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

Samuel M.H. Luk, Ph.D.

July 13, 2022

SAM Therapy Educational Course – Artificial Intelligence for QA

The University of Vermont
LARNER COLLEGE OF MEDICINE

Introduction

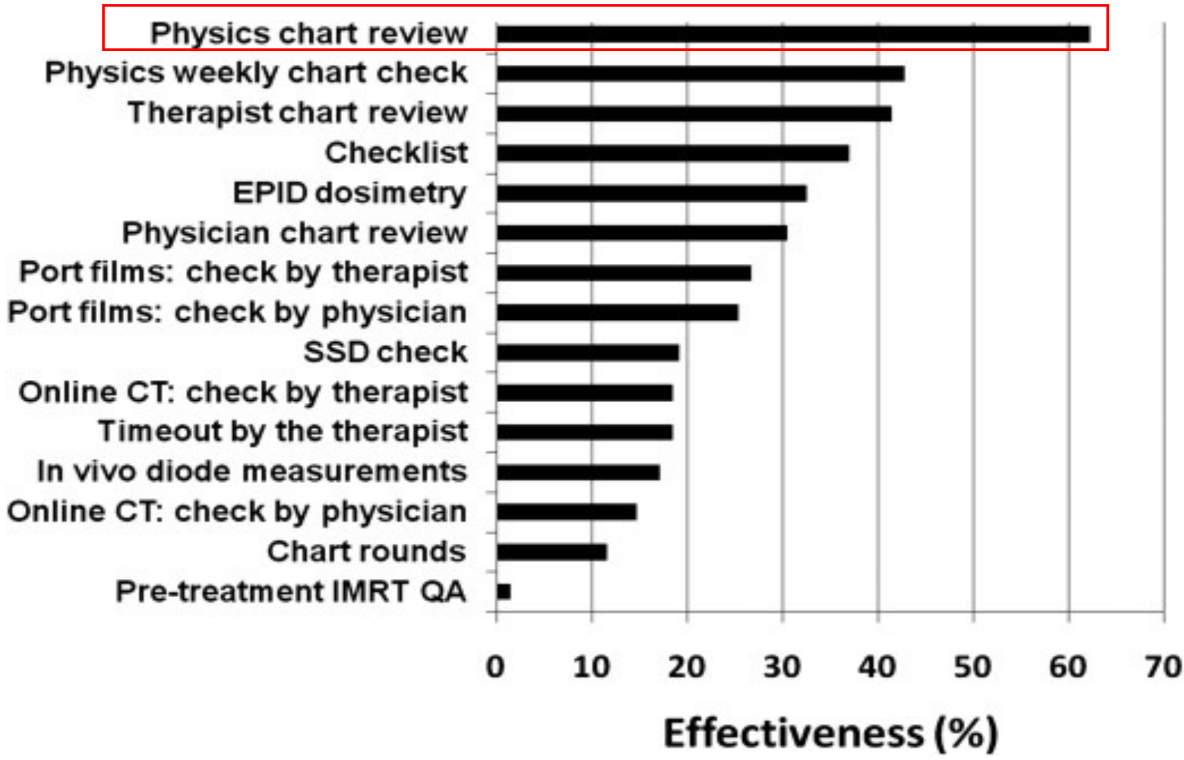
RT Processes	Diagnosis and Physician Consultations	Simulation	Treatment Planning	Quality Assurance	Treatment Delivery
Example tasks benefit from AI	• Tumor delineation • Treatment decision support	• Determine optimal setup • Image artifacts reduction	• Auto-segmentation • Automated planning	• Plan review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

The University of Vermont
LARNER COLLEGE OF MEDICINE

Luk et.al. Clinical Oncology 34(2):89-98 (2021)

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



The University of Vermont
LARNER COLLEGE OF MEDICINE

Ford etal. IJROBP, 84(3): e263 - e269 (2021)

Recommendations on Initial Treatment Plan Review

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
  - Patient assessment
  - Simulation
  - Treatment planning
  - Data Transfer (for some combinations of TPS and OIS)

Strategies for effective physics plan and chart review in radiation therapy: Report of AAPM Task Group 275

Eric Ford[a]
University of Washington Medical Center, Seattle, WA, USA

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.

e236 Med. Phys. 47 (6), June 2020 0094-2405/2020/47(6)/e236/37 e236

The University of Vermont
LARNER COLLEGE OF MEDICINE

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 ONCOLOGY PHYSICS

WILEY

Combining automatic plan integrity check (APIC) with standard plan document and checklist method to reduce errors in treatment planning

