Building a Successful Adaptive Radiotherapy Program

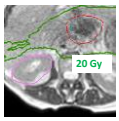
Patient-Specific QA Strategies for Adaptive Radiotherapy

D.A. Low, Ph.D UCLA

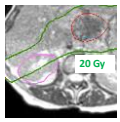
Disclosures

- ViewRay Stock
- Varian MRA

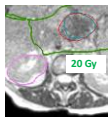
Why ART QA is Needed



Initial plan: kidney far away and not getting much dose, so not included in optimization.

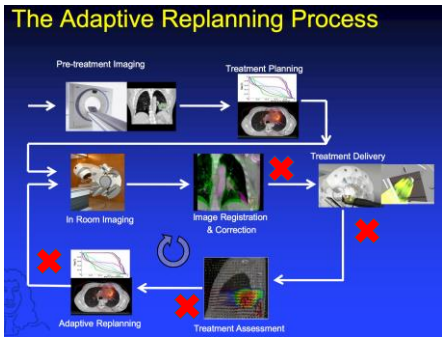


Re-optimized plan: still far away, but not weighted and optimizer happens to puts a beam through it.



Edited optimization: Fixed the problem but added time and complexity.

James Lamb



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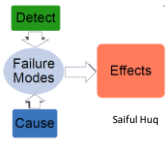
Patient-Specific QA

- Patient-specific QA paradigms need to be revisited for Adaptive RT
- Time, complexity, and changes in risk profiles demand updated approach
- No anecdotal or recorded data concerning errors
- Proactive approach is needed

How to Approach?

- TG100 based concepts
- FMEA
- Identify potential failure modes
- Evaluate relative priority to manage failure mode (risk priority number)
- RPN = O*D*S
  - O: Probability of occurrence
  - D: (non) Detection
  - S: Severity



Saiful Huq

Example ODS Table

Highly Nonlinear!

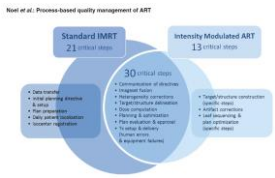
Rank	Occurrence	Detection	Severity
	Probability that the cause will occur and lead to the failure mode	Probability that the failure mode will be detected before resulting in the end effect	Seriousness of the end effect when it occurs
1	Remote probability	Always	No effect
2	Low probability	High likelihood	Minor effect
3			
4	Moderate probability	Moderate likelihood	Moderate effect
5			
6			
7	High probability	Low likelihood	Serious effect
8			
9	Very high probability	Very low likelihood	Injury
10	100% probable	Never	Death

FMEA ranking scales for Occurrence, Detection and Severity.

Death = 5X Minor Effect!

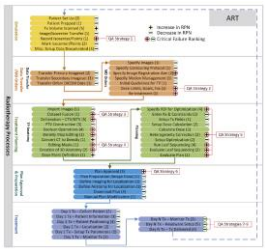
Adaptive FMEA

- FMEA for ART conduced by Noel et al
- Evaluated "critical steps" in conventional IMRT and ART
- 21 critical steps unique to standard IMRT
- 30 critical steps common to both
- 13 new critical steps



Relative FMEA

- Followed up by Cai et al to compare conventional IMRT and Adaptive
- Divided into 5 workflow categories
  - Simulation
  - Data Transfer and MD Orders
  - Treatment Planning
  - Plan Approval and Preparation
  - Treatment



Cai et al, Med Phys in press

Why Different?

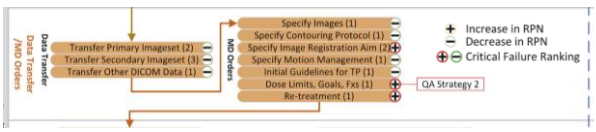
- Timescales
  - Off-line allows 1 day for entire workflow
  - On-line allows minutes for entire workflow
- Workflow more complex
  - Similar to retreatment
  - Requires assessment of prior dose
    - Registration and re-segmentation
  - Requires optimization with updated contours
  - Rapid evaluation of plan quality

Simulation

Failures	Associated Steps	QA Strategies
Incorrect isocenter documentation	Daily imaging/simulation, adaptive planning setup, adaptive plan setup and delivery	Automated isocenter capture, checklists, monitoring trends in daily patient shifts

Cai et al, Med Phys in press

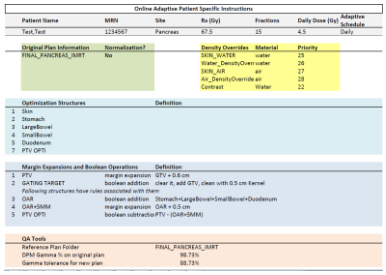
Data Transfer and MD Orders



Failures	Associated Steps	QA Strategies
Miscommunication of planning directives and failure to properly account for dose accumulation	Dose prediction/evaluation, adaptive planning setup, adaptive plan evaluation	Well-defined protocols, stable clinical workflow, staff training, integrated record management, electronic physician order, electronic tracking systems

