Automation and Standardization of Planning, Plan Evaluation and System Testing Through Advanced Programming in Treatment Planning System

Improve Plan Evaluation with Advanced Scripting

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MO-B-KDBRA2-0
Monday 8:30 – 9:30 am
Karl Dean Ballroom A2

Disclosures

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Patent protections

Acknowledgements

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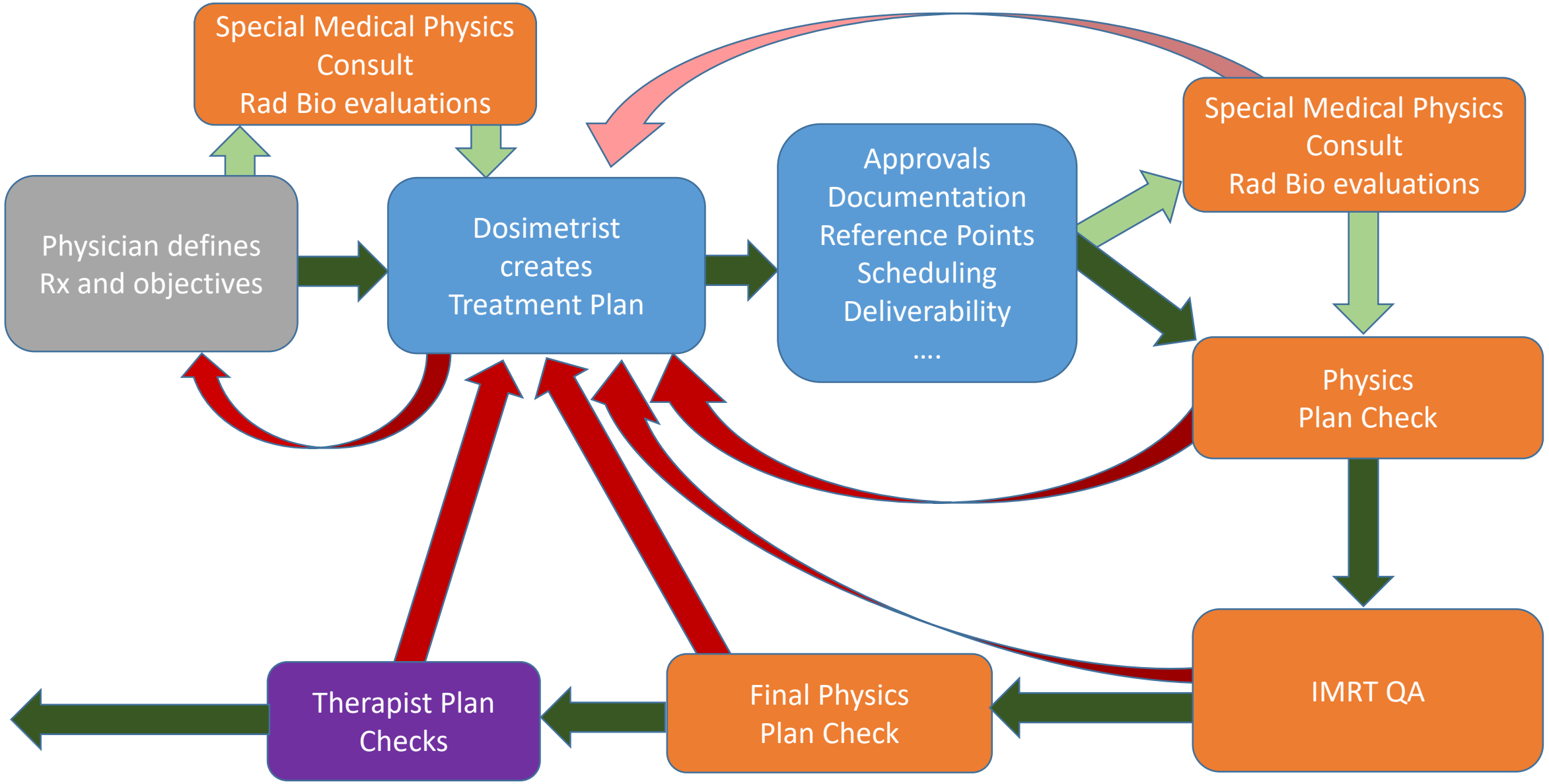
- Jason Hearn PhD
- Theodore Lawrence MD PhD

Plan Evaluation has Many Component Nodes and Connections

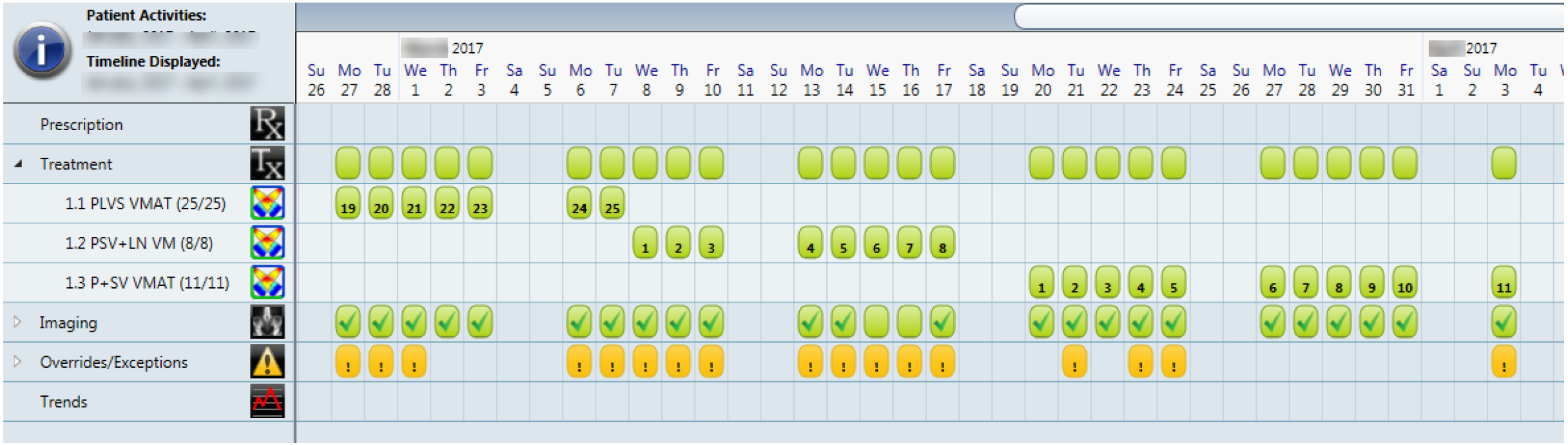


Standardizations are key to improving plan evaluation through scripting

Reduce variability and inconsistencies

Example TG-263 : Nomenclature for structures, targets, DVH metrics

We often treat to multiple dose levels.

