Improving Quality of Care in Radiation Therapy using AI in Physics Plan and Chart Review

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July 13, 2022

SAM Therapy Educational Course – Artificial Intelligence for QA



Introduction

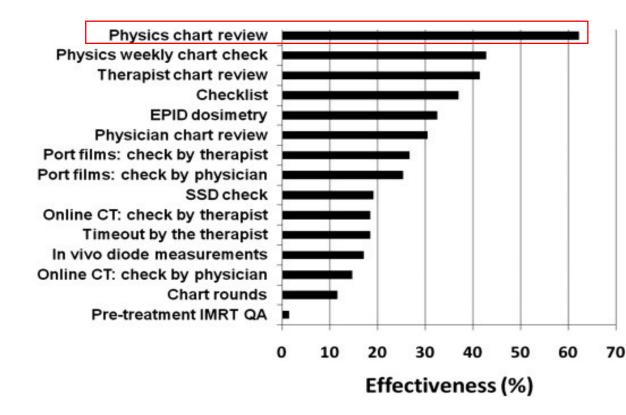


RT Processes	Diagnosis and Physician Consultations	Simulation	Treatment Planning	Quality Assurance	Treatment Delivery
Example tasks benefit from Al	 Tumor delineation Treatment decision support 	 Determine optimal setup Image artifacts reduction 	 Auto- segmentation Automated planning 	 Plan review Patient specific QA Machine QA 	 Motion management Adaptive planning and QA
,				Contour QA	~



What is Physics Plan and Chart Review in Radiation Oncology?

- "Assure MUs are correct, all machine parameters used for patient setup are correct, additional setup instructions are correct, quality of the plan meets department standards, all signatures, prescriptions are recorded" – TG-40
- Initial plan review has shown to be the most effective individual QC check for detecting high severity incidents





Recommendations on Initial Treatment Plan Review Report of AAPM Task Group 275 Eric Ford^{a)} University of Washington Medical Center, Seattle, WA, USA

TG-275 – Strategies for Effective Physics Plan and Chart Review in Radiation Therapy

- Use a risk-based approach (FMEA) to develop recommendations to physics plan and chart review
- Photon/Electron EBRT initial plan/chart review checks ٠
 - Patient assessment
 - Simulation
 - Treatment planning
 - Data Transfer (for some combinations of TPS and OIS) ۲

Strategies for effective physics plan and chart review in radiation therapy:

Leigh Conroy The Princess Margaret Cancer Centre, Toronto, ON, Canada

Lei Dong University of Pennsylvania, Philadelphia, PA, USA

Luis Fong de Los Santos Mayo Clinic, Rochester, MN, USA

Anne Greener Veterans Affairs NJHCS, East Orange, NJ, USA

Grace Gwe-Ya Kim University of California, San Diego, CA, USA

Jennifer Johnson Landauer Medical Physics, Houston, TX, USA

Perry Johnson University of Miami, Miami, FL, USA

James G. Mechalakos Memorial Sloan-Kettering Cancer Center, Manhattan, NY, USA

Brian Napolitano Massachusetts General Hospital, Boston, MA, USA

Stephanie Parker Wake Forest Baptist Health, High Point, NC, USA

Deborah Schofield Saint Vincent Hospital, Worcester, MA, USA

Koren Smith Mary Bird Perkin Cancer Center, Baton Rouge, LA, USA

Ellen Yorke Memorial Sloan-Kettering Cancer Center, Manhattan, NY, USA

Michelle Wells Piedmont Cancer, Atlanta, GA, USA

(Received 9 August 2019; revised 3 January 2020; accepted for publication 8 January 2020; published 15 April 2020)

Background: While the review of radiotherapy treatment plans and charts by a medical physicist is a key component of safe, high-quality care, very few specific recommendations currently exist for this task. Aims: The goal of TG-275 is to provide practical, evidence-based recommendations on physics plan and chart review for radiation therapy. While this report is aimed mainly at medical physicists, others may benefit including dosimetrists, radiation therapists, physicians and other professionals interested in quality management.

