Online MR-IG-ART Dosimetry and Dose Accumulation

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Disclosure

- Received research grants from the Agency for Healthcare Research and Quality (AHRQ) under award R01-HS022888
- Received research grants and software licensing fee from Viewray Inc.
- Received research grants from Varian Medical System

ViewRay – MRI-Guided Cobalt Radiotherapy (0.35 T) / LINAC (6FFF)

Unity by Elekta / Philips – MRI (1.5T) + Linac (7 MV)

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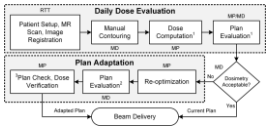
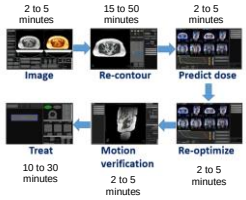
Online MR-IG-ART Clinical Workflow





Total: 40 to 80 minutes

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4

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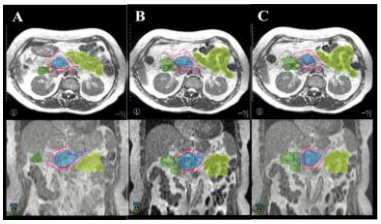
Need of Online MR-IG-ART



FX1 | FX2 –Dose computed Using FX1 plan, evaluated on FX2 contours | FX2 plan after adaptation

A: Fraction 1 imaging showing plan isodose lines
B: Daily MRI obtained on Fraction 2 prior to MRgRT showing translation of duodenum and small bowel into high dose region resulting in violation of OAR constraints
C: Daily adaptive planning performed resulting in resolution of constraint violations and improved tumor volume coverage.

Pancreatic tumor
Duodenum
Small bowel

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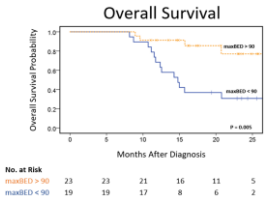
Overall survival and GI toxicity



Gr 3+ GI Toxicity	
$maxBED_{10}$>90	0%
$maxBED_{10}$<90	15.8%

maxBED > 90 = adaptive patient

~75% fractions were adapted

67.5 Gy in 15 fractions or 50 Gy in 5 fractions

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Dosimetry goals and regular options

Stage	Goals	Regular Dosimetry Measurement Options
Pre-treatment	To verify TPS dose	MRI compatible devices: ArcCheck, IC, film, etc. and Log QA
During treatment	To assure correct beam delivery	MRI compatible real-time in-vivo dosimeters: MOSFET, etc.
Post-treatment	To verify the overall delivery	Film, OSLD, TLD and Log QA

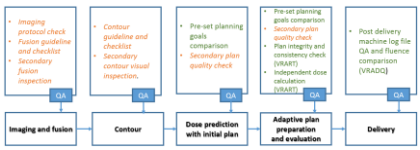
Other talks at AAPM 2018

Authors / Institutions	Titles
D Tweatia, Wisconsin	Feasibility of MOSFET Real-Time In-Vivo Dosimetry for MR-Linac Beams Under 0.345 T Magnetic Field
I Xhaferllari, Henry Ford	Investigating the Clinical Utility of Gafchromic EBT3 Film Dosimetry in An MR-Guided Linac
A Stalmann, Wisconsin	Characterization and Validation of TLD and EBT3 Film in MR/CT Visible Phantoms Under the Presence of 0T, 0.35T and 1.5T
P Bruza, Dartmouth	Towards Time Resolved 3D Dosimetry in MR-Linacs: Scintillation Images Surrogate Dose Distribution with High Accuracy

New challenges to pre-treatment QA

- QA efficiency / time
- Water phantom measurement cannot be used
  - Patients cannot be moved from their aligned treatment position.
- Choice – a secondary and independent dose calculation, plus 3D Gamma analysis
- Concerns – a secondary dose calculation is not based on measurement.