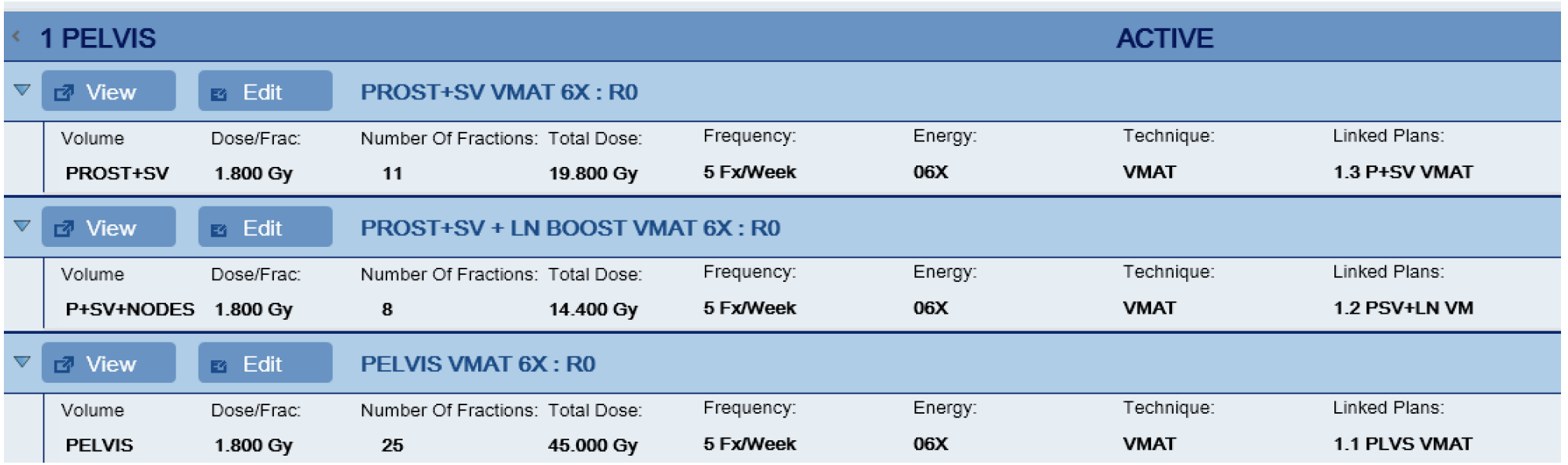


Here's what we need to know to script checks

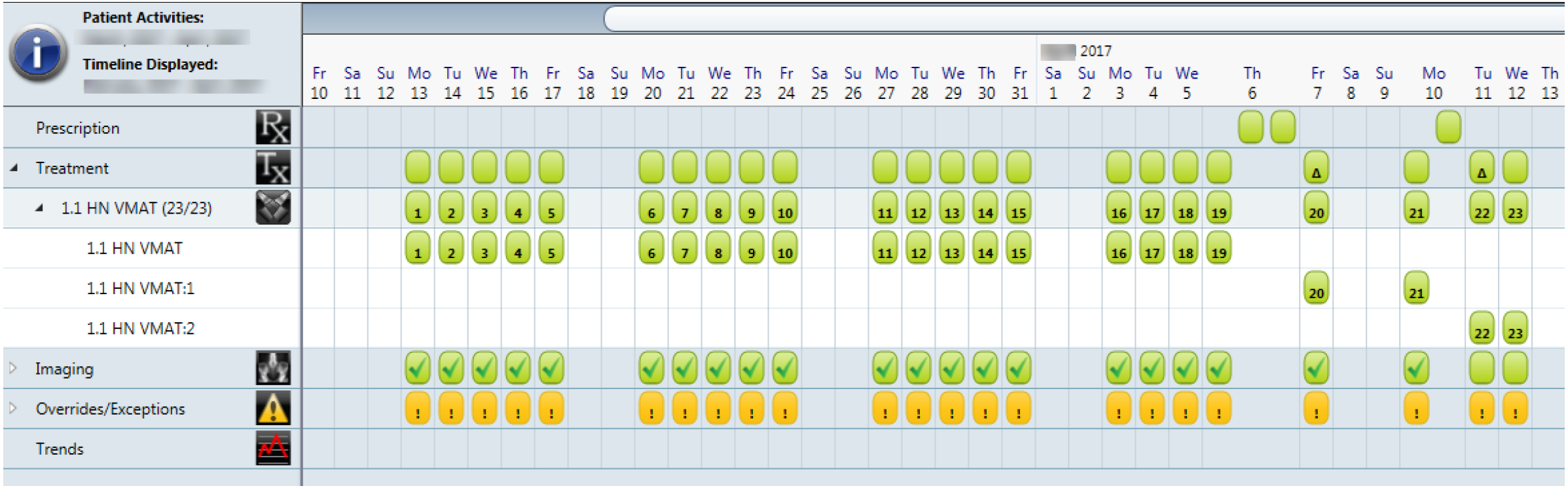
with matching reference points

Plan	N Fractions	PTV_High (Prostate + SV)	PTV_Mid00 (Prostate + SV + LN)	PTV_Low (Pelvis)
1.1 PLVS VMAT	25	45	45	45
1.2 PSV+LN VM	8	14.4	14.4	0
1.3 P+SV VMAT	11	19.8	0	0
	Total	**79.4**	**59.4**	**45**