Methods: The scope of the report includes photon/electron external beam radiotherapy (EBRT), proton radiotherapy, as well as high-dose rate (HDR) brachytherapy for gynecological applications (currently the highest volume brachytherapy service in most practices). The following review time points are considered: initial review prior to treatment, weekly review, and end-of-treatment review. The Task Group takes a risk-informed approach to developing recommendations. A failure mode and effects analysis was performed to determine the highest-risk aspects of each process. In the case of photon/electron EBRT, a survey of all American Association of Physicists in Medicine (AAPM) members was also conducted to determine current practices. A draft of this report was provided to the full AAPM membership for comment through a 3-week open-comment period, and the report was revised in response to these comments.



Recommendations on Initial Treatment Plan Review

MPPG 11a – Plan and Chart Review in External Beam Radiotherapy and Brachytherapy

- Goal: Provide recommendations on plan/chart review in the form of example lists of items to check for medical physicists and other clinical staff
- Initial EBRT Treatment Plan/Chart Review Items for Medical Physicists
 - Plan integrity check
 - E.g. Isocenter/initial reference point
 - Plan Quality and dose metrics reasonable
 - Preparation in RO-EMR
 - E.g. Prescription
 - Tolerance table

Received: 10 February 2020	Revised: 15 June 2020	Accepted: 16 June 2020
DOI: 10.1002/acm2.12981		
RADIATION ONC	OLOGY PHYSIC	<u>s</u>
Combining a	automatic p	plan integrity check (APIC) with
standard pla	an documer	nt and checklist method to reduce
errors in tre	atment pla	nning

Ping Xia | Danielle LaHurd | Peng Qi | Anthony Mastroianni | Daesung Lee Anthony Magnelli | Eric Murray | Matt Kolar | Bingqi Guo | Tim Meier | Samual T. Chao | John H. Suh | Naichang Yu



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Components of Initial Treatment Plan Reviews

- Items require simple check
 - Examples:
 - Prescription matches order
 - Dose constraints are fulfilled
 - Data transfer accuracy
- Items require logical judgement
 - Examples
 - Prescription is suitable for tumor type
 - Treatment technique fits the patient anatomy



Automation and Tools to Support Initial Plan Review

- Multiple in-house software and commercial products are developing/developed to assist initial plan review
- Perform mostly rules-based checks
 - e.g. Rx matches, DVH constraints met etc.
 - Good for items require only simple checks
- They are great tools to improve efficiency and effectiveness as recommended in MPPG 11.a and TG 275

CHECKLIST	
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Image: Sector A and the sector A and	
	:



Rules-based Algorithms

First order logic

- E.g. If the isocenter of setup beams is different from treatment fields, then it is flagged as an error
- > Advantages
 - > Fast
 - > Transparent
 - Good at finding static errors (protocols)

Disadvantages

- Difficult to check complex relationships
- Need to update manually





Artificial Intelligence for Plan Review



AI as an Assistive Tool in Physics Plan Review

- Can factor in different information of a treatment plan to assist physicists on judging the appropriateness of the technical aspects of treatment
 - E.g. is the prescription appropriate, should a bolus be used etc.
- Can be kept up-to-date to latest clinical development by re-training the models with latest clinical data



Outlier Detection Model

- Outlier detection model using a k-mean clustering algorithm for plan review of prostate cases
 planned with 'four-field' box
- Look for outliers in MU as well as beam energy

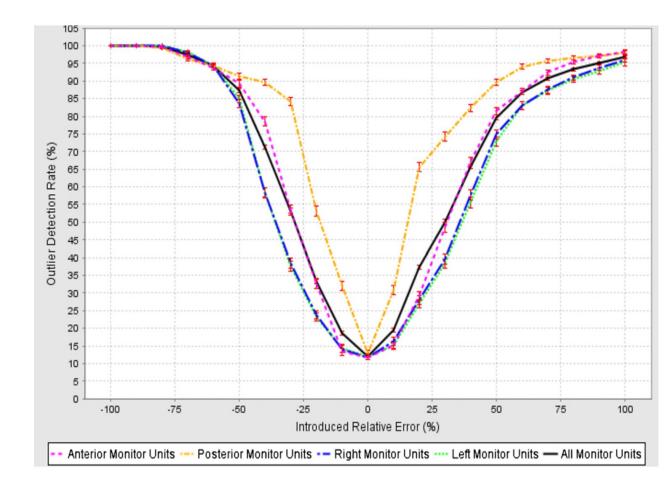


Figure 3. Outlier detection rate as a function of error level for each of the MU features and all MU features combined. The error bar shows one standard deviation.