Checklists and Standardization

Sasa Mutic



Online Adaptive Patient Specific Instructions

Patient Name	MRN	Site	Rx (Gy)	Fractions	Daily Dose (Gy)	Adaptive Schedule
Test,Test	1234567	Pancreas	67.5	15	4.5	Daily

Original Plan Information	Normalization?
FINAL_PANCREAS_IMRT	No

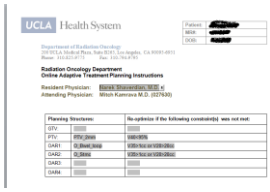
Density Overrides	Material	Priority
SKIN_WATER	water	25
Water_DensityOverri	water	26
SKIN_AIR	air	27
Air_DensityOverride	air	28
Contrast	Water	22

	Optimization Structures	Definition
1	Skin	
2	Stomach	
3	LargeBowel	
4	SmallBowel	
5	Duodenum	
7	PTV OPTI	

	Margin Expansions and Boolean Operations	Definition	
1	PTV	margin expansion	GTV + 0.6 cm
2	GATING TARGET	boolean addition	clear it, add GTV, clean with 0.5 cm Kernel
	Following structures have rules associated with them		
3	OAR	boolean addition	Stomach+LargeBowel+SmallBowel+Duodenum
4	OAR+5MM	margin expansion	OAR + 0.5 cm
5	PTV OPTI	boolean subtractio	PTV - (OAR+5MM)

QA Tools	
Reference Plan Folder	FINAL_PANCREAS_IMRT
DPM Gamma % on original plan	98.73%
Gamma tolerance for new plan	98.73%

UCLA Checklists and Communications



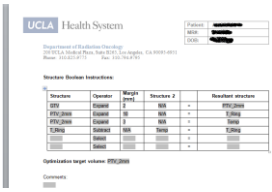
UCLA Health System

Radiation Oncology Department
Online Adaptive Treatment Planning Instructions

Resident Physician: [redacted]
Attending Physician: Minoh Kamrava M.D. (027630)

Planning Structures:		Re-optimize if the following constraint(s) was not met:
GTV	[redacted]	[redacted]
PTV	PTV_2mm	V40<95%
OAR1	D_5cm3_bowel	V30<1cc or V20<20cc
OAR2	D_5cm3	V30<1cc or V20<40cc
OAR3:	[redacted]	[redacted]
OAR4:	[redacted]	[redacted]

For covering physician: critical constraints



UCLA Health System

Structure Boolean Instructions:

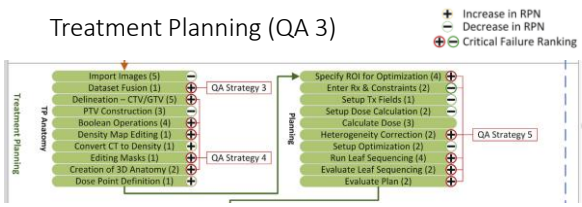
	Structure	Operator	Margin (mm)	Structure 2		Resultant structure
	GTV	Expand	6	N/A	+	PTV_2mm
	PTV_2mm	Expand	10	N/A	+	T_Ring
	PTV_2mm	Expand	5	N/A	+	Temp
	T_Ring	Subtract	N/A	Temp	+	T_Ring
	[redacted]	Select	[redacted]	[redacted]	+	[redacted]
	[redacted]	Select	[redacted]	[redacted]	+	[redacted]

Optimization target volume: PTV_2mm

Comments:
[redacted]

For covering planner: optimization structures and booleans

Treatment Planning (QA 3)

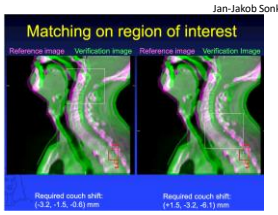


Failures	Associated Steps	QA Strategies
Poor dataset fusion	Daily imaging, image registration	Automated fusion tools, special training for onsite staff

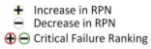
Fusion QA

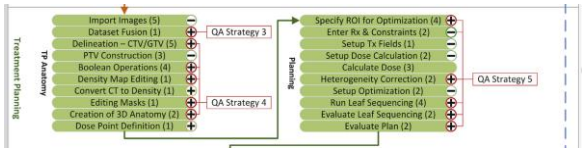
- Same processes as traditional fusion
  - Manual evaluation
- Focus, focus, focus

Jan-Jakob Sonke



Treatment Planning (QA 4)