ART QAs - a comprehensive approach



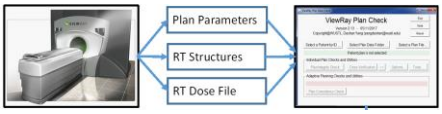
- Checklist
- Morning machine QA
- Manual QA while contouring and planning
- Secondary QA calculation (to verify TPS dose)
- Automatic plan integrity and consistency check (for everything else)
- Automatic post-treatment log QA, physics chart check, and optional ArcCheck and IC QA

Major QA steps

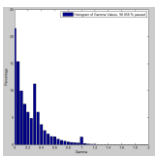
Major ART Steps	Personnel	Major Risks	QA tasks	QA Personnel	QA Time required
Daily Imaging and fusion	Therapist	Using wrong imaging parameters resulting in bad images	Imaging protocols and fusion guidelines are followed	Physicist	1~2 min
Daily Imaging and fusion	Therapist	Suboptimal image registration	Imaging registration check	Physicist	1~2 min
Contour	Physician	Wrong contours, mis-contoured or mis-labeled structures	Contour guidlines and checklists are followed; Contour visual inspection	Physicist	2~3 min
Plan preparation and evaluation	Physician	Incorrect selection of dosimetry constraints; Plan with bad quality	Pre-set planning goals comparisons and plan quality evaluation	Physicist	1~3 min
Plan preparation and evaluation	Physicist	Incorrect plan parameter settings result in indeliverable plan	Plan integrity and consistency check; Independent dose calculations	Physician and Physicist	2~4 min
Delivery	Therapist	Delivery interuptions; machine malfunctions	Delivery Monitoring	Physicist	Per plan

Plan integrity and consistency checks

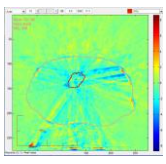
- Check the plan parameter integrity to assure if all planning parameters and settings are correct or within the tolerance
- Check the plan and beam parameter consistency between the original plan and the new adapted plan



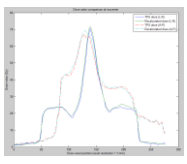
Computational dosimetry verification



3D Gamma Passing Rate Histogram



Dose Difference



Dose Distribution Line Profiles at Isocenter

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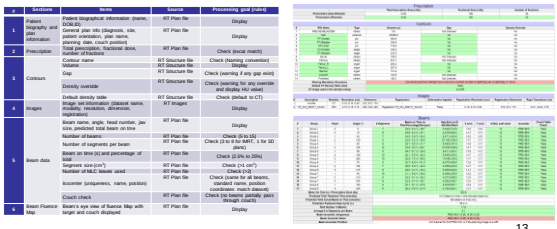
Plan parameter integrity check



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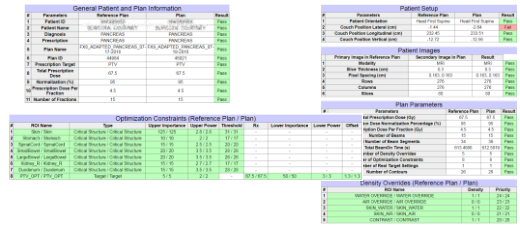
Plan parameter consistency check



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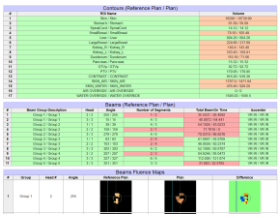