Azmandian etal. Phys Med Biol 52:6511-6524 (2007)

Bayesian Network-based algorithm

> Artificial intelligence

Mimic human reasoning to some degree by learning from data

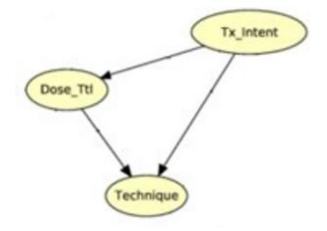
> Advantages

- Address points that require judgement
- Leverage clinical data and adapts to local practice and update with latest practice
- > Interpretable

Disadvantages

- Slower running speed
- Probabilistic results







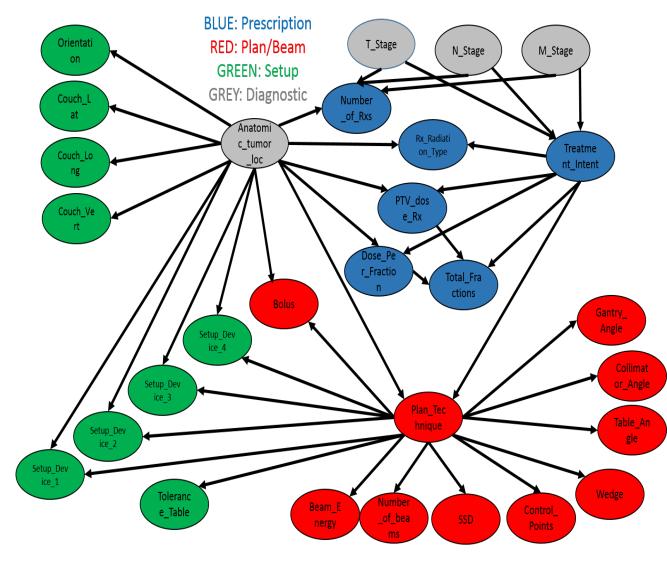
Error Detection Bayesian Network (EDBN)

- EDBN was developed to help detect potential errors in treatment plans
- Provide assistant on judging the appropriateness of treatment parameters given the diagnostic parameters
- 4 categories of parameters
 - Diagnostic
 - Prescription

The University of Vermont

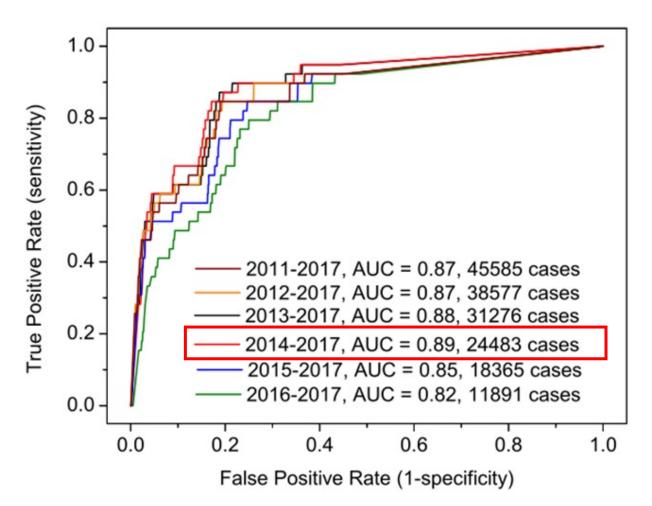
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- Plan and field parameter
- Setup



Effectiveness of the Network

- Testing cases with manually embedded errors
- > Types of errors
 - Prescription
 - Plan/Beam
 - Setup
- Area Under Curve = 0.89





Multi-Layered Approach using Rules and Al

- Combining the advantages of Bayesian Network and Rules
- Rules
 - Fast and good at identifying static errors
- Bayesian Network
 - Can mimic human logic and leverage clinical data to adapt local practice

	Bayes net	Rules
Errors of judgment	×	х
Maintenance/Updating	1 A C	х
Complex relationships	1	
Transparency	1 A A A A A A A A A A A A A A A A A A A	1 A -
Speed	х	1 de la compañía de la
Static Errors (protocols)	х	1