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

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

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

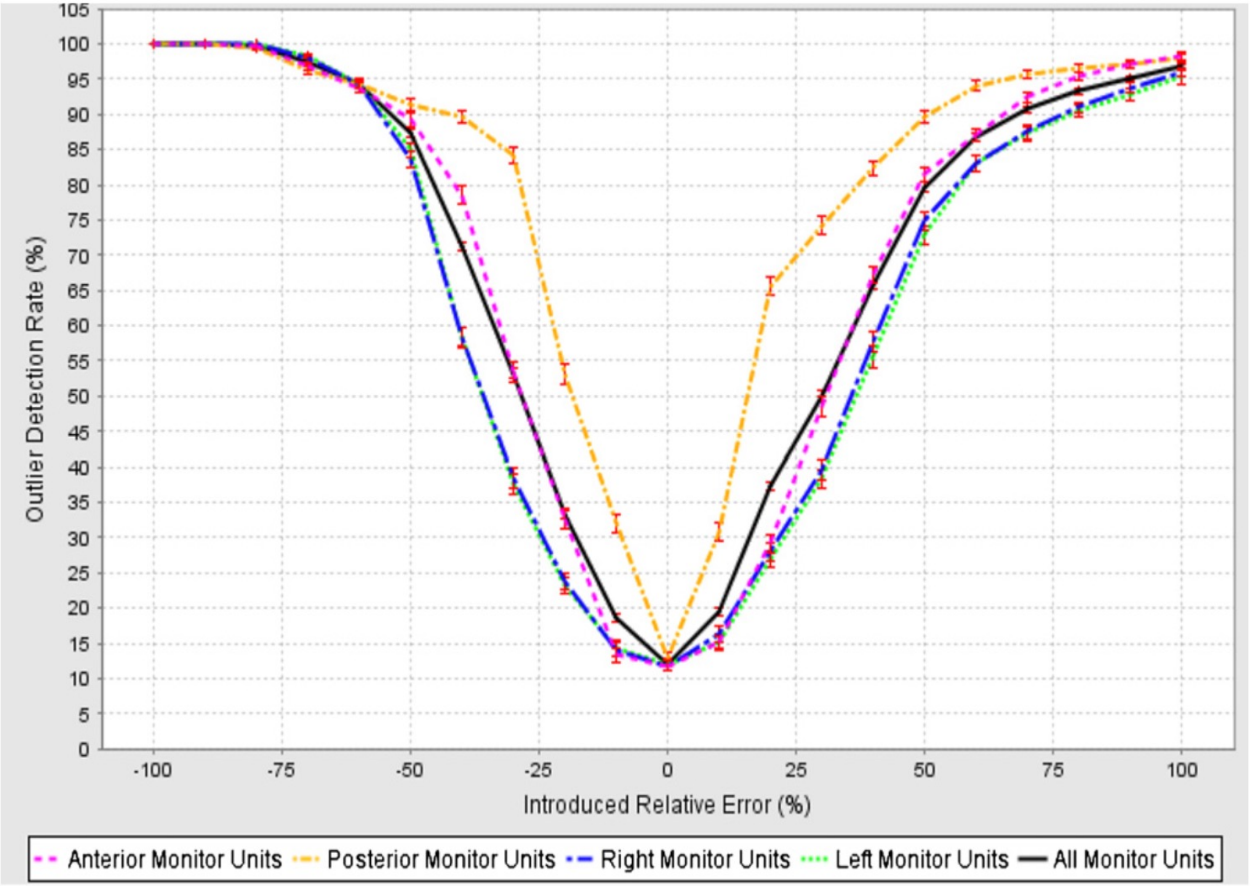


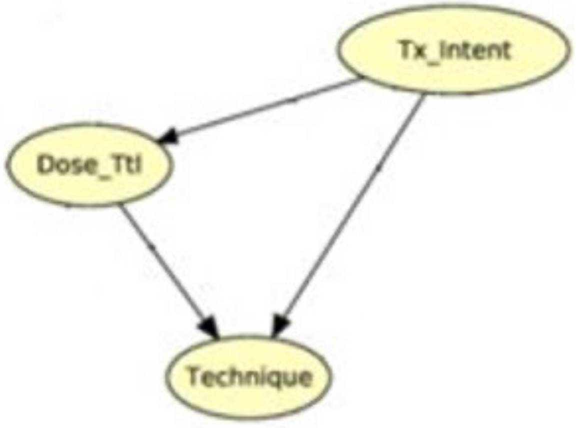
Figure 3. Outlier detection rate as a function of error level for each of the MU features and all MU features combined. The error bar shows one standard deviation.

The University of Vermont
LARNER COLLEGE OF MEDICINE

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

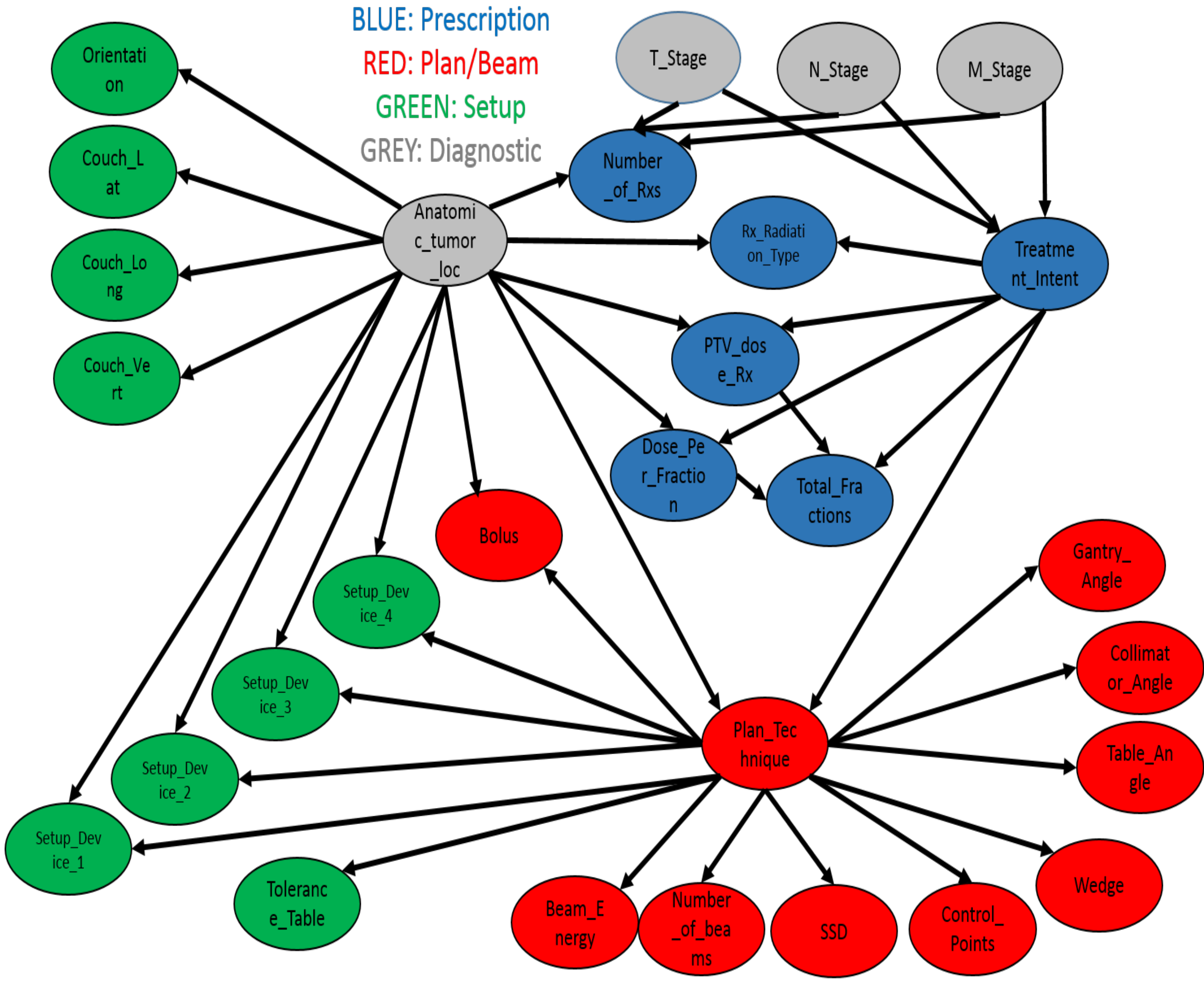
Bayesian Network-based algorithm

- 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
  - Plan and field parameter
  - Setup

