Strategies for Adaptive RT

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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."

Yan, D., Vicini, F., Wong, J., & Martinez, A. (1997). Adaptive radiation therapy. Physics in medicine and biology, 42(1), 123.

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?

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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

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What is needed for ART?

- High quality imaging
- Fast replanning
- Quality assurance methods

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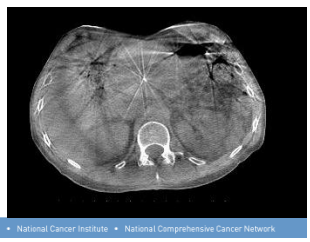
What is needed for ART?

- High quality imaging
  - CBCT seldom sufficient (currently)



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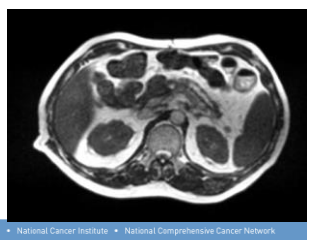
What is needed for ART?

- High quality imaging
  - MRI provides superior soft tissue contrast even at low field strength (0.35 T)



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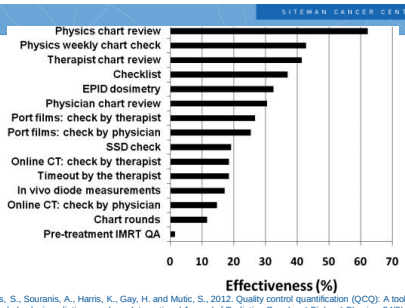
What is needed for ART?

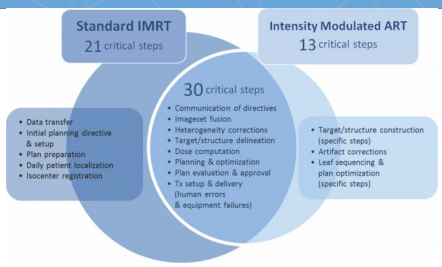
- Fast replanning
  - Registration of image of the day to planning image and underlying electron density
  - Contour transfer – manual or automatic
  - Robust reoptimization
  - Efficient decision mechanism

What is needed for ART?

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



Ford, E.C., Terezakis, S., Souranis, A., Harris, K., Gay, H. and Mutic, S., 2012. Quality control quantification (QCQ): A tool to measure the value of quality control checks in radiation oncology. *International Journal of Radiation Oncology* Biology* Physics*, *84*(3), pp.e263-e269.



Noel, C.E., Santanam, L., Parikh, P.J. and Mutic, S., 2014. Process-based quality management for clinical implementation of adaptive radiotherapy.Medical physics, 41(8), p.081717.

Learning Objectives

- What is ART?
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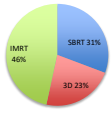
- Example from experience

Washington University MR-IGRT Experience

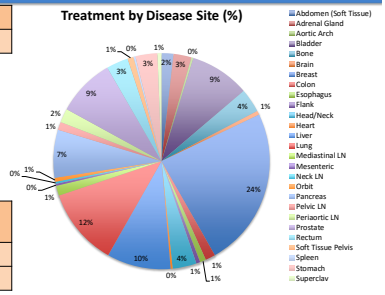
335 Treated Patients	
Total Fractions Treated	4428

Treatment Type (%)



62 Adapted Patients	
Total Fractions Prescribed	398
Total Adapted Fractions	241

Treatment by Disease Site (%)



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 artifically-generated structures)

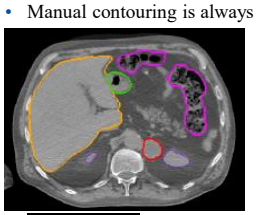
Example from Experience: 4. Patient Setup

- 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

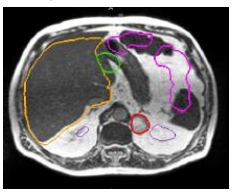
Example from Experience: 5. Registration and Recontouring

- 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

ViewRay Online Adaptive Patient Specific Instructions

Patient Name	RO	Site	Rx (Gy)	Fractions	Daily Dose (Gy)	Adaptive Schedule
SAMPLE PATIENT	1111111	Left Adrenal	50	5	10.0	Daily