Commercial systems may not yet provide it cleanly



There may be changes to plans during treatment



Here's what we need to know to script checks

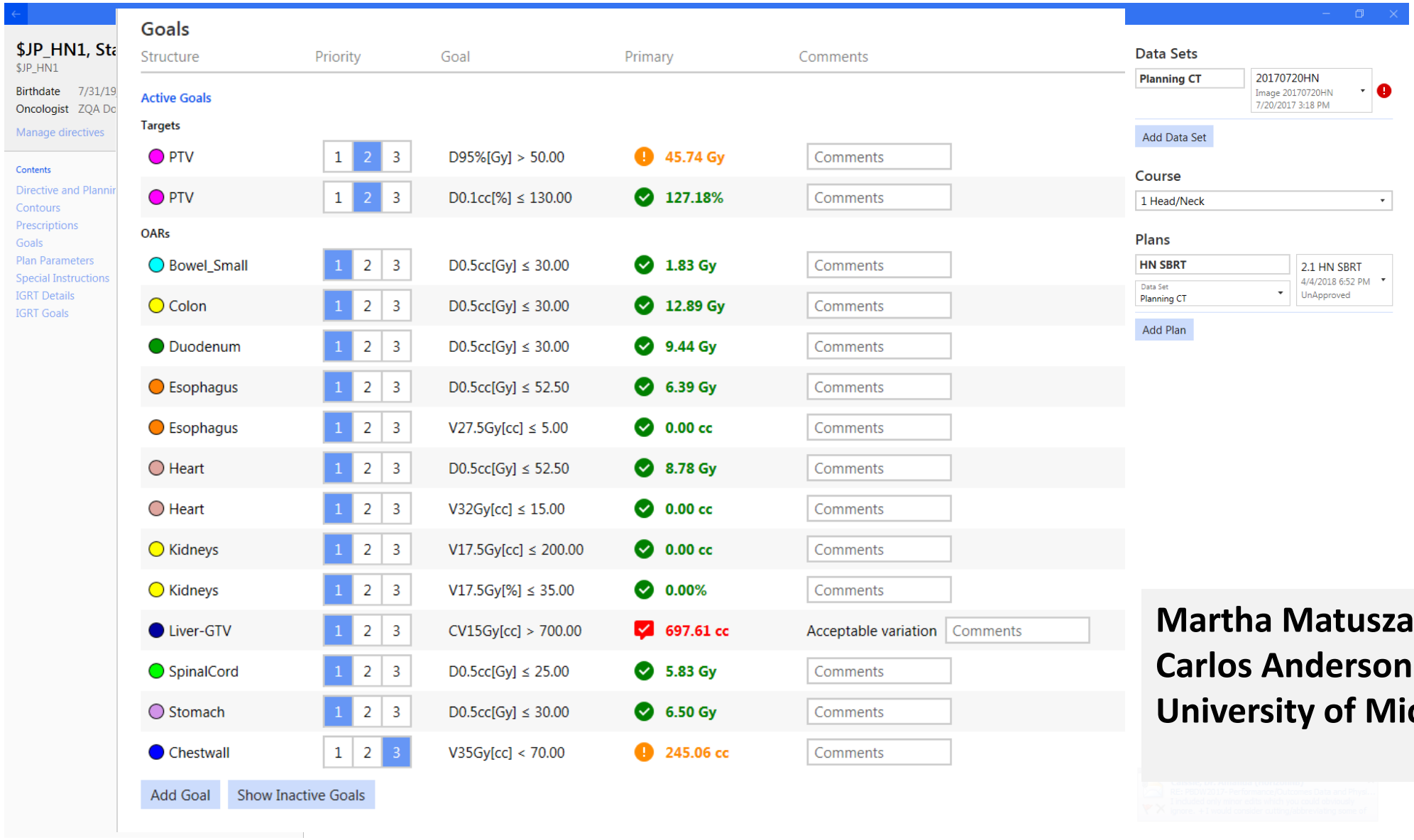
with matching reference points

Plan	N Fractions	PTV_High (PTV_High^50)
1.1 HN VMAT	25	50
	Total	**50**

Plan	N Fractions	PTV_High (PTV_High^50)
1.1 HN VMAT	19	47.5
1.1 HN VMAT :1	2	5
1.1 HN VMAT :2	2	5
	Total	**57.5**

Commercial systems may not yet provide it cleanly

BluePrint : University of Michigan Electronic Prescription and Plan QA System



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Prescription Constraints: Prostate - ConvFX Normal Tissue Constraints: Prostate - ConvFX

(•) Single Site ( ) Multiple Mets

Target Dose Volume Definitions ( ) Only High ( ) High and Low (•) High, Intermediate and Low

Relative Dose	Alias	Contains
ptv_high	ptv7800	prostate and seminal vesicles
ptv_intermediate	ptv5940	gross pelvic nodes
ptv_low	ptv4500	remaing pelvic nodes

Number of Prescription Fractions in Total Dose: 3 Dose for fractions must be entered in *centi-Gray*!

Group	Number of Fractions	PTV High	PTV Intermediate	PTV Low
Initial Volume	25	5000 (200 cGy per Fx)	4500 (180 cGy per Fx)	4500 (180 cGy per Fx)
1st Boost	8	1600 (200 cGy per Fx)	1440 (180 cGy per Fx)	0 (0 cGy per Fx)
2nd Boost	6	1200 (200 cGy per Fx)	0 (0 cGy per Fx)	0 (0 cGy per Fx)
Total	**39**	**7800 cGy**	**5940 cGy**	**4500 cGy**

Bolus: ( ) Yes (•) No [ ] Calcs - only

Instructions: full bladder; rectal balloon; match with carbon markers for the entire course; CBCT -- pre--RT daily for the first 2 weeks and then qMon and Thur for the rest of treatments

Prescription DVH Constraints Add...

Structure	DVH Endpoint	Constraint Value	Planning Priority
[x] ptv7800	Max[Gy]		Report
	Max[%]		Report
	Min[Gy]		Report
	Min[%]		Report
	Mean[Gy]		Report
	D2%[%]	<= 107 %	3
	D5%[%]		Report
	D95%[%]	>= 99 %	3
	D98%[%]		Report
	V110%[cc]	<= 0.5 cc	2
	V98%[%]	>= 98 %	1
	V99%[%]	>= 98 %	2
	V100%[%]	>= 95 %	2
	V107%[%]	<= 2 %	1
	Volume[cc]		Report
	CV98%[%]	<= 2 %	1
	CV98%[cc]		Report

Target DVH Objectives			Priority	Achieved
ptv6480	Max[Gy]		Report	70.14 Gy
	Max[%]		Report	108.2 % (70.13Gy)
	Min[Gy]		Report	58.1 Gy
	Min[%]		Report	89.7 % (58.1Gy)
	Mean[Gy]		Report	67.18 Gy
	D2%[%]	<= 107 % (69.34Gy)	3	106.2 % (68.84Gy)
	D5%[%]		Report	105.8 % (68.56Gy)
	D95%[%]	>= 99 % (64.15Gy)	3	100.9 % (65.41Gy)
	D98%[%]		Report	99.6 % (64.52Gy)
	V110%[cc]	<= 0.5 cc	2	0 cc
	V98%[%]	>= 98 %	1	99.1 %
	V99%[%]	>= 98 %	2	98.6 %
	V100%[%]	>= 95 %	2	97.4 %
	V107%[%]	<= 2 %	1	0.2 %
	Volume[cc]		Report	249.5 cc
	CV98%[%]	<= 2 %	1	0.9 %
	CV98%[cc]		Report	2.14 cc
ptv5625	Max[Gy]		Report	69.67 Gy
	Max[%]		Report	123.9 % (69.67Gy)
	Min[Gy]		Report	55.55 Gy
	Min[%]		Report	98.8 % (55.55Gy)
	Mean[Gy]		Report	64.19 Gy

Page:

Mayo et al, Practical Radiation Oncology 2016; 6(4): e117-e126 PM26825250

Brain Site Example-BN001 Plan Evaluation

Eclipse Scripts Plan Evaluation Results for BN001

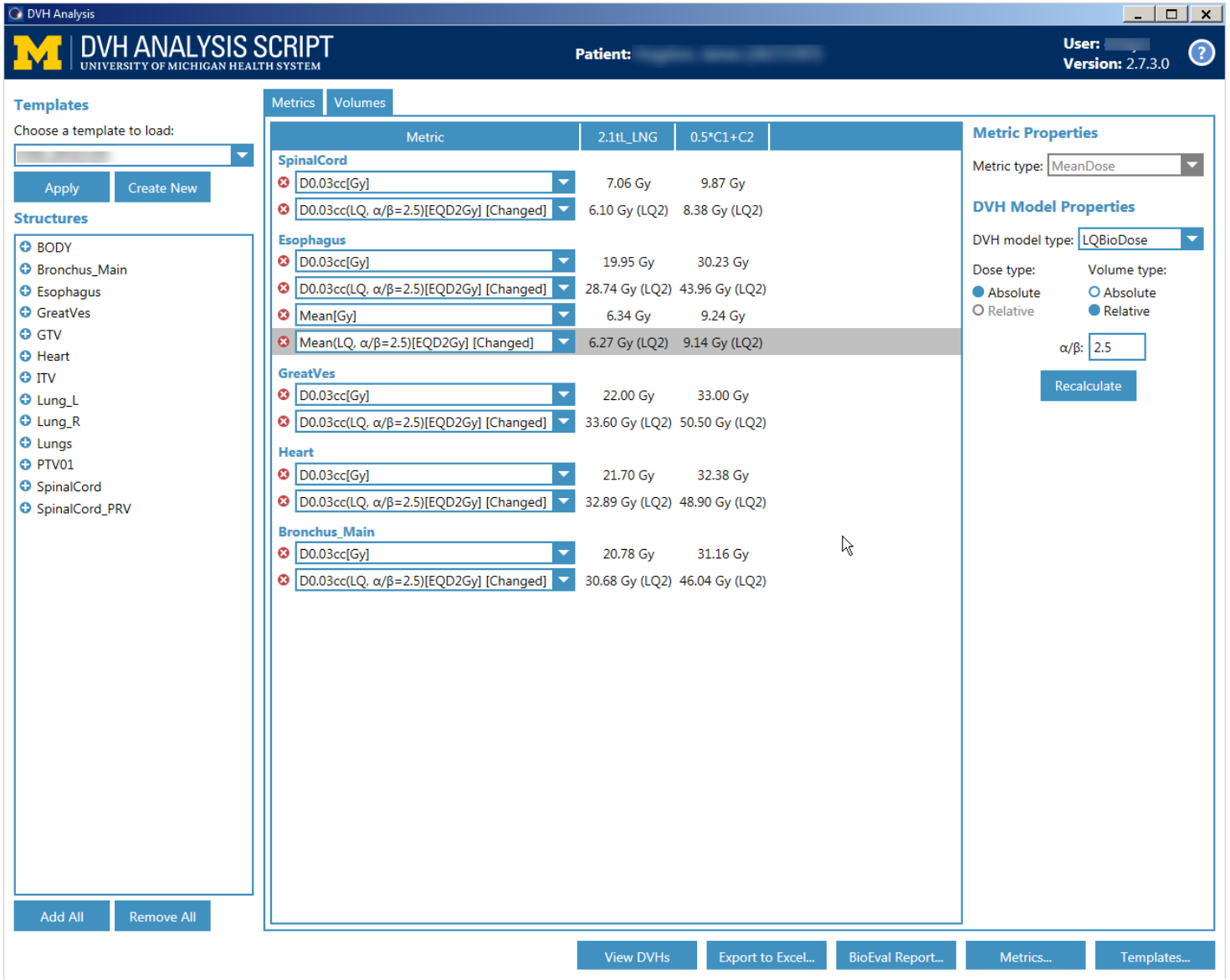
Name (ID) [redacted], (NRG-BN001)
Plan or PlanSum ID: EXPORTMHTest
Printed :2016-11-08 10:49:35

Structure ID	Structure Code	Patient Structure	DVH Objective	Evaluator	Variation	Priority	Met	Achieved
PTV_4600		PTV_4600	D95%[Gy]	>=46	43.7	2	Goal	51.541 Gy
PTV_6000		PTV_6000	D95%[Gy]	<=60.75	63	2	Not met	76.307 Gy
PTV_6000		PTV_6000	D95%[Gy]	>=59.75	57	2	Goal	76.307 Gy
PTV_6000		PTV_6000	D10%[Gy]	<=63	65.12	2	Not met	79.647 Gy
PTV_6000		PTV_6000	D0.03cc[Gy]	<=64	66	2	Not met	81.210 Gy
PTV_5000		PTV_5000	D95%[Gy]	>=50	47.5	2	Goal	51.205 Gy
PTV_7500		PTV_7500	D95%[Gy]	<=75.75	78.75	2	Goal	71.603 Gy
PTV_7500		PTV_7500	D95%[Gy]	>=74.25	71.25	2	Variation	71.603 Gy
PTV_7500		PTV_7500	D10%[Gy]	<=78.7	81.4	2	Variation	79.524 Gy
PTV_7500		PTV_7500	D0.03cc[Gy]	<=80	82.5	2	Variation	81.210 Gy
SpinalCord		SpinalCord	D0.03cc[Gy]	<=50	50	1	Goal	8.137 Gy
BrainStemCore		BrainStemCore	D0.03cc[Gy]	<=55	60	2	Variation	59.867 Gy
BrainStemSurf		BrainStemSurf	D0.03cc[Gy]	<=55	64	2	Variation	63.579 Gy
OpticChiasm_PRV		OpticChiasm_PRV	D0.03cc[Gy]	<=55	60	2	Variation	58.335 Gy
OptNrv_L_PRV		OptNrv_L_PRV	D0.03cc[Gy]	<=55	60	2	Goal	41.774 Gy
Retina_L		Retina_L	D0.03cc[Gy]	<=45	50	2	Goal	13.454 Gy
Retina_R		Retina_R	D0.03cc[Gy]	<=45	50	2	Goal	31.863 Gy
Brain		Brain	D5%[Gy]	<=78.7	81.4	1	Goal	64.170 Gy
Lens_L		Lens_L	D0.03cc[Gy]	<=7	10	2	Goal	5.425 Gy
Lens_R		Lens_R	D0.03cc[Gy]	<=7	10	2	Variation	[illegible]

CIRO
Center for Innovation in Radiation Oncology
NRG Oncology

Ying Xiao, Ph.D.
UPENN, NRG

Scripting to standardize calculations of physical and biological dose metrics



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University of Michigan

Scripting to Evaluate Plan in Context of Prior Plans

- **Statistical DVH**
  - Visualization method quantifying comparison of plan DVH curve with historical values
- **Weighted Experience Score (WES)**
  - Ranking score (0-1) quantifying comparison of DVH curves to historical values
- **Generalized Evaluation Metric (GEM)**
  - Ranking score (0-1) quantifying comparison of DVH metrics to constraints and historical values
- **Population Generalized Evaluation Metric (GEM_{POP})**
  - Ranking score (0-1) quantifying As Low As Reasonably Achievable (ALARA) using historical values for DVH metrics

Mayo CS, Yao J Eisbruch A, et al. Incorporating big data into treatment plan evaluation: Development of statistical DVH metrics and visualization dashboards. Advances in Radiation Oncology 2017; 2(3):503-514

Weighted Experience Score

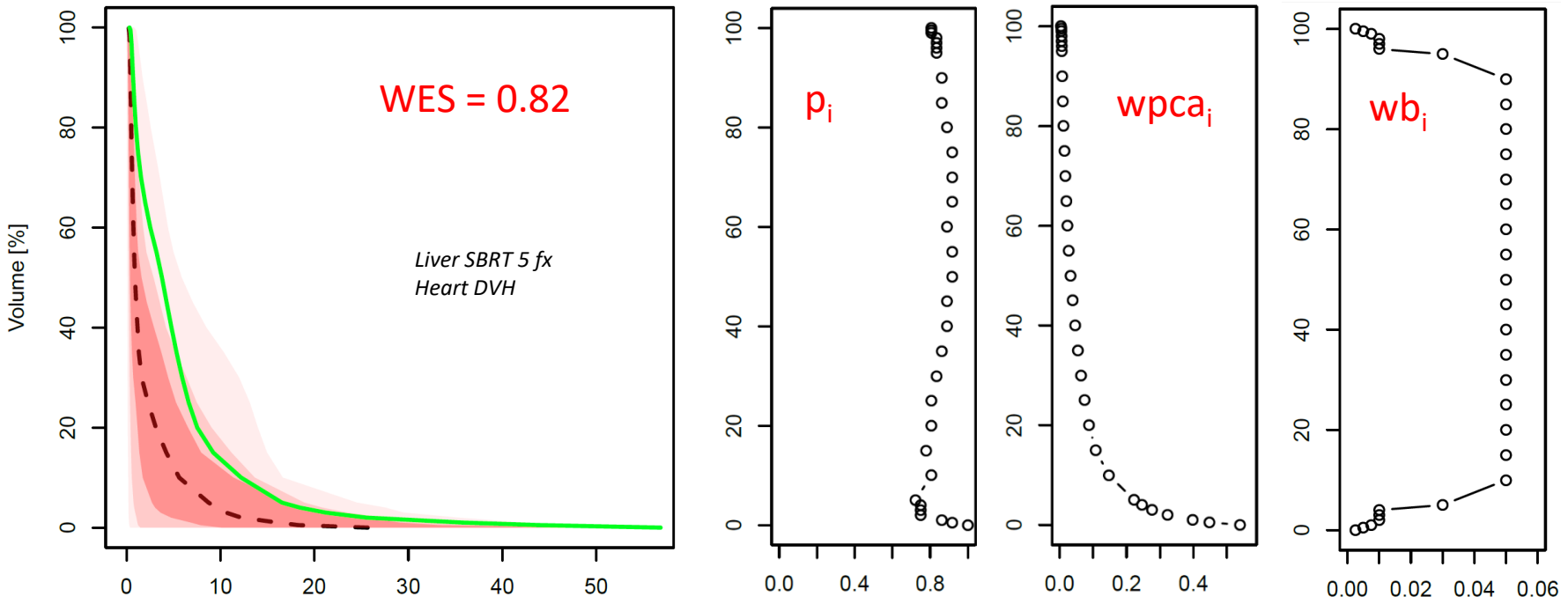
A score ranking DVH curves in Historical Context?