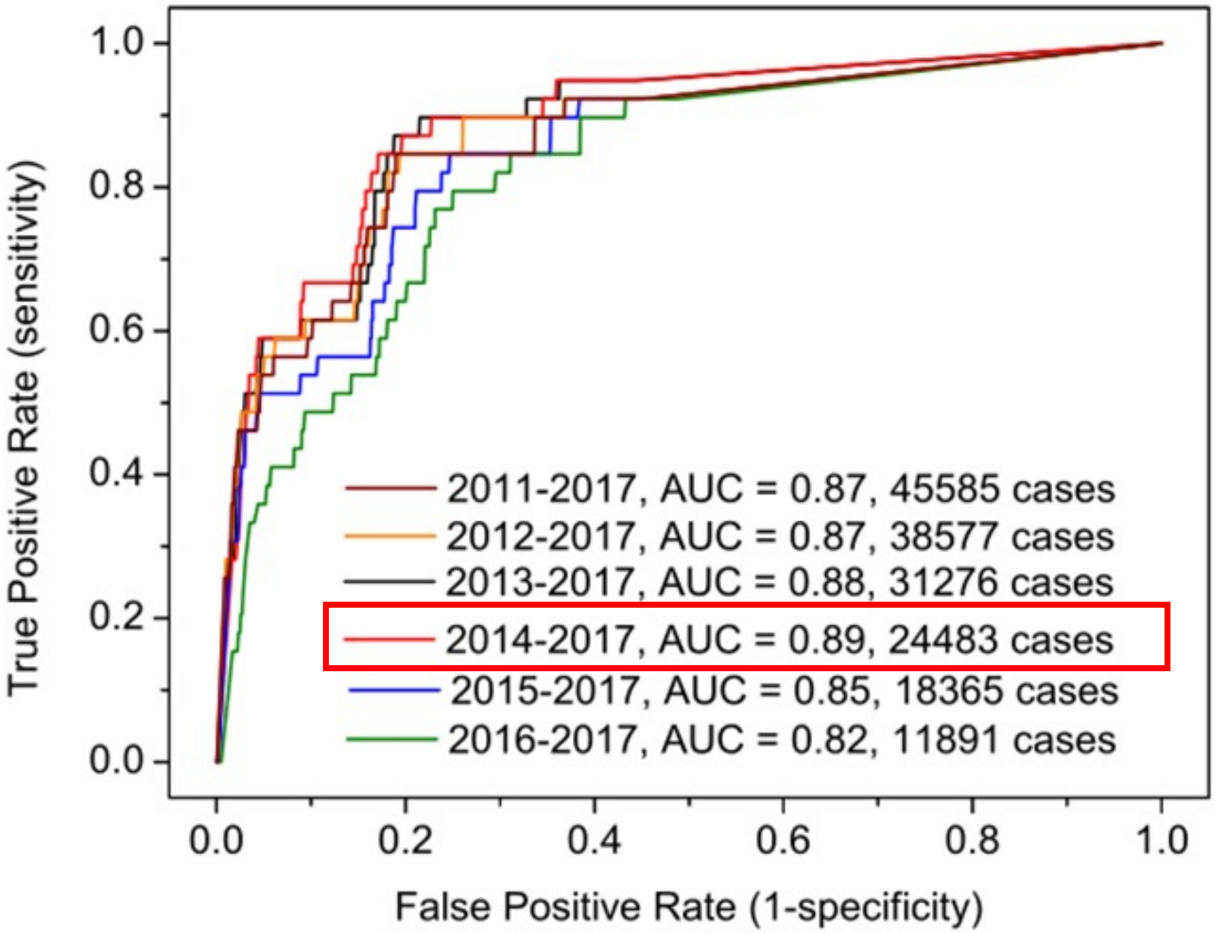


The University of Vermont
LARNER COLLEGE OF MEDICINE

Luk et.al. Med Phys 46(5):2006-2014 (2019)

Effectiveness of the Network

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



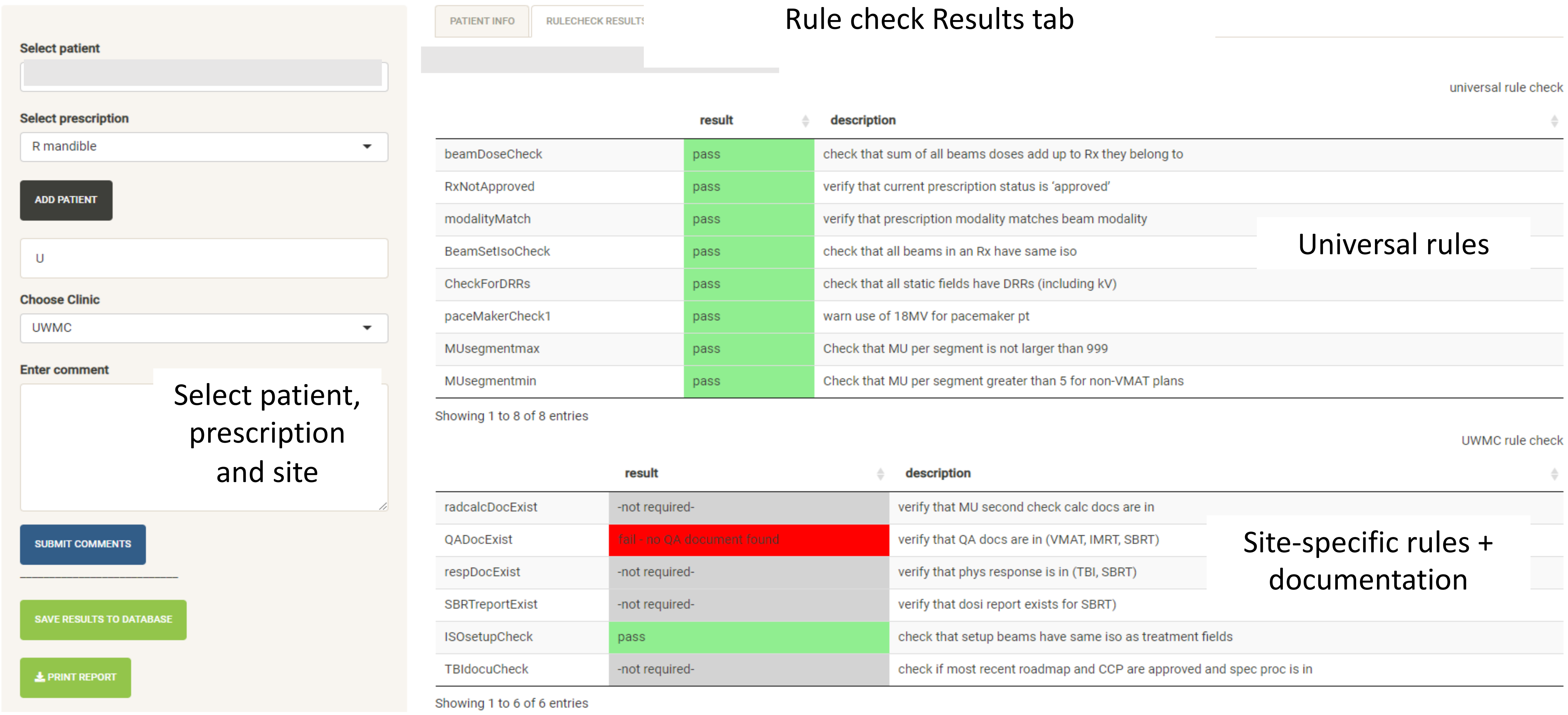
Multi-Layered Approach using Rules and AI