Plan Check Tool - Rules

Select patient		PATIENT INFO RULECH	ECK RESULT!	R	ule ch	eck Results tab	
							universal rule check
Select prescription				result	descriptio	n	\$
R mandible	•	beamDoseCheck		pass	check that	sum of all beams doses add up to Rx they belong to	
ADD PATIENT		RxNotApproved		pass	verify that	current prescription status is 'approved'	
		modalityMatch		pass	verify that	prescription modality matches beam modality	
U		BeamSetIsoCheck		pass	check that	all beams in an Rx have same iso	Universal rules
Choose Clinic		CheckForDRRs		pass	check that	all static fields have DRRs (including kV)	
		paceMakerCheck1		pass	warn use o	f 18MV for pacemaker pt	
		MUsegmentmax		pass	Check that	MU per segment is not larger than 999	
Enter comment	Select patient,	MUsegmentmin		pass	Check that	MU per segment greater than 5 for non-VMAT plans	
	prescription	Showing 1 to 8 of 8 entries	s				UWMC rule check
	and site		result		÷	description	\$
	l	radcalcDocExist	-not require	:d-		verify that MU second check calc docs are in	
SUBMIT COMMENTS		QADocExist	fail - no QA	document found		verify that QA docs are in (VMAT, IMRT, SBRT)	Site-specific rules +
		respDocExist	-not require	:d-		verify that phys response is in (TBI, SBRT)	documentation
SAVE RESULTS TO DATAE	RASE	SBRTreportExist	-not require	:d-		verify that dosi report exists for SBRT)	
SAVE RESOLTS TO DATAE		ISOsetupCheck	pass			check that setup beams have same iso as treatment	fields
		TBIdocuCheck	-not require	ed-		check if most recent roadmap and CCP are approved	and spec proc is in

Showing 1 to 6 of 6 entries

Bayesian Network – Web Application

The University of

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	PATIENT IN	FO RULECHECK RESULTS	PROBABILISTIC RESULTS	VIEW REPORT	SETTINGS EVALUATIO	N ABOUT				
Select patient										
ZZ_FMEA001_SL, TEST	RUN BAYES NET ANALYSIS BAYES NET ANALYSIS					nalysis	Choose initial values to instantiate			
Select prescription								stage+intent	•	
neck -										
	checking	patient: ZZ_FMEA001_SL, T	TEST prescription: neck	Click RUN BAYES	NET ANALYSIS button abo	ove to compute	results			
ADD PATIENT									Search:	
U					2		\$	3		÷
	Field_N	um			1			2		
(type in U#, then click 'ADD PATIENT' to add Pt to list)	Field_N	ame			P4R_G184_176 Necl	k		<u> </u>		
Choose Clinic	T_Stage	•			Instantiated		Probability	of each		
UWMC -	N_Stage			Instantiated						
	M_Stag	e			Instantiated		parameter	in the ne	etwork	
SAVE RESULTS TO DATABASE	Anatom	ic_tumor_loc			Instantiated		-			
(run BN analysis first)	Treatment_Intent			Instantiated		is calculate				
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RESET APPLICATION			1							
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	SSD				0.51			0.51		
	Control	Points			0.626		0.626			
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	C	Annia			0.571			0.40		

Bayesian Network – Web Application (Cont.)

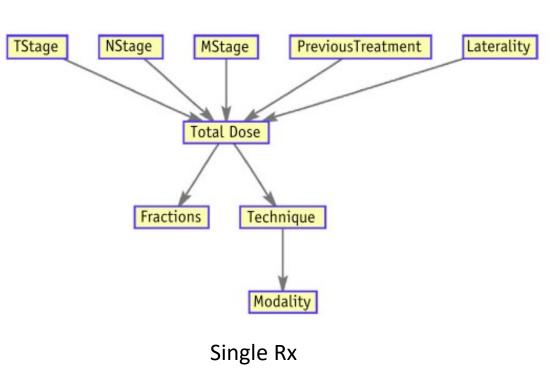
T_Stage		
N_Stage	"Probabilisti	c Results" tab
M_Stage	Instantiated	Instantiated
Anatomic_tumor_loc	Instantiated	Instantiated
Treatment_Intent	Instantiated	Instantiated
Number_of_Rxs	0.495	0.495
Rx_Radiation_Type	1	1
PTV_dose_Rx	0.082	0.082
Dose_Per_Fraction	0.633	0.633
Total_Fractions	0.4	0.4
Setup_Device_1	0.232	0.232
Setup_Device_2	0.044	0.044
Setup_Device_3	0.023	0.023
Setup_Device_4	0.082	0.082
Orientation	1	1
Couch_Lat	0.054	0.054
Couch_Long	0.056	0.056
Couch_Vert	0.156	0.156
Plan_Technique	0.324	0.324
Bolus	1	1
Beam_Energy	1	1
Number_of_beams	1	1
SSD	0.21	0.21
Control_Points	0.186	0.186
Wedge	А	lert!
Table_Angle		
Collimator_Angle	0.001	0.103
Gantry_Angle	0.323	0.28
Tolerance Table	0.48	0.48