Post-treatment delivery QA

- Automated log QA
- Regular physics QAs (optional)
  - ArcCheck QA
  - IC QA

Beam Delivery Verification

Group	#	Plan Head/Gantry	Beam On Time (s) (Expected/Delivered)	Head	Gantry	Number of Segments	Pass Rate	MLC Error (mm) Mean +/- Std
Group 3	1	1 - 45.00°	230.59 / 230.59	1	45.00°	5 / 5	100.0%	0.0 +/- 0.0
	2	2 - 165.00°	12.09 / 12.09	2	165.00°	1 / 1	100.0%	0.0 +/- 0.0
	3	3 - 285.00°	155.34 / 155.34	3	285.00°	5 / 5	100.0%	0.0 +/- 0.0
Group 4	4	1 - 60.00°	165.42 / 165.56	1	60.00°	5 / 5	100.0%	0.0 +/- 0.0
	5	2 - 180.00°	4.60 / 4.61	2	180.00°	1 / 1	100.0%	0.0 +/- 0.0
	6	3 - 300.00°	94.04 / 94.06	3	300.00°	6 / 6	100.0%	0.0 +/- 0.0
Group 5	7	1 - 80.00°	133.77 / 133.78	1	79.96°	7 / 7	100.0%	0.0 +/- 0.0
	8	2 - 200.00°	47.19 / 47.19	2	199.96°	4 / 4	100.0%	0.0 +/- 0.0
	9	3 - 320.00°	292.35 / 292.40	3	319.96°	9 / 9	100.0%	0.0 +/- 0.0
Group 6	10	1 - 105.00°	9.96 / 9.97	1	104.96°	1 / 1	100.0%	0.0 +/- 0.0
	11	3 - 345.00°	176.23 / 176.23	3	344.96°	9 / 9	100.0%	0.0 +/- 0.0
Group 1	12	2 - 245.00°	154.79 / 154.81	2	245.06°	5 / 5	100.0%	0.0 +/- 0.0
	13	3 - 5.00°	156.00 / 156.01	3	5.00°	7 / 7	100.0%	0.0 +/- 0.0
Group 2	14	1 - 25.00°	139.55 / 139.55	3	25.00°	5 / 5	100.0%	0.0 +/- 0.0
	15	2 - 145.00°	23.60 / 23.61	1	145.00°	1 / 1	100.0%	0.0 +/- 0.0
	16	3 - 265.00°	129.64 / 129.65	2	265.00°	6 / 6	100.0%	0.0 +/- 0.0
Total Delivery Time				26.10 (minutes)				
Beam On Time (%)				54.4%				

Need of dose accumulation

- Planned dose is not the dose received by target and OARs
  - Machine output variation, delivery inaccuracies (on MLC, jaw, gantry, etc.), gating inaccuracy and delays
  - Patient setup uncertainties and organ position variations
  - Tissue motion

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Improved by online MR-IG-ART via soft tissue target based patient setup, adaptation and real-time gating.

Gated treatment

- 2D Cine MRI in sagittal at the center of tumor, 4 f/s
- Automatic target tracking
- Gating based on region overlapping percentage

Intra-fraction dose accumulation

- The need of intra-fraction dose accumulation is reduced by gated treatment based on real-time 2D cine movie and automatic target tracking
- Could be accomplished by
  - Compute 2D motion on the sagittal CINE MRI movie using rigid or deformable registration
  - Correlate 2D motion to beam delivery records by timestamp
    - Instantaneous gantry, MLC, MU, dose rate, gated beam on/offs
  - MC dose re-calculation, incorporating the estimated tissue motion and the correlated beam delivery records

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Inter-fractional dose accumulation

- General procedure
  - Image registration between images of fractions
  - Adding the intra-fraction accumulated dose volumes based on motion vector field computed by image registration methods
- Work better for MRI than for CBCT due to improved soft tissue contrast in MRI
- Work well for treatment sites with minimal inter-fractional OAR positional variations
- Does not work well for abdominal tumors

Inter-fractional dose accumulation

- Regular deformable image registrations (DIR) do not work well for abdomen due to excessive OAR positional variations (small and large bowel, duodenum, stomach)
- DIR options ← further research tasks
  - Surface mesh based DIR for digestive organs
  - FEM based DIR for liver and kidneys
  - Intensity based DIR for the tumor and the near proximity
  - Dose accumulation to be performed separately for OARs and tumor tagets.

Summary

- Online MR-IG-ART is effective for pancreas and abdominal tumors, can improve treatment outcome significantly.
- Measurement based pre-treatment dosimetry QA cannot be applied for adaptive cases.
  - A comprehensive QA approach (manual + automatic + secondary dose calculation) is applied.
- Dose accumulation is possible but not yet applied routinely in the clinic.