- 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

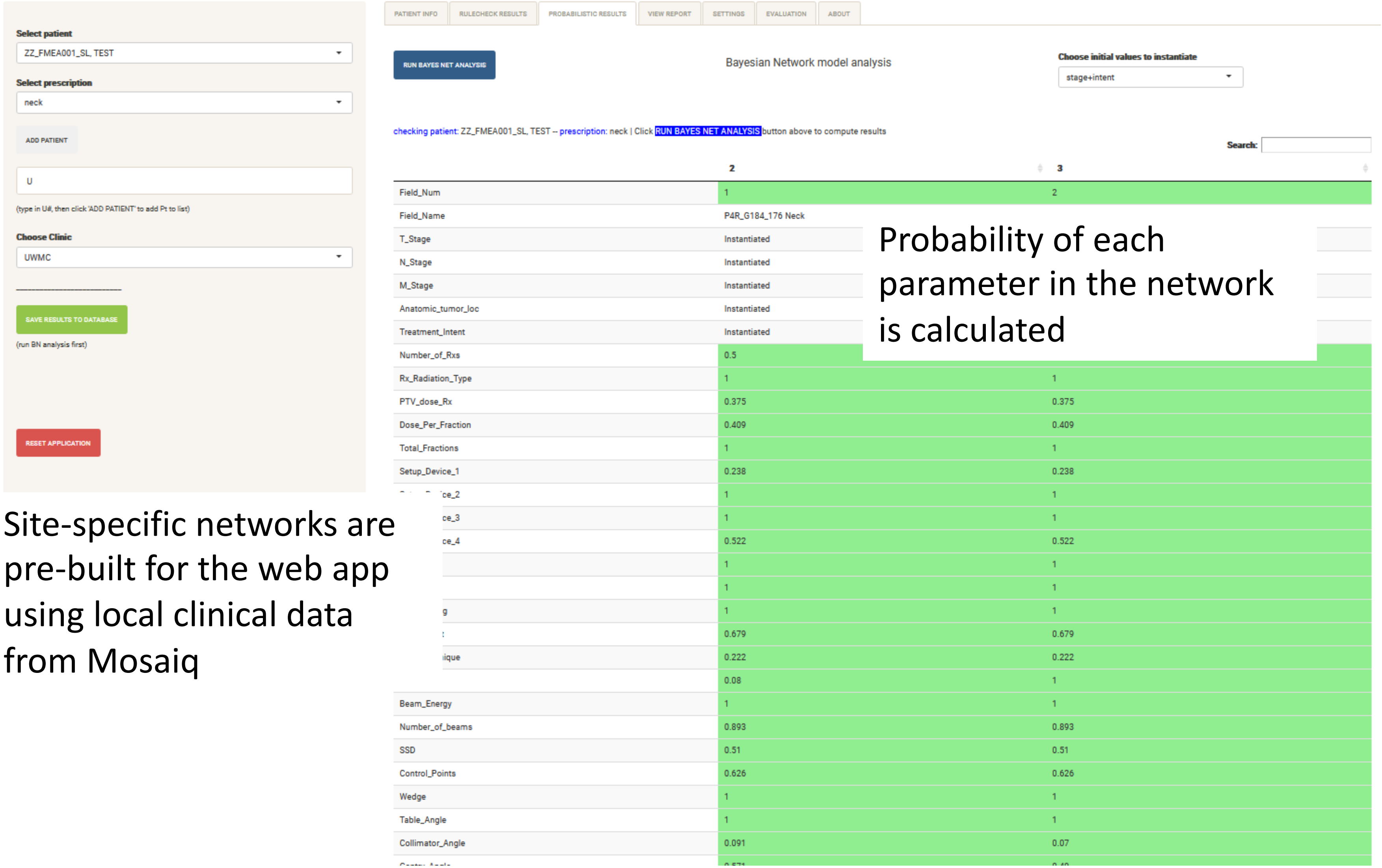
	Bayes net	Rules
Errors of judgment	✓	X
Maintenance/Updating	✓	X
Complex relationships	✓	✓
Transparency	✓	✓
Speed	X	✓
Static Errors (protocols)	X	✓

Luk etal., AAPM Annual Meeting 2020, TU-EF-TRACK 3-4

Plan Check Tool - Rules



Bayesian Network – Web Application



Probability of each parameter in the network is calculated

Site-specific networks are pre-built for the web app using local clinical data from Mosaiq

The University of LARNER COLLEGE OF

Bayesian Network – Web Application (Cont.)

"Probabilistic Results" tab

T_Stage		
N_Stage		
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		
Table_Angle		
Collimator_Angle	0.001	0.003
Gantry_Angle	0.323	0.28
Tolerance_Table	0.48	0.48

Alert!