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	282	12	-
	184	176	
	1	2	
	0	0	
	UW Head Neck Brain	UW Head Neck Brain	
SSD	0.21	1	
Control_Points	0.18	86	
Wedge	1		
Table_Angle	1		
Collimator_Angle	-0.01	21	
Gantry_Angle	0.32	23	
Tolerance_Table	0.48	8	

Bayesian Network for Prescriptions

- Detect errors in physician orders/Rx
- Divided the prescription orders into 3 groups: single Rx, concurrent boost and sequential boost
- Detect errors in new orders given the disease information





Quality Assurance on Contours

IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 32, NO. 6, JUNE 2013

Groupwise Conditional Random Forests for Automatic Shape Classification and Contour Quality Assessment in Radiotherapy Planning

Chris McIntosh*, Igor Svistoun, and Thomas G. Purdie

Received: 12 January 2022 Revised: 27 February 2022 Accepted: 28 April 2022

DOI: 10.1002/acm2.13647

RADIATION ONCOLOGY PHYSICS

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS

Automatic contouring QA method using a deep learning-based autocontouring system

Dong Joo Rhee ^{1,2} Chidinma P. Anakwenze Akinfenwa ³ Bastien Rigaud ⁴
Anuja Jhingran 3 Carlos E. Cardenas 2 Lifei Zhang 2 Surendra Prajapati 2
Stephen F. Kry ² Kristy K. Brock ⁴ Beth M. Beadle ⁵ William Shaw ⁶
Frederika O'Reilly ⁶ Jeannette Parkes ⁷ Hester Burger ⁷ Nazia Fakie ⁷
Chris Trauernicht ⁸ Hannah Simonds ⁹ Laurence E. Court ²

Automatic detection of contouring errors using convolutional neural networks

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Adam S. Garden

ACTA ONCOLOGICA https://doi.org/10.1080/0284186X.2020.1863463



ORIGINAL ARTICLE

1043

OPEN ACCESS Check for updates

Investigating the potential of deep learning for patient-specific quality assurance of salivary gland contours using EORTC-1219-DAHANCA-29 clinical trial data

Hanne Nijhuis^a*, Ward van Rooij^a*, Vincent Gregoire^b, Jens Overgaard^c (), Berend J. Slotman^a, Wilko F. Verbakel^a and Max Dahele^a

^aDepartment of Radiation Oncology, Amsterdam UMC, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands; ^bDepartment of Radiation Oncology, Centre Leon Berard, Lyon, France; ^cDepartment of Clinical Medicine – Department of Experimental Clinical Oncology, Aarhus University, Aarhus N, Denmark



McIntosh et.al. IEEE TMI 32(6): 1043-1057 (2013)Rhee et.al. Med Phys, 46(11):5086-5097 (2019)Nijhuis et.al. Acta Onco 1863463 (2020)Rhee et.al. JACMP e13647 (2022)

Challenges of Development and Implementation on AI for Plan Review



What are the Hurdles?