$$WES = \frac{\sum_i wb_i * wpca_i * p_i}{\sum_i wb_i * wpca_i}$$

Probability historical Dx%[Gy] are smaller or equal

Weight by 1st vector of principle component analysis of Dx%[Gy] values

Weight by bin size

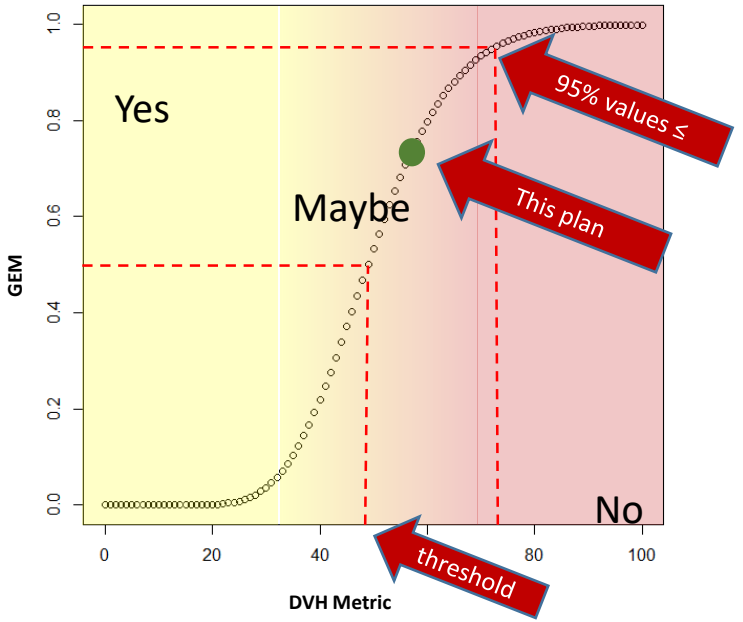


Generalized Evaluation Metric

A score ranking ability to meet dose constraints, in historical context

Planning Goals:				
Structures	**Drawn by**	**Priority**	**Parameter**	**Planning Limit**
☐ Rectum	MD	1 or ____	Max Dose to 0.1 cc (including PTV overlap) ≤ Rx dose	____
		1 or ____	<15% ≥ 75 Gy	
		1 or ____	<25% ≥ 70 Gy	
		1 or ____	<35% ≥ 65 Gy	
		1 or ____	<50% ≥ 50 Gy	
		3 or ____	<5% ≥ 75 Gy	
		3 or ____	<15% ≥ 70 Gy	
		3 or ____	<17% ≥ 65 Gy ALARA	
		4 or ____	____	
☐ Bladder	MD	3 or ____	<25% ≥ 75 Gy	____
		3 or ____	<35% ≥ 70 Gy	
		3 or ____	<50% ≥ 65 Gy ALARA	
		4 or ____	____	
☐ Femur R/L	Dosim	3 or ____	Max ≤ 45 Gy	____
		4 or ____	ALARA	
☐ Penile Bulb	MD	3 or ____	____ Mean ≤ 50 Gy	____
		4 or ____	ALARA	
☐ Bowel	MD	1 or ____	Max to 1cc ≤ 54 Gy	____
		4 or ____	ALARA	
☐ Sigmoid	MD	____	Max to 1cc ≤ 60 Gy	____
☐ Other	____	____	____	____

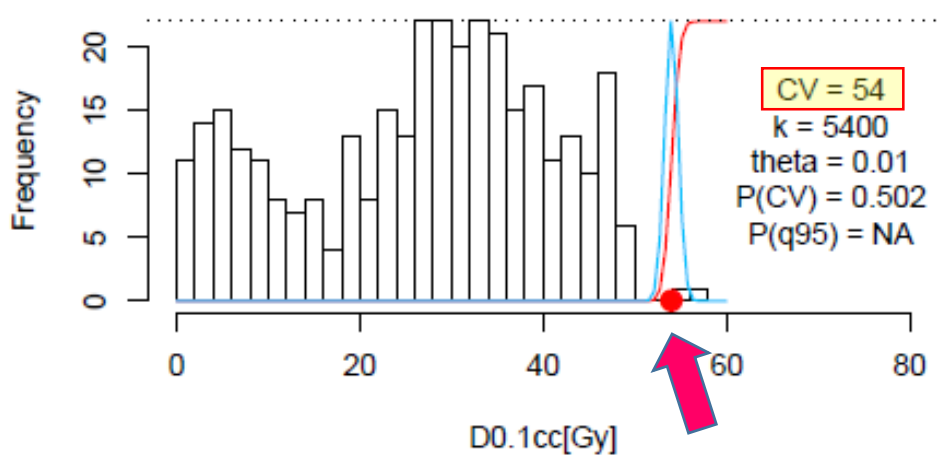
Acceptable value compared to constraint?



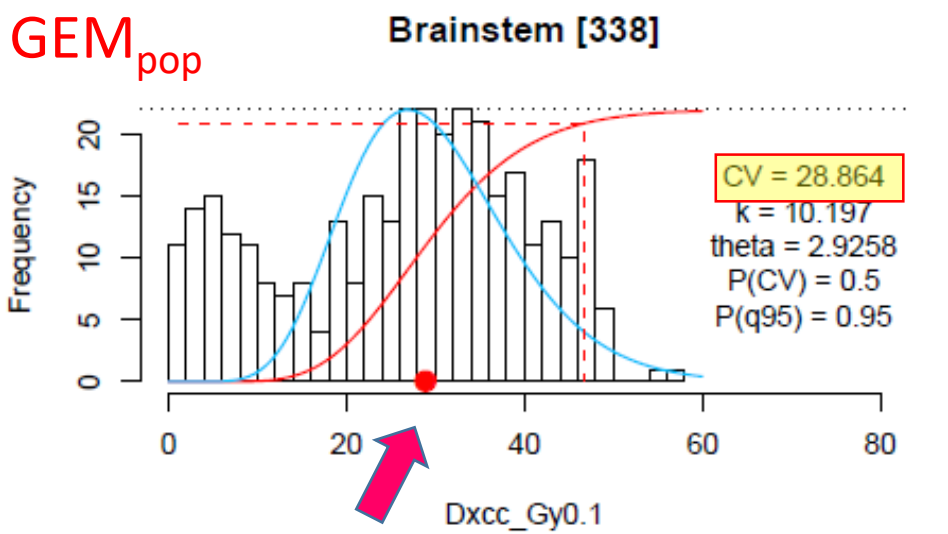
$$GEM = \frac{\sum_i \left[2^{-(Priority_i - 1)} \cdot \gamma\left(k_i, \frac{PlanValue_i}{\theta_i}\right) \right]}{\sum_i 2^{-(Priority_i - 1)}}$$