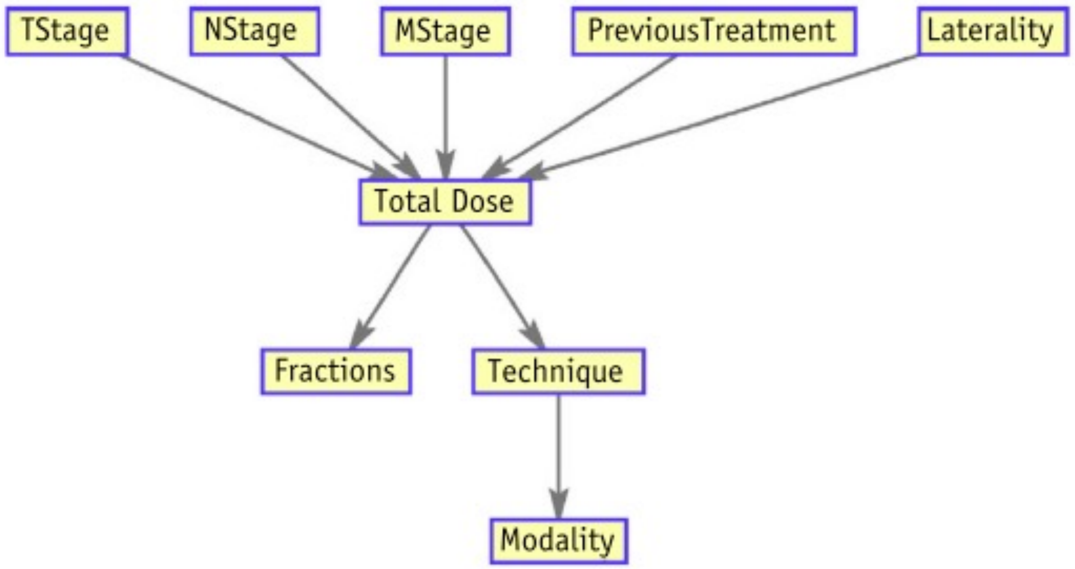
511.4	620.4
1	1
P4R_G184_176 R_Mandi	P4L_G176 R_Mandi
76.9	77.0
282	12
184	176
1	2
0	0
UW Head Neck Brain	UW Head Neck Brain

Make sure it is correct!

SSD	0.21
Control_Points	0.186
Wedge	1
Table_Angle	1
Collimator_Angle	0.001
Gantry_Angle	0.323
Tolerance_Table	0.48

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



Single Rx

Chang et.al. IJROBP 105(2):423-431 (2019)

Quality Assurance on Contours

IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 32, NO. 6, JUNE 2013 1043

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

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

Automatic detection of contouring errors using convolutional neural networks

Dong Joo Rhee[a)]
The University of Texas Graduate School of Biomedical Sciences at Houston, Houston, TX 77030, USA
Department of Radiation Physics, Division of Radiation Oncology, The University of Texas MD Anderson Cancer Center Houston, TX 77030, USA

Carlos E. Cardenas
Department of Radiation Physics, Division of Radiation Oncology, The University of Texas MD Anderson Cancer Center Houston, TX 77030, USA

Hesham Elhalawani
Department of Radiation Oncology, Division of Radiation Oncology, The University of Texas MD Anderson Cancer Center Houston, TX 77030, USA

Rachel McCarroll
Department of Radiation Oncology, The University of Maryland Medical System, Baltimore, MD 21201, USA

Lifei Zhang, and Jinzhong Yang
Department of Radiation Physics, Division of Radiation Oncology, The University of Texas MD Anderson Cancer Center Houston, TX 77030, USA

Adam S. Garden

Received: 12 January 2022 | Revised: 27 February 2022 | Accepted: 28 April 2022
DOI: 10.1002/acm2.13647
JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS
RADIATION ONCOLOGY 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]

ACTA ONCOLOGICA
https://doi.org/10.1080/0284186X.2020.1863463
Taylor & Francis
Taylor & Francis Group
ORIGINAL ARTICLE
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]

[a]Department of Radiation Oncology, Amsterdam UMC, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands; [b]Department of Radiation Oncology, Centre Leon Berard, Lyon, France; [c]Department 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

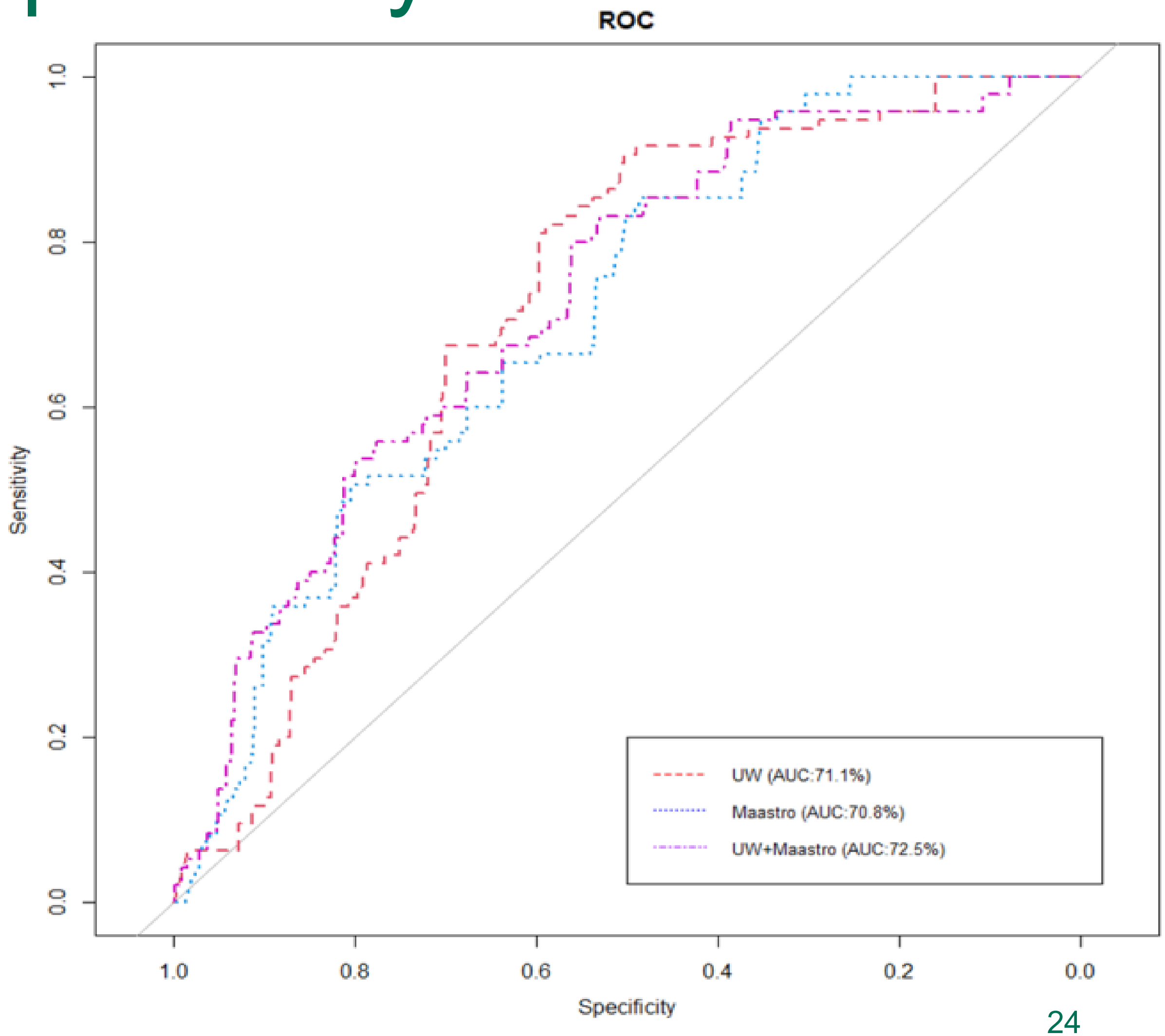
What are the Hurdles?