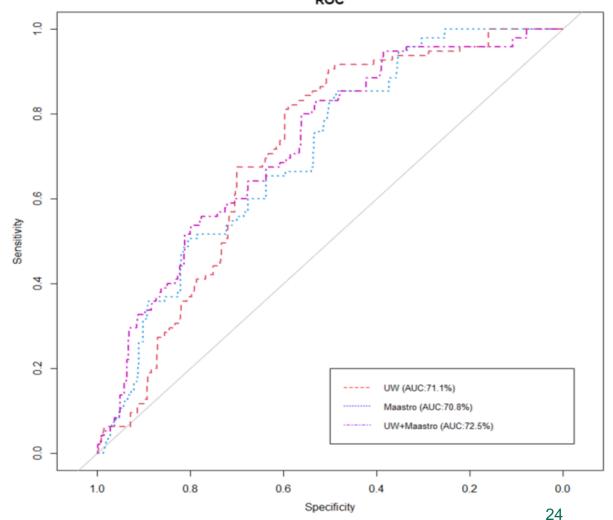
- Standardization of data content, data format, data structure, and nomenclature
- Data Extraction
- Model generalizability and external validation
- Model Interpretability
- Quality assurance procedures for AI tools
- Simulated plans with errors for test and validation
- Trust on AI-generated results



Standardization, Data Extraction, Model Generalizability and Interpretability

- Collaboration between UVM, UW and Maastro
- Tested the network on cases with simulated errors in Maastro
- Multiple networks are trained (UW, Maastro, UW+Maastro)
- Performance has shown to be reduced





Kalendralis etal. IEEE TRPMS 6(2):200-206 (2021)

Causes of Change in Performance

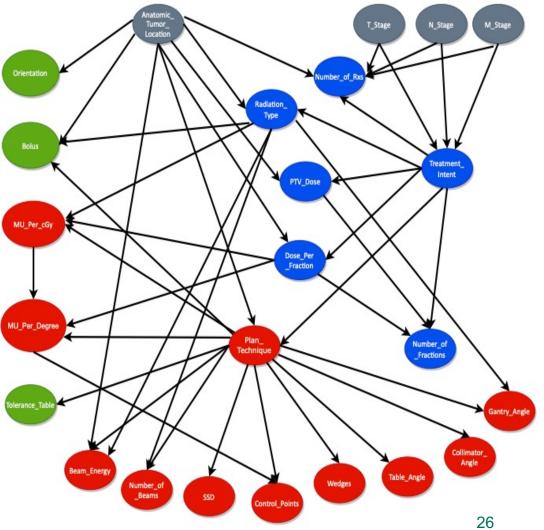
				Type of error	Mean AUC
				Bolus	0.76
Institution/Clinical Settings	Linacs	Treatment planning system	Oncology information system	Collimator angle	0.70
UW	Elekta	RayStation	Mosaiq	Table angle	0.90
Maastro	Varian	Eclipse	Aria	Prescription dose	0.55
UVMMC	Elekta	Pinnacle	Mosaiq	Gantry angle	0.67
Table 1. Differences in	technologies between t	Overall	0.68		

Table 2. AUCs for different types of errors in the external validation of UW-trained EDBN on Masstro data.



Improvements that We Are Working On

- Map the data of each clinic to a standardized list
- New network structure to accommodate all clinical profiles
- Distributed learning to adopt to individual clinical practice vs pooled data





Phillips et.al. Physica Medica 72:103-113 (2020)

Quality Assurance Procedures for AI Model

- Independent QA procedures of AI products are required
 - Performance of AI model will decay over time
- QA needs to ensure a consistent performance and require update of the model when it is underperforming
- No standards or guidelines yet for AI performance metrics





Kalet et.al. Med Phys 47(5):e168-177(2020) Luk et.al. Clinical Oncology 34(2):89-98 (2021)

Simulated Plans for Test and Validation

P	Clin	ical 🔻	Patients	Filter patients	٩	Showing 18 pat	tients
Patients	D	ID	_	^	Name		
Workflows		103_VMAT	/holeBrain_MosaiqRay _ProstateSVNodes_M	losaiqRaystation	WGPE4 [^] WGPE4 WGPE_Prostate [^] W	/GPE	
Collections		105_3D_M	_SBRTLLung_Mosaiq ediastinum_MosaiqRa	aystation	SBRT^Lung 3DCRT^Mediastinu	ım	*
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			Abdomen_AriaEclips ain_AriaEclipse	e	WGPE, Abdomen WGPE, Brain		
	0		_Spine_AriaEclipse		WGPE, Spine		
			ip_AriaEclipse on_Neck_AriaEclipse		WGPE, Hip WGPE, Neck		*
		122_IMRT_	Thorax_AriaEclipse		WGPE, Thorax		

AAPM webpage → Quality & Safety Resources → Simulated Error Training for the Physics Plan Review

Credit: Perry Johnson and WGPE, AAPM 2022 MO-FG-201



Error details

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T1a # Failure mode

1 Rectal balloon contrast not over-ridden to air 85 Wrong dose calculated due to contrast override

A rectal balloon with contrast is evident when reviewing the CT dataset. During treatment this will be filled with air according to the sim order. A density override is missing. In Raystation, this would be evident in the ROI Matl column (see arrow) and in the treatment plan report.



