An updates on ART for prostate, pancreas and breast

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Learning Objectives

- Understanding rationale, indications and promise of ART
- Review of imaging, planning, and delivery technologies for ART
- Recent technology developments
- Clinical implementation, workflow, QA, cautions and initial clinical experience for using ART at several tumor sites.
In-room imaging
Daily contours overlaid with planning contours (target in red). (a) prostate, (b) prostate (c) pancreas, (d) craniopharyngioma, (e) adrenal carcinoma, (f) head-and-neck cancer. The planning CTs were registered with daily CTs by aligning the center of mass of the targets.
Prostate case (2 fractions)

Planning CT

CT of Fr#1
Moderate Deformation
Overlap: 85%

CT of Fr#2
Large Deformation
Overlap: 74%
Interfraction variations (setup errors, anatomy changes) is a major issue affecting RT.

Seems changes are being found wherever and whenever one looks.

**IGRT**
- *reposition the patient without modifying plan*
- addresses setup error and organ translational variation but not organ deformation and rotation

Adaptive Replanning is needed!
• On-line vs. off-line ART

**Off-line ART**
- replan based on previous fractions and deliver to subsequent fractions
- *gradual/systematic changes*
- *e.g., H&N, lung, breast, cervix*

**On-line ART**
- replan near real-time prior to a fraction and deliver to the fraction
  - *unpredictable/random changes*
  - *e.g., prostate, pancreas, cervix, breast*
Challenges for online ART

- Imaging quality (e.g., CBCT)
- Accuracy and efficiency of auto-segmentation
- replanning time
- QA
- Intrafractional changes
- Accuracy of deformable image registration
Example of online ART techniques

- Replan by deforming fluence map based on anatomy of the day (Mohan, MDACC)
- MLC segment morphing (Yu, Uni MD),
- Segment morphing and weight optimization (Li, Ahunbay, MCW)
- Adaptation using plan library created from pre-simulated volume and anatomy changes (several groups, Wu, Duke, ....)
- GPU-powered image registration, dose calculation and re-optimization (Jiang, UCSD)
- Auto-segmentation and auto-plan tools (Li, Zhang, MDACC)
- ....
MCW Online ART

1. Image Acquisition via CT-on-Rails
2. Contour generation (auto segmentation with manual editing) 2-5 min
3. Segment Aperture Morphing (SAM) & Segment Weight Optimization (SWO) 2 min
4. Dose/DVH evaluation and comparison 1 min
5. ART plan transferring & QA verification with software 2 min
6. Delivery and documentation

8-12 min for prostate
Rapid contour delineation/modification

**Software:**
- auto segmentation
- drag and drop planning contours
- interpolate contours for skipped images

**Hardware:**
user-friendly interactive Grip pen display (Cintiq 21UX, Wacom).

Decimating/Interpolating slices

Dropping contours from planning CT

Drawing tablet and pen

Moving in Sagittal/Coronal view
Fast plan modification:

Segment Aperture Morphing
How to perform pre-Tx QA for online ART Plans?

- Re-opt from scratch
- Re-opt from existing plan
- SAM

96% of leaf changes < 1mm for SAM plan)

Pre-Tx QA with software may be adequate, as long as original plan is fully QA’ed.
ART Process

Imaging

Treatment planning system

Treatment management system

Radiation delivery system

QA Check by software

Verification of plan

Verification of plan transfer

Verification of plan delivery

Imaging

Treatment planning system

Treatment management system

Radiation delivery system

QA Check by software

Verification of plan

Verification of plan transfer

Verification of plan delivery
Software tools for QA prior and after delivery: verifying MU#, plan data transferring and actual delivery
Online ART for prostate
Prostate: unpredictable inter-fraction change
Prostate

Dash: IGRT repositioning. Solid: online ART
Rectum

![Graph showing V70Gy in relation to rectal volume]

- **V70Gy / %**
- **Rectal volume / cm^3**

- **Repositioning**
- **Adaptive**
Projected reduction in rectal bleeding
Initial Clinical Experience with Prostate

Online ART has been used on 12 prostate cancer cases and one bladder cancer case so far.

Online replanning, eliminating the need to shift the patient, can be performed within the similar or slightly longer time frame required for the current IGRT repositioning and fits into the routine clinical workflow.
Combined online and offline adaptive radiation therapy: a dosimetric feasibility study

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Dian Wang MD a, Selim Firtat MD a, Beth Erickson MD a, X. Allen Li PhD a,*

Hybrid ART: online ART + IGRT
Clinical Investigation: Genitourinary Cancer

A Fully Automated Method for CT-on-Rails-Guided Online Adaptive Planning for Prostate Cancer Intensity Modulated Radiation Therapy

Xiaoqiang Li, PhD, * Enzhuo M. Quan, PhD, * Yupeng Li, MS, * Xiaoning Pan, PhD, † Yin Zhou, PhD, † Xiaochun Wang, PhD, * Weiliang Du, PhD, † Rajat J. Kudchadker, PhD, * Jennifer L. Johnson, MS, * Deborah A. Kuban, MD, † Andrew K. Lee, MD, † and Xiaodong Zhang, PhD *