- 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

Kalet et.al. Medical Physics 47(5):e168-e177 (2020)
Luk et.al. Clinical Oncology 34(2):89-98 (2021)

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



The University of Vermont
LARNER COLLEGE OF MEDICINE

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

Causes of Change in Performance

Institution/Clinical Settings	Linacs	Treatment planning system	Oncology information system
UW	Elekta	RayStation	Mosaiq
Maastro	Varian	Eclipse	Aria
UVMMC	Elekta	Pinnacle	Mosaiq

Table 1. Differences in technologies between the participating institutions.

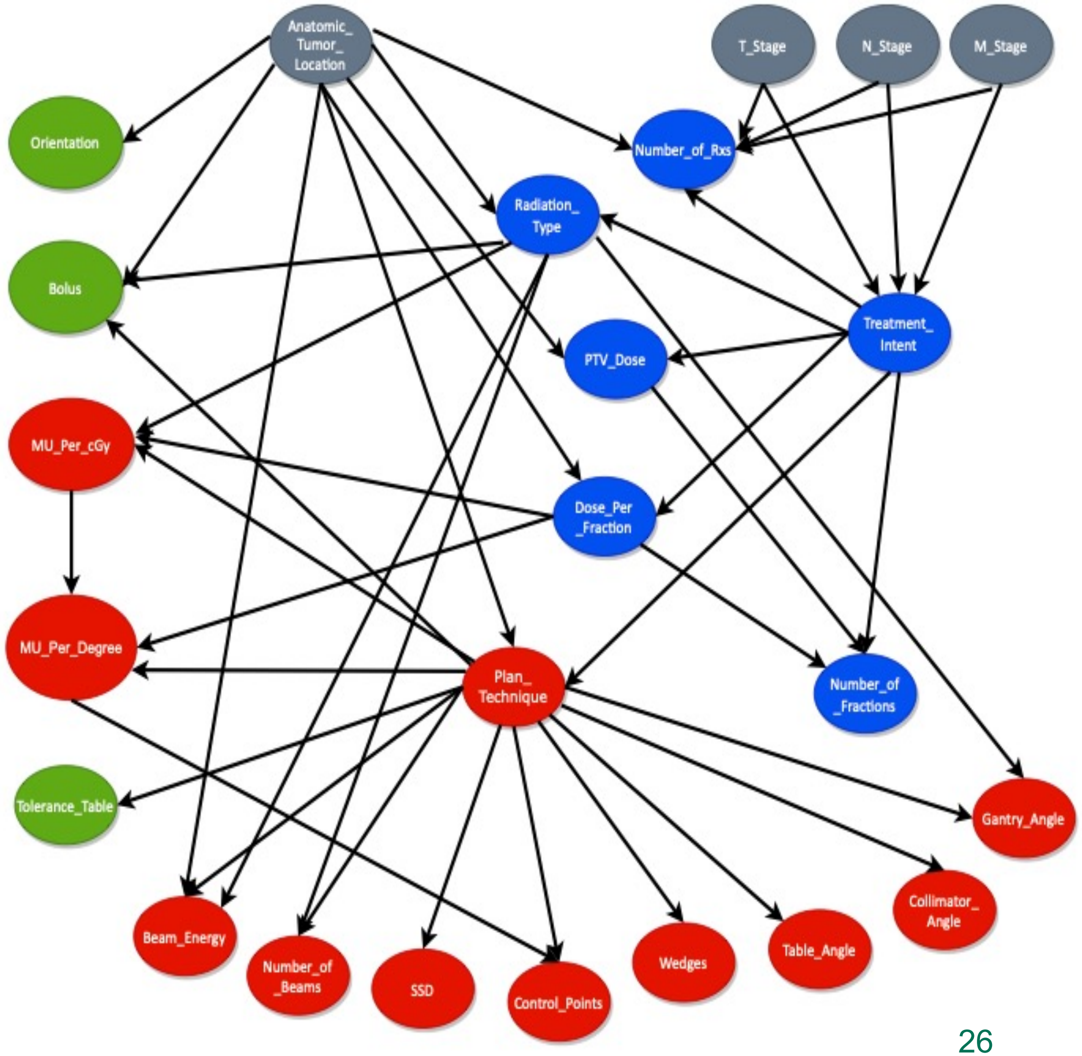
Type of error	Mean AUC
Bolus	0.76
Collimator angle	0.70
Table angle	0.90
Prescription dose	0.55
Gantry angle	0.67
Overall	0.68