15 High-Z material, contrast, artifacts, etc.) .,...,, Simulation instructions Orientation Head first supine Head Neutral Arms On chest Straight, feet pointed inward Legs Vak-Lok, hand ring, towel between legs, rectal balloo Immobilization requested to be filled with 80 cc saline/iodine solution for simulation and 80 cc air for treatment WGPE WGPE Prostate Patient name Report creation time 08 Nov 2010 18:47:42 (hr min sec) Patient ID Plan last save time 07 Nov 2019, 15:46:29 (hr:min:sec) 191550 RaySearch: VMAT PSVN Treatment plan name Plan approved by Plan approved Plan approval time Plan Report Patient data Patient ID Patient name WGPE WGPE_Prostate Patient gender Other 30 Oct 2019 Patient birth date Case data CASE 1 Case name Physician Body site **Treatment plan data** VMAT PSVN Treatment plan name Plan last save time 07 Nov 2019, 15:46:29 (hr:min:sec) Planned by Number of beam sets Patient treatment position HFS : Head First Supine Treatment plan approval data Approved No Approved by Approval time Imported plan Plan comment Planning image set CT 1 Name Modality Imaging system BigBore_v2 29 Nov 2016, 11:50:27 (hr:min:sec) Patient soanning position 08 Oct 2019, 10:34:09 (hr:min:sec) Series date and time Acquisition date and time External ROI z_PlanBody General data RayStation 8A (8.0.1.10) Treatment planning system Report creation time 08 Nov 2019, 18:47:42 (hr:min:sec) Time zone info UTC-05:00 Template name RayStation treatment plan report

IEC 61217

Density overrides applied as needed (ex.

T1c # Plan/chart check

ROI properties

29

Trust on AI-Generated Results

- Participating physicists expressed difficulties to understand how to interpret results of probabilistic component generated from AI
- Presentation and frequency of false positive results present a challenge of tradeoffs between trust, efficiency, and efficacy



Luk et.al. AAPM 2021 ePoster

Select patient		PATENTINFO BALEDIE	Rule	cheo	ck Results		
Select prescription			result	descriptio	n	universal rule	
Rmandible	•	beamDoseCheck	pass		sum of all beams doses add up t	to Ret they belong to	
_		RxNotApproved	pasa		current prescription status is 'epp		
ADD PATIENT		modalityMatch	pass		rescription modality matches be		
u		BeamSethoCheck	pass		all bearrs in an Rx have same is:		
	Coloct notiont	CheckForDRRs	pass	check that a	all static fields have DRRs (includ	Universal rules	
Choose Clini	Select patient,	paceMakerCheck1	pass	wern use of	18MV for pacemaker pt		
LWMC	prescription	MUsegmentmax	pass	Check that I	MU per segment is not larger that	un 999	
Enter comm		MUsegmentmin	pass	Check that I	NU per segment greater than 5 f	for non-VWAT plana	
	and site	Showing 1 to 8 of 8 entries					
			result		description	UWMAC rule	
		radcalcDocexest	-not required-		verify that MU second check or	No. dourse anno an	
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SUBART COMMENTS		respondent	-hot required-		verify that phys response is in a	Site-specific rules +	
		SERTreportExist	-not required-		verify that doal report exists for		
	ATABASE	ISOsefupCheck	-soc required-		check that setup beams have s	uocumentation	
		TBidocuCheck -not required-			check that setup beams have si check if most recent roadmap and CCP are approved and spec proc is in		
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vide	Alert!		in ance_rate		11.4		
enge bar, Hegle							
regie	0323	323					
	100						



- Initial plan review is an important safety barrier in radiotherapy processes
- Despite its importance, AI development is not commonly found in plan review due to multiple challenges
- There are still a lot of opportunities to develop AI to assist medical physicists on plan review in conjunction with the automated rulesbased tools



Thank You!