Fig. 4. Cumulative DVHs of the adaptive plans using the AAP method (solid lines) and prostate COV alignment (dashed lines) for patient 5. Each of the DVHs shown is derived from the cumulative dose distributions of 8 repeat CT scans and was evaluated with the manual contours on simulation CT.
ART: pancreatic cancer

Prognosis: 5% at 5 year
Inter-fractional Variations: pancreas head
Soft-tissue based registration with gated CT

PTV 10 mm margin

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Adaptive radiotherapy
Development of an online adaptive solution to account for inter- and intra-fractional variations

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Major Challenge of Online ART for Pancreas

Target/OAR delineation

– difficult for auto-segmentation due to large deformations and insufficient soft-tissue contrast
– a large number of OARs (duodenum, bowels, stomach, kidneys, liver, spinal cord)
Online Adaptive Replanning

ART allows smaller (e.g., 5mm) PTV margin, compared to repositioning (e.g., 10 mm margin)
Adaptive v.s. Repositioning

- Duodenum

10 cases
Dosimetric Impact of RT delivery technologies on pancreas RT

<table>
<thead>
<tr>
<th></th>
<th>ART gating</th>
<th>IGRT gating</th>
<th>IGRT No gating</th>
<th>No IGRT no gating</th>
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<tbody>
<tr>
<td>Duodenum V50.4</td>
<td>19%</td>
<td>42%</td>
<td>66%</td>
<td>72%</td>
</tr>
<tr>
<td>L-Kidney V15</td>
<td>8%</td>
<td>15%</td>
<td>22%</td>
<td>19%</td>
</tr>
<tr>
<td>R-Kidney V15</td>
<td>14%</td>
<td>23%</td>
<td>32%</td>
<td>35%</td>
</tr>
<tr>
<td>Large Bowel V45</td>
<td>0.4%</td>
<td>3%</td>
<td>8%</td>
<td>11%</td>
</tr>
<tr>
<td>Stomach V45</td>
<td>1%</td>
<td>4%</td>
<td>9%</td>
<td>11%</td>
</tr>
<tr>
<td>Liver V30</td>
<td>2%</td>
<td>6%</td>
<td>13%</td>
<td>17%</td>
</tr>
<tr>
<td>Small Bowel V45</td>
<td>1%</td>
<td>4%</td>
<td>10%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Average of 5 patients
Dose escalation for unresectable pancreatic cancer

- MRI/PET defined GTV
- 4DCT based planning
- Daily gated CT guided gated delivery
- Hybrid ART

\[
\text{GTV: } 31 \times 2.25 = 69.75 \text{ Gy} \\
\text{PTV: } 33 \times 1.76 = 54.56 \text{ Gy}
\]
ART for breast
Lumpectomy cavity volume and shape change

Prone

Supine

Graph showing volume ratio changes over time.
ART for PBI

- Improve target conformity
- Reduce skin dose
Repositioning vs Adaptive Plan: Supine

![Graph showing dose vs volume for different repositioning methods](image)

- Clip-based Repositioning
- Contour-based Repositioning
- Adaptive
- Re-optimized

PTV-EVAL

Ipsilateral Breast Reference Volume

Ipsilateral Lung

Dose (cGy)

95% Dose
Breast WBI + ART for boost
Changes in lump cavity between daily CT at boost and plan CT.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Quantity</th>
<th>IGRT</th>
<th>ART</th>
</tr>
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<tbody>
<tr>
<td>PTV eval</td>
<td>$V_{95%}$</td>
<td>93.7%</td>
<td>96.0%</td>
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<tr>
<td>Breast eval</td>
<td>$V_{50%}$</td>
<td>42.3%</td>
<td>39.3%</td>
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<tr>
<td>Breast eval</td>
<td>$V_{100%}$</td>
<td>18.6%</td>
<td>17.0%</td>
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<tr>
<td>PTV eval</td>
<td>CI</td>
<td>2.0</td>
<td>1.8</td>
</tr>
</tbody>
</table>
Offline ART for IMRT SIB

- ART replanning based on new CT at 10th fr (28 fr total)
- Eligibility:
  - lump cavity > 30 cc
- Findings
  - 9% of patient eligible
  - significant reduction of high dose volume

Hurkmans et al, Radiother Oncol. 2012;103:183-7
A study in design at MCW

Whole breast irradiation + ART boost

• ART plan based on CT one day before boost; boost treated with ART plan

• Eligibility:
  ➢ lump cavity > 30 cc
  ➢ V54Gy > 40%

• End points:
  ➢ Primary: reduction of fibrosis
  ➢ Secondary: reduction of local recurrence
Summary

- The current standard of IGRT (repositioning) can not address volume change, deformation and rotation.
- ART (Online, offline, hybrid) not only address only anatomy changes (translational and rotational shifts and deformation), eliminating repositioning, but can also potentially consider patient specific treatment response.
- As demonstrated on tumor sites of prostate, pancreas and breast, ART replanning leads to improved target coverage and/or normal tissue sparing.
- The online ART enables “image-plan-treat”, particularly important for hypofractionations, SBRT.
- ART begins moving into clinic for various tumor sites.