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

The University of Vermont
LARNER COLLEGE OF MEDICINE

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



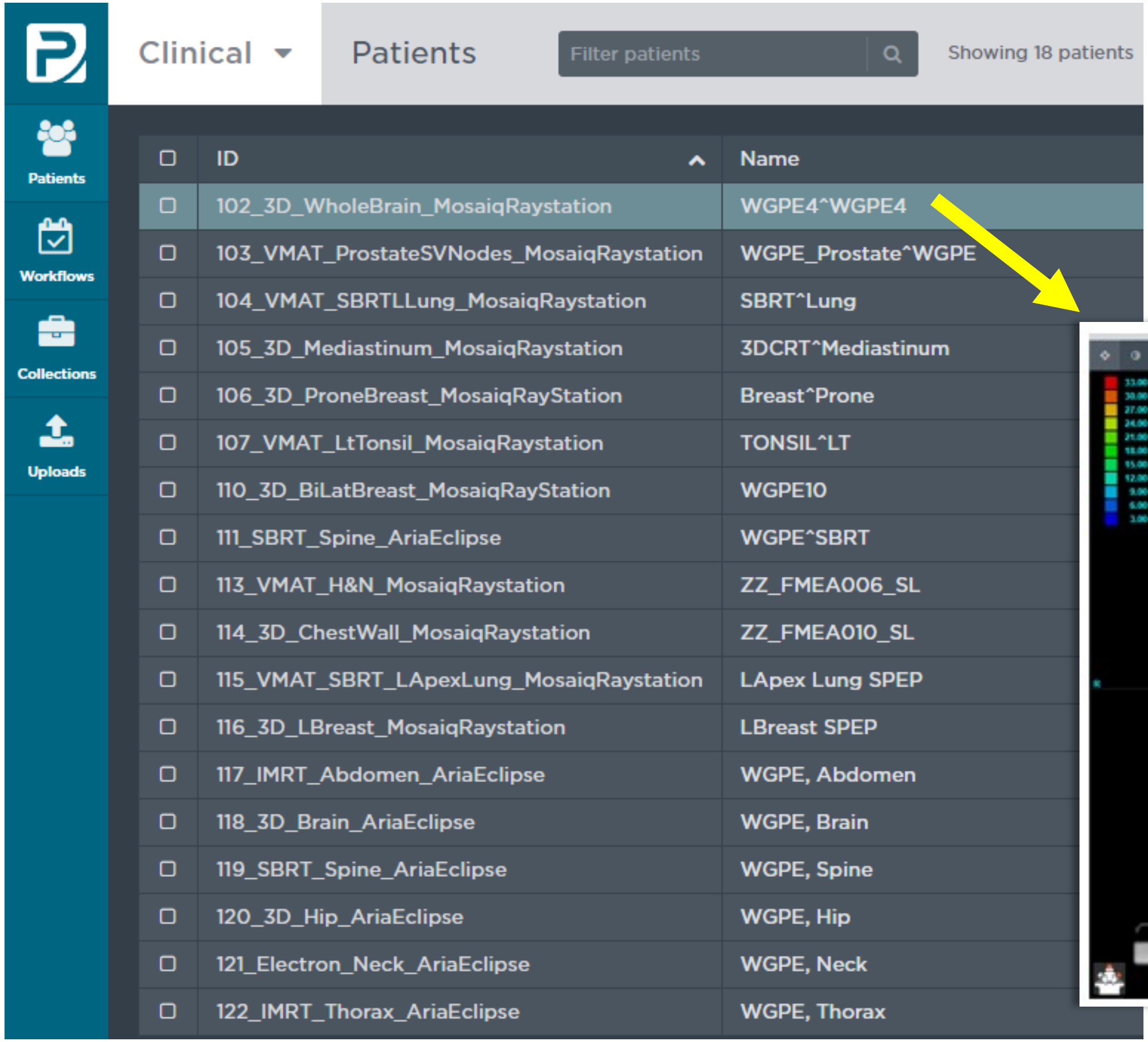
Phillips et.al. Physica Medica 72:103-113 (2020)

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 under-performing
- 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



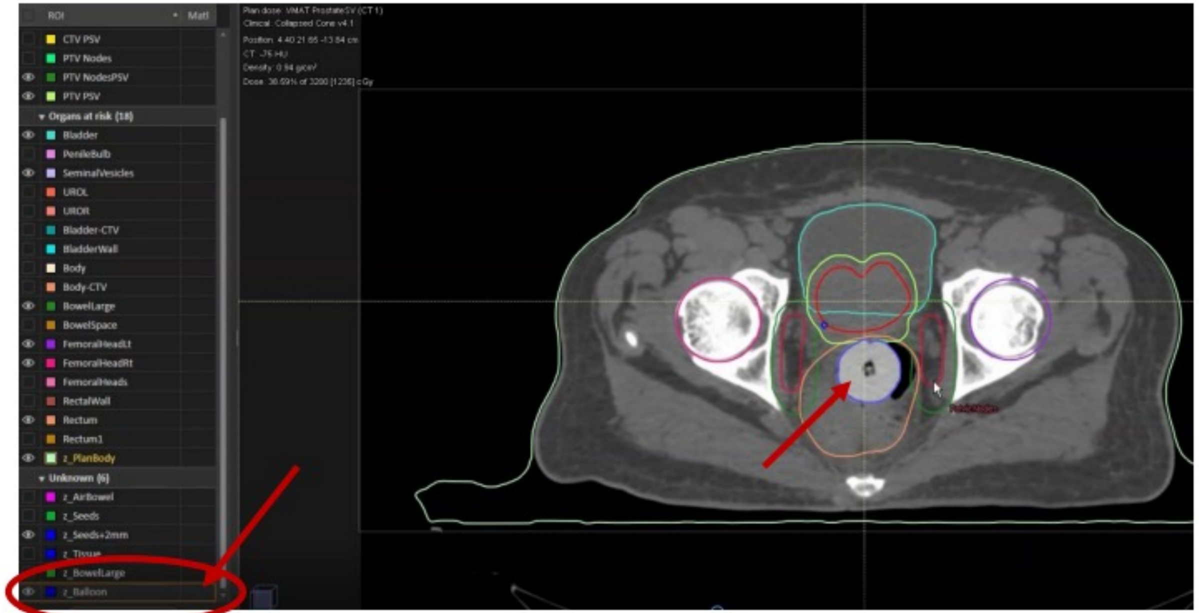
AAPM webpage → Quality & Safety Resources → Simulated Error Training for the Physics Plan Review

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

#	Error details	T1a #	Failure mode	T1c #	Plan/chart check
1	Rectal balloon contrast not over-ridden to air	85	Wrong dose calculated due to contrast override	15	Density overrides applied as needed (ex. High-Z material, contrast, artifacts, etc.)