Mine data from prior treated plans to parametrize evaluation metrics for current plans

GEM



GEM_{pop}



GEM - What we must do

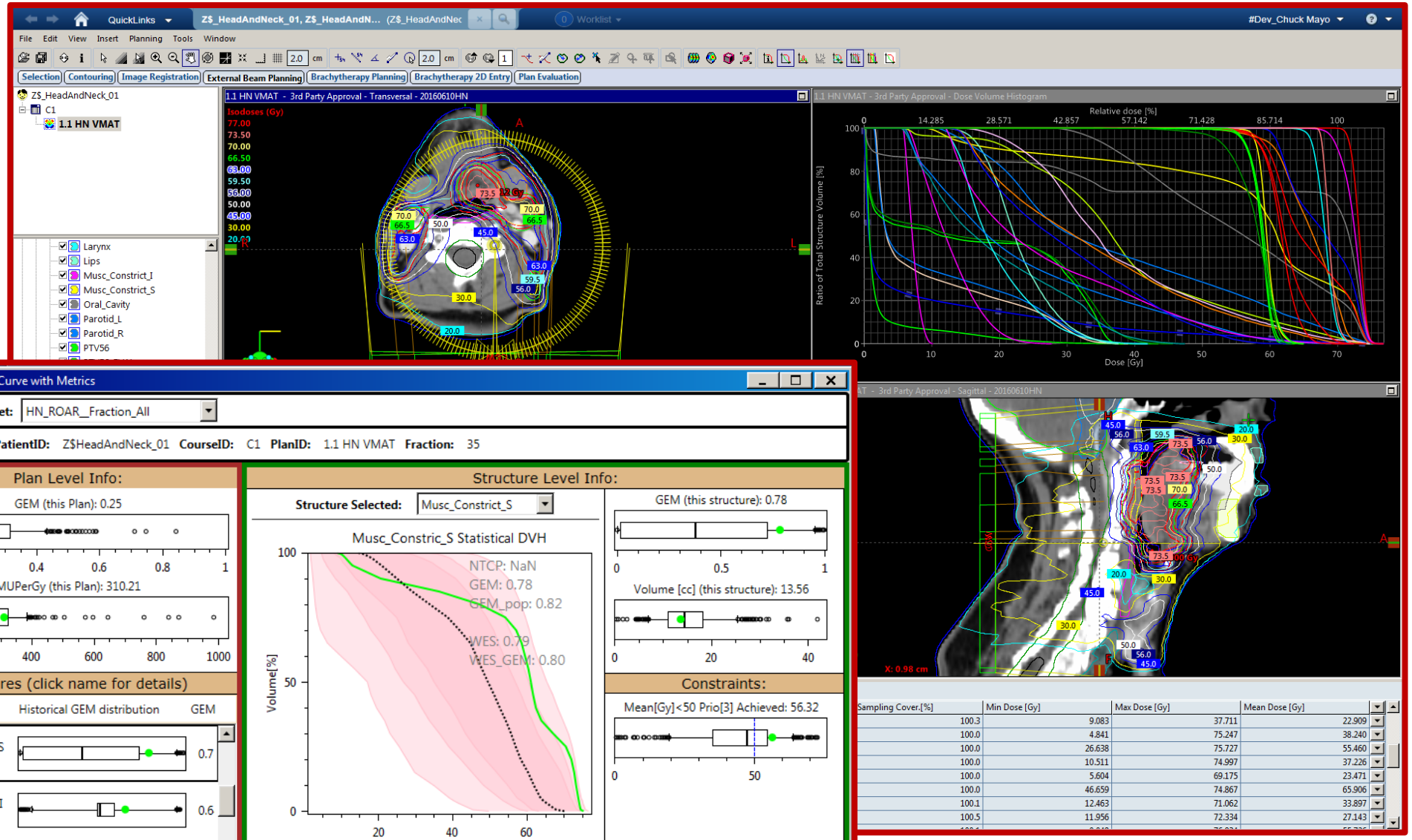
Historically we meet the physician's constraint

GEM << 1

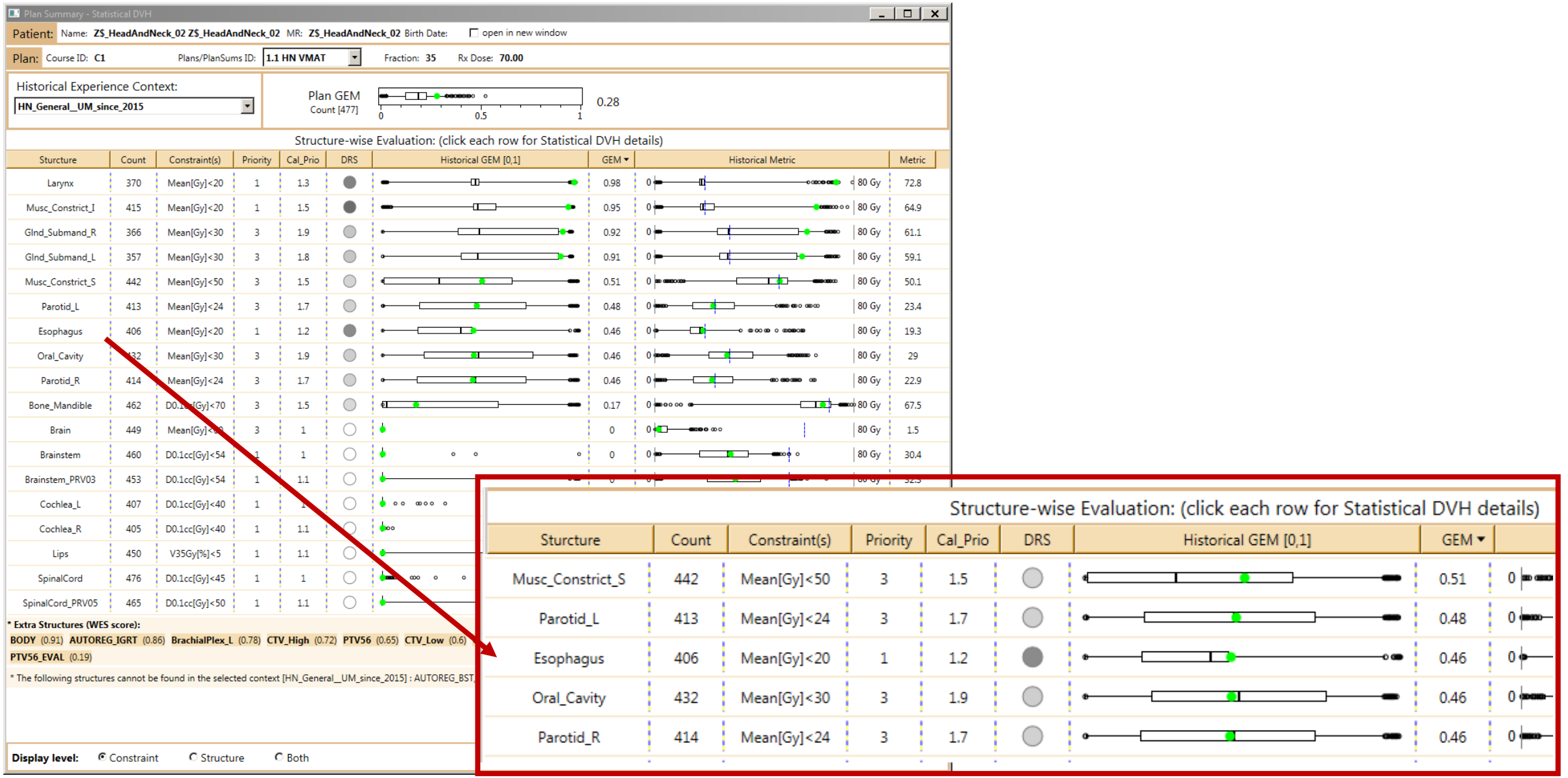
GEM_{pop} - Could we do better ? - Have we done better ?