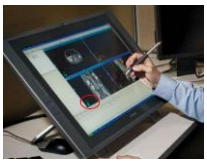




Failures	Associated Steps	QA Strategies
Incorrect target/structure delineation	Daily imaging/simulation, image registration, segmentation	Automated contour integrity verification software

Contouring

1) Manual and auto-contouring with and without deformation
   - Number of structures – need to minimize
   - Contouring errors – Focus on errors that have dosimetric impact
   - The goal is to quickly (minutes) create needed structures which are sufficiently accurate to create adaptive plan
2) Manual contour QA
3) Automatic contour QA
   - Not the same as automatic contouring
   - Generally a separate algorithm/software
   - Developing paradigm and tools



Altman et al (PMB 2015, 5199)

- Developed automated contour QA technique
- Relied on knowledge-based approach
- Technique able to detect most errors
- Adaptive is subtly different
  - Same patient, different day
  - Patient is its own knowledge base
- Metrics:
  - Size/shape
  - Positional
  - Image/pixel properties
  - Binary type metrics (e.g. presence)

Contour QA

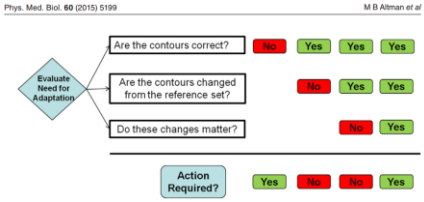
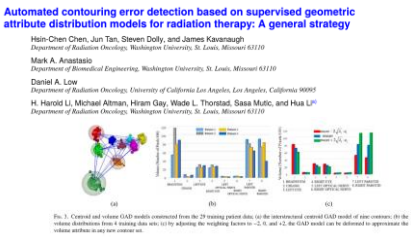


Figure 4. OL-ART contour QA decision tree.

Altman et al PMB 60, 5199 (2015)

Chen et al, Geometric Attribute Distribution Model



Automated contouring error detection based on supervised geometric attribute distribution models for radiation therapy: A general strategy

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Department of Radiation Oncology, Washington University, St. Louis, Missouri 63110

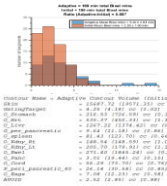
Chen et al Medical Physics, Vol. 42, No. 2, February 2015

GAD Model

- Characterize intra-structural centroid and volume variations
- Intra-structural shape variations
- Iterative weighted GAD model-fitting to detect contouring errors
- Trained and demonstrated on head and neck patients
- Sensitivity and specificity >0.9 for centroid and volume related contouring errors
- Sensitivity and specificity of 0.82 and 0.94, respectively, for shape errors

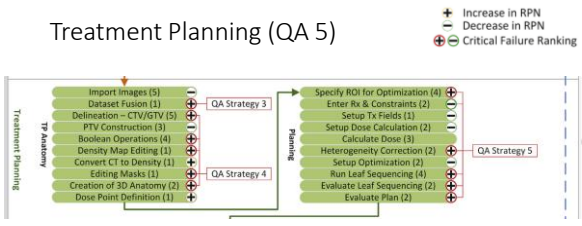
Our QA Process

- Manual during initial processes (physicist and physician)
- After plan completed, QA report contains quantitative comparisons between original and new contours



Project lead at UCLA: David Thomas, PhD
Acknowledgements:
- Zeus MC support: Tony Apicella / ViewRay
- 3D Gamma code: Mark Geurts / UW

Treatment Planning (QA 5)

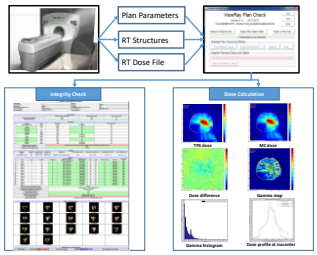


Failures	Associated Steps	QA Strategies
Poor plan optimization and/or incorrect dose computation	Adaptive planning setup, plan re-optimization	Automated software verifying: dose computation, leaf sequencing, plan integrity

Plan verification

- Traditional workflow
  - measurement based
- Adaptive workflow
  - calculation based

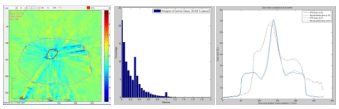
Wash U Process, Courtesy Sasa Mutic



Dose Distribution Comparison

Wash U Software, Courtesy Sasa Mutic

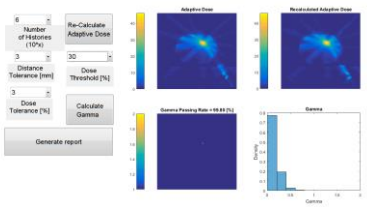
- 3D gamma calculation over the full volume with 3%, 3 mm criteria
- Everything outside the skin is ignored



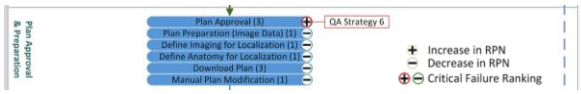
(a) Dose difference. PTV contour and skin contour are displayed in this case	(b) Gamma histogram calculated with 3%/3mm criteria.	(c) Dose profile passing isocenter. Solid line represents the Anterior-Posterior direction and dashed line is the Left-Right direction.

