patient’s compatibility with MRI
     - MRI questionnaire
     - Claustrophobia evaluation
     - Physical restrictions
       - 70-cm bore (50-cm field of view)
       - 440 lb limit on couch
       - Patient ability to tolerate having arms up

Example from Experience:

2. Simulation
   - Every patient receives CT simulation scan
   - (Almost) every adaptive or gating patient receives MR-IGRT (ViewRay) simulation scan
   - Another thorough review of MRI questionnaire

Example from Experience:

3. Treatment Planning
   - For most patients, CT image set used as primary
     - If secondary, CT set is registered, electron density comes along
   - Treatment planning goals
     - Efficiency
     - For SBRT cases – minimize time
     - For adaptive cases – minimize potential for having to change optimization constraints at the machine by using real anatomy in optimizer (rather than artificially-generated structures)
4. Patient Setup

- Acquire pilot image
  - Volumetric scan, 15 sec
  - Only needed if setting potentially narrow field of view for hi-res scan
- Acquire volumetric scan
  - Minimum – 17 -25sec (typically exhale breath hold)
  - Maximum – 172 sec (only if no breathing artifact)
- Image comparison
  - Determine and apply couch shifts

Example from Experience:

5. Registration and Recontouring

- Primary reference image can be registered to the volumetric image of the day:
  - Rigid or deformable registration
  - Same registration is applied to both contours and electron density
  - System allows manual edits to the contours

- Manual contouring is always necessary

CT simulation
MR simulation ~ 45 min later
Example from Experience:

6. Electron density evaluation

- Electron density is transferred from primary density map to image of the day
  - Based on the deformation map if CT is used
  - Along with the transferred contours if bulk density overrides are used
- Errors in electron density map
  - The errors in deformation will propagate to the electron density map
  - Any significant deviations observed, can be resolved with manually overriding the density to air, or water

Example from Experience:

7. Dose Prediction

- Original plan is recalculated using the electron density and contours of the day
- Evaluation of isodose lines, DVHs, and prescription constraints is made
Example from Experience:

7. Dose Prediction

- Necessity for reoptimization is made by consulting the physicians Adaptive Guideline note in the Record & Verify system (Mosaiq)
Example from Experience:

8. Plan reoptimization

• Single click re-optimization preserves the beam angles and original set of optimization parameters

Example from Experience:

8. Plan reoptimization

• If plan is not optimal, may be normalized or optimization objectives changed in plan workflow
Example from Experience:
9. Quality Assurance

- Independent dose calculation
  - 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%

Example from Experience:
How long does all this take?

- Contour edits – 5-15 min (electron density edits 1-2 min)
- Dose prediction – 1 min
- Reoptimization – 1-2 min
- Plan evaluation – 3-5 min
- QA – 3-5 min
- Total time – 20-30 min for the adaptive process
  - (prior to treatment)

Example from Experience:
Challenges

- Physicist and physician must be present
- Each treatment is scheduled as a procedure
- Requires coordination between nursing, therapy, physics, physician
- Change from ‘typical’ external beam radiation therapy culture to interventional/surgery culture
Contouring on demand

Our next patient is here.

When is he going to finish?

Don't ask, it just makes him grumpy.

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Summary

- On-board MR imaging coupled with fast reoptimization and a robust workflow allows for practical real-time, online adaptive radiotherapy
- Upfront agreement among radiotherapy department team members is essential for safe, efficient implementation

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