- Set threshold to median of historic distribution
- Set priority to 4

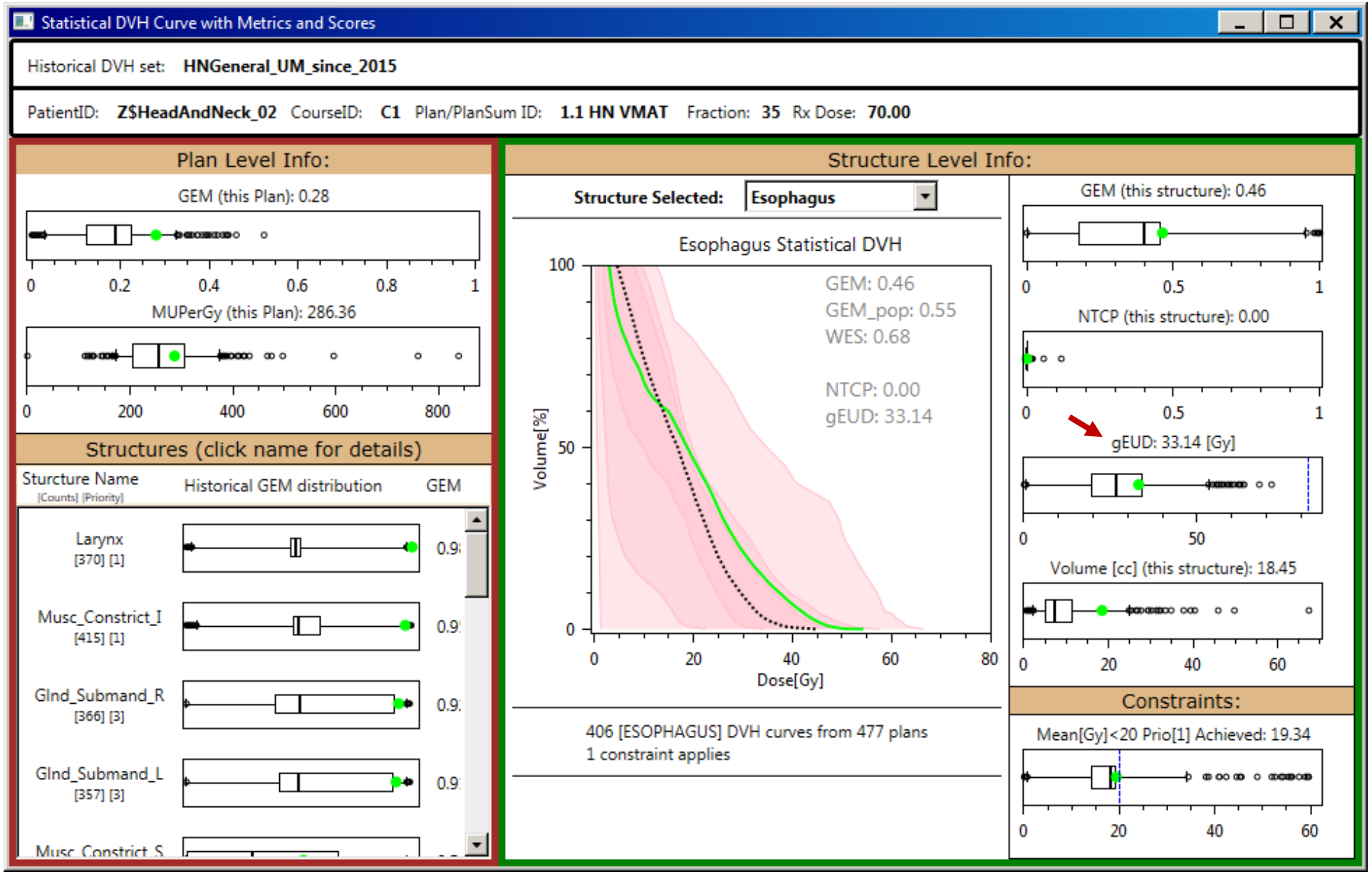
Now we can quantify what we mean by ALARA from our history of what has been clinically acceptable


QuickLinks
Z$_HeadAndNeck_01, Z$_HeadAndN... (Z$_HeadAndNec
Worklist
#Dev_Chuck Mayo
File Edit View Insert Planning Tools Window
Selection Contouring Image Registration External Beam Planning Brachytherapy Planning Brachytherapy 2D Entry Plan Evaluation
Z$_HeadAndNeck_01
C1
1.1 HN VMAT
Larynx
Lips
Musc_Constrict_I
Musc_Constrict_S
Oral_Cavity
Parotid_L
Parotid_R
PTV56
1.1 HN VMAT - 3rd Party Approval - Transversal - 20160610HN
Isodoses (Gy)
77.00
73.50
70.00
66.50
63.00
59.50
56.00
50.00
45.00
30.00
20.00
1.1 HN VMAT - 3rd Party Approval - Dose Volume Histogram
Relative dose [%]
Ratio of Total Structure Volume [%]
Dose [Gy]
Statistical DVH Curve with Metrics
Historical DVH set: HN_ROAR_Fraction_All
Current Plan -- PatientID: Z$HeadAndNeck_01 CourseID: C1 PlanID: 1.1 HN VMAT Fraction: 35
Plan Level Info:
GEM (this Plan): 0.25
MUPerGy (this Plan): 310.21
Structures (click name for details)
Sturcture Name
[Counts] [Priority]
Historical GEM distribution
GEM
Musc_Constrict_S [522] [3] 0.7
Musc_Constrict_I [496] [1] 0.6
Glnd_Submand_R [414] [3] 0.5
Larynx [440] [1] 0.4
Structure Level Info:
Structure Selected: Musc_Constrict_S
Musc_Constric_S Statistical DVH
NTCP: NaN
GEM: 0.78
GEM_pop: 0.82
WES: 0.79
WES_GEM: 0.80
Volume[%]
Dose[Gy]
522 [Musc_Constrict_S] DVH curves from 553 plans
1 constraint applies
GEM (this structure): 0.78
Volume [cc] (this structure): 13.56
Constraints:
Mean[Gy]<50 Prio[3] Achieved: 56.32
Sampling Cover.[%]
Min Dose [Gy]
Max Dose [Gy]
Mean Dose [Gy]
100.3 9.083 37.711 22.909
100.0 4.841 75.247 38.240
100.0 26.638 75.727 55.460
100.0 10.511 74.997 37.226
100.0 5.604 69.175 23.471
100.0 46.659 74.867 65.906
100.1 12.463 71.062 33.897
100.5 11.956 72.334 27.143