UCLA Process

- Also use Monte Carlo
- Developed our "wrapper"



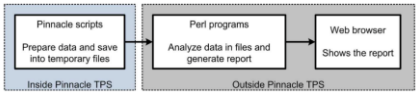
Plan Approval and Preparation



Failures	Associated Steps	QA Strategies
Poor plan review	Dose prediction/evaluation, adaptive plan evaluation	Automated comparisons between planning goals and achieved goals, decision support software

Automated Plan Quality Checks

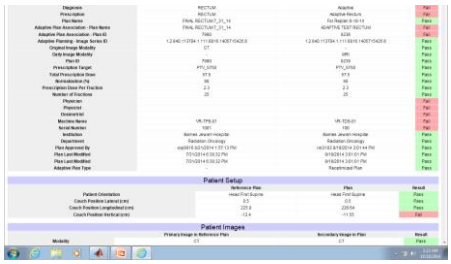
- Yang et al, (Wash U) Plan integrity verification



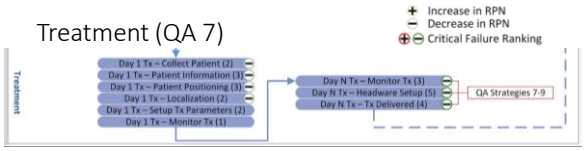
- Covington et al, (Michigan) Plan Checker Tool
- Zhu et al, (Duke), Prostate adaptive plan quality tool, predicts dose quality and compares against plan

Plan Quality Evaluation

Wash U Software, Courtesy Sasa Mutic



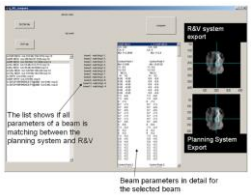
Treatment (QA 7)



Failures	Associated Steps	QA Strategies
Incorrect interpretation of plan data for treatment delivery	Adaptive plan setup and delivery	Independent verification software comparing data indicated by the planning system to data read by the delivery system

Early Approach

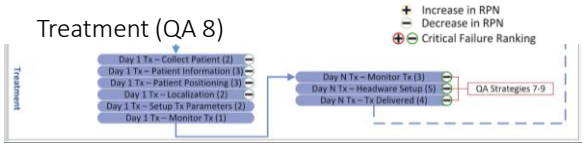
- Peng et al (PMB 201 3659) developed 4 step approach for prostate ART
  - Offline phantom measurement of original plan
  - Online independent MU calc
  - Online plan-data transfer verification
  - Offline validation of delivered parameters (post-treatment)



Wash U

Sasa Mutic

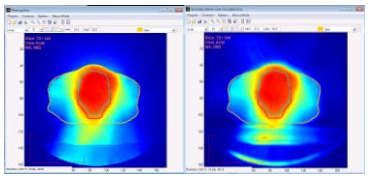
Treatment (QA 8)



Failures	Associated Steps	QA Strategies
Failures in treatment parameter setup on treatment machine	Adaptive plan setup and delivery	Simulated delivery, pretreatment, retrospective MLC QA

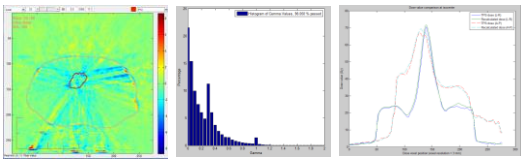
Independent Dose Calculations

- Wash U Software
- Rapid Monte Carlo calculation
- Relatively poor statistics

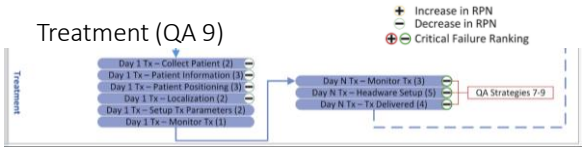


Dose Calculation Comparisons

- 3D Gamma comparison, histograms, profiles, etc.



Treatment (QA 9)



Failures	Associated Steps	QA Strategies
Failures during treatment delivery	Adaptive plan setup and delivery	Transmission detectors, real-time MLC/Gantry monitoring, post delivery machine record QA

Conclusions

- Substantial differences between conventional and adaptive patient-specific QA
- Calculation-based dose distribution and treatment delivery QA replaces measurement base
- Need for quantitative and rapid QA will rely on automation
  - Meanwhile, more manual techniques are employed
- Excellent example of use of FMEA