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.

Simulation instructions	
Orientation	Head first supine
Head	Neutral
Arms	On chest
Legs	Straight, feet pointed inward
Immobilization requested	Vak-Lok, hand ring, towel between legs, rectal balloon to be filled with 80 cc saline/iodine solution for simulation and 80 cc air for treatment



RaySearch Laboratories

Patient name	WGPE WGPE_Prostate	Report creation time	08 Nov 2019, 18:47:42 (hr:min:sec)
Patient ID	191550	Plan last save time	07 Nov 2019, 15:46:29 (hr:min:sec)
Treatment plan name	VMAT PSVN	Plan approved by	-
Plan approved	No	Plan approval time	-

Plan Report

Patient data

Patient ID	191550
Patient name	WGPE WGPE_Prostate
Patient gender	Other
Patient birth date	30 Oct 2019
Case data	
Case name	CASE 1
Physician	-
Body site	-

Treatment plan data

Treatment plan name	VMAT PSVN
Plan last save time	07 Nov 2019, 15:46:29 (hr:min:sec)
Planned by	
Number of beam sets	1
Patient treatment position	HFS : Head First Supine
Treatment plan approval data	
Approved	No
Approved by	-
Approval time	-
Plan comment	Imported plan
Planning image set	
Name	CT 1
Modality	CT
Imaging system	BigBore_v2 29 Nov 2016, 11:50:27 (hr:min:sec)
Patient scanning position	HFS
Series date and time	08 Oct 2019, 10:34:09 (hr:min:sec)
Acquisition date and time	-
External ROI	z_PlanBody

General data

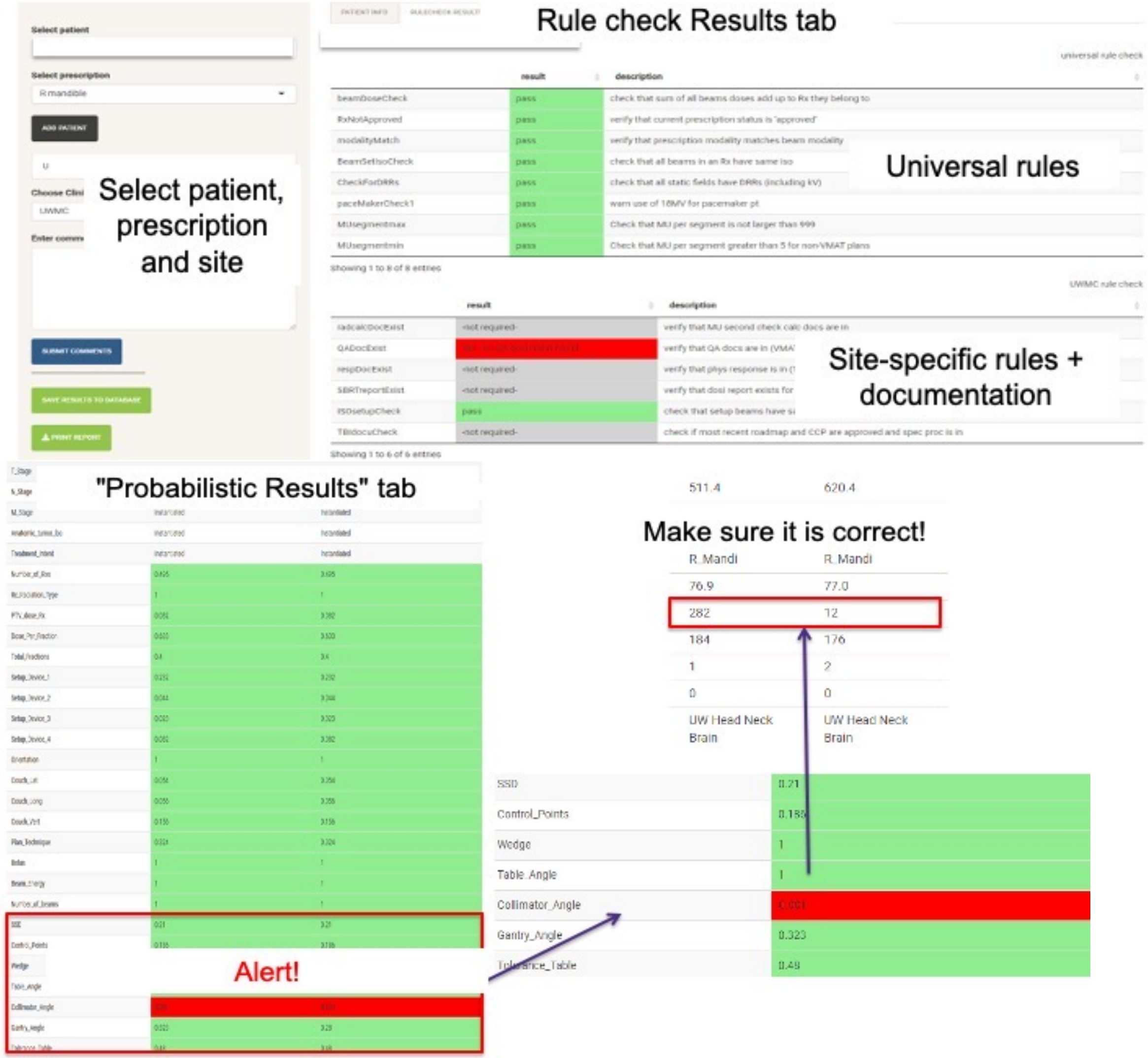
Treatment planning system	RayStation 8A (8.0.1.10)
Report creation time	08 Nov 2019, 18:47:42 (hr:min:sec)
Time zone info	UTC-05:00
Template name	RayStation treatment plan report
Patient coordinate system	IEC 61217

ROI properties

No density override

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



The University of Vermont
LARNER COLLEGE OF MEDICINE

Luk et.al. AAPM 2021 ePoster

Summary

- 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 rules-based tools

Thank You!