Summary Report Card Dashboard



Statistical DVH Dashboard



Scripting to Make Plan Checking Faster and More Effective

Plan Checker Tool

Graphical depiction of results / checker status

Report patient orientation from CT dataset	✓	Image orientation : HeadFirstSupine Treatment orientation : HeadFirstSupine Automatic Checks passed
Report number of CT slices in planning dataset		Number of CT slices in planning dataset '20141120LTARM' is '144'.
Verify number of CT slices against move sheet	–	
Verify 3D vs IMRT Carepath	⚑	This is a VMAT plan but may be on a 3D carepath. Please confirm carepath is correct

Jean Moran, Ph.D.
Kelly Younge, Ph.D.
Elizabeth Covington, PhD
Xiaoping Chen

E. L. Covington et al. Improving Plan Quality with Automation of Treatment Plan Checks. Journal of Applied Clinical Medical Physics 17(6):16-31, 2016.

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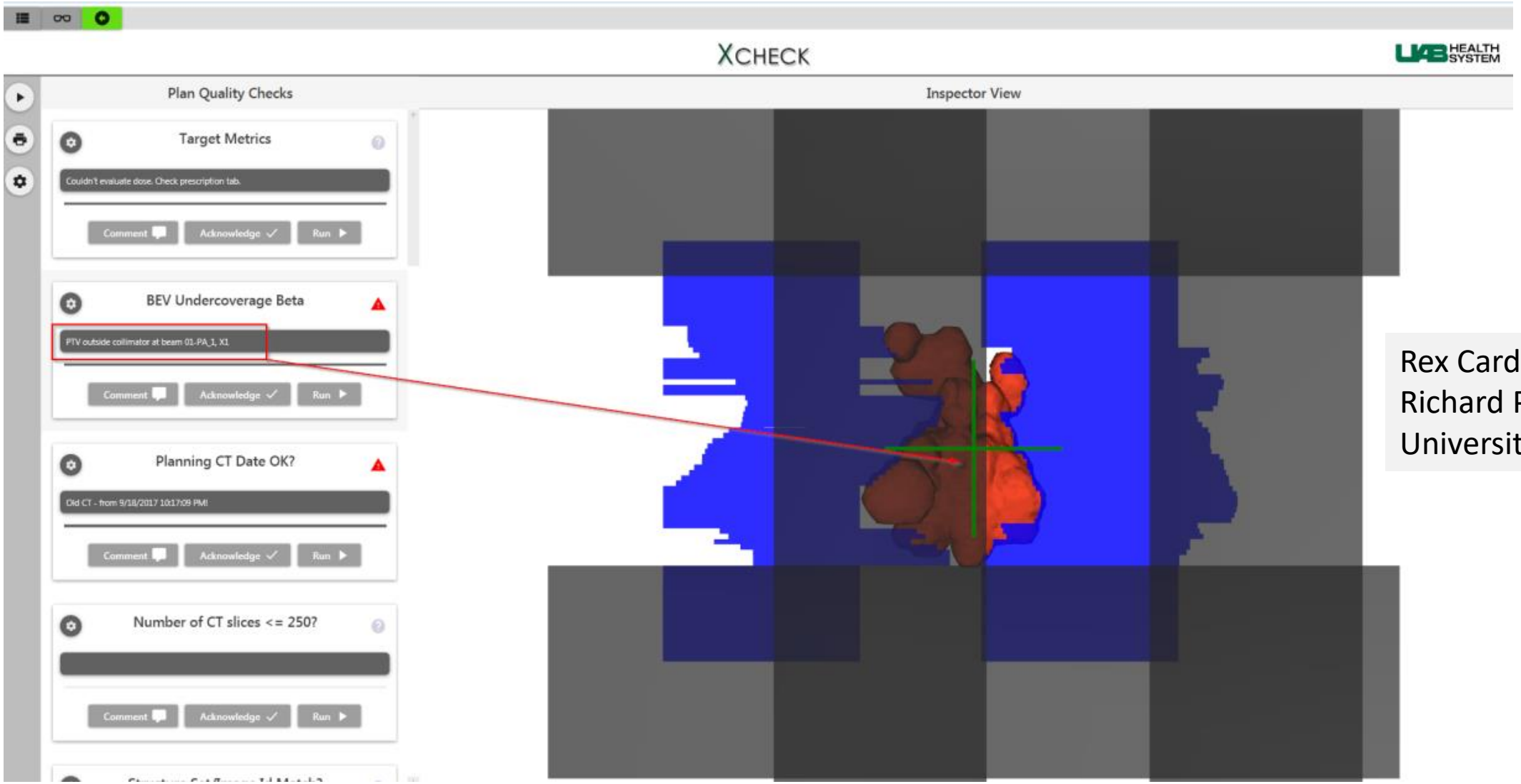
Scripting to Make Plan Checking Faster and More Effective

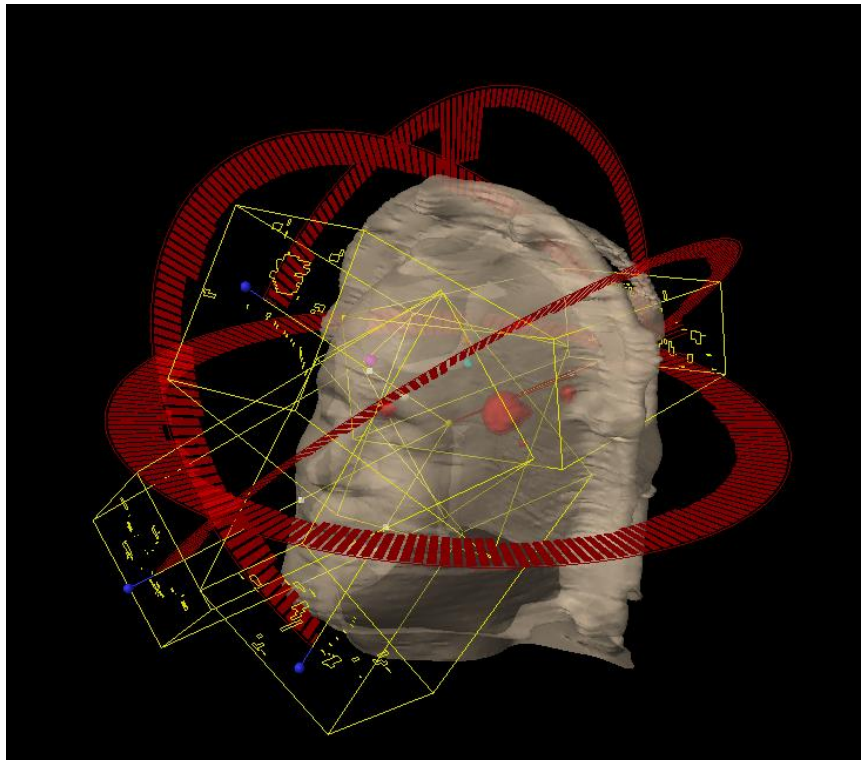