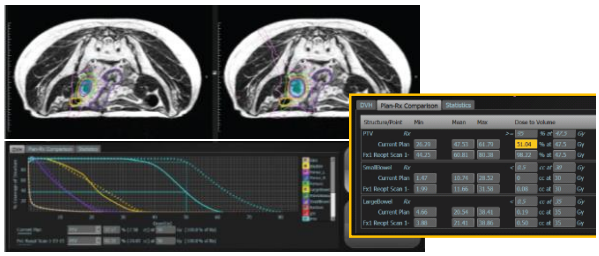
Original Plan Information	Normalization?	Density Overrides	Material	Priority
FINAL_SBRT LT ADRENAL_07.27.2016	no	Water_DensityOverride	Water	18
		Air_DensityOverride	Air	17

	Optimization Structures	Definition
1	Skin	
2	Kidney_R	
3	SmallBowel	
4	SpinalCord	
5	Stomach	
6	PTV_opt	

	Margin Expansions and Boolean Operations		Definition
1	PTV	margin expansion	GTV + 0.6 cm
2	GATING TARGET	boolean addition	clear gating target, add GTV, clean with 0.5 cm Kernel
	There is a 5-cm ring structure, it does not need to be reproduced		
	The following structures have associated rules that need to be applied to recreate them		
1	Stomach + 7mm	margin expansion	stomach + 0.7 cm
2	SmallBowel + 7mm	margin expansion	SmallBowel + 0.7 cm
3	S7+SB7	boolean addition	Stomach + 7 mm + SmallBowel + 7 mm
4	PTV_opt	boolean subtraction	PTV - (S7+SB7)
5	KIDNEYS	boolean addition	Kidney_L + Kidney_R

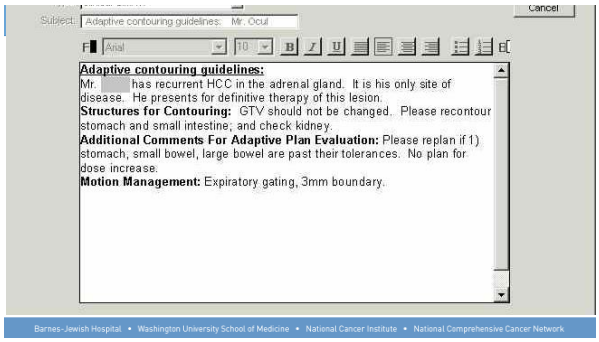
Example from Experience: 7. Dose Prediction

- 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)



Adaptive contouring guidelines:

has locally recurrent pancreatic cancer s/p Whipple and adjuvant gemcitabine. He is receiving palliative chemotherapy and radiation.

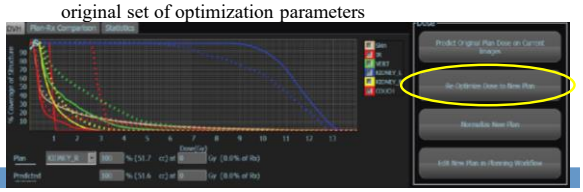
Structures for Contouring: GTV should not be changed and extends to the vasculature, and is difficult to see. Recontour small bowel, large bowel and stomach.

Additional Comments For Adaptive Plan Evaluation: Please replan if 1) stomach, small bowel, large bowel are greater than .75 cc past 45 Gy. 2) if CTV coverage at 64.1 Gy Gy improves past 90%. No constraint on hot spot.

Motion Management: Expiratory gating, 3mm boundary.

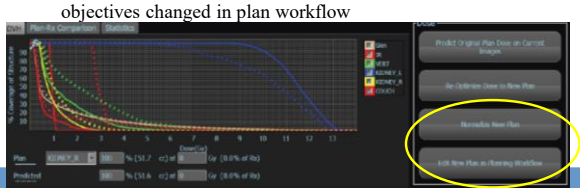
Example from Experience: 8. Plan reoptimization

- 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



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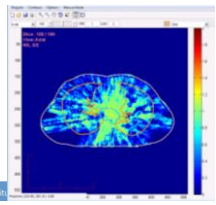
Example from Experience: 9. Quality Assurance

- 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%



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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)

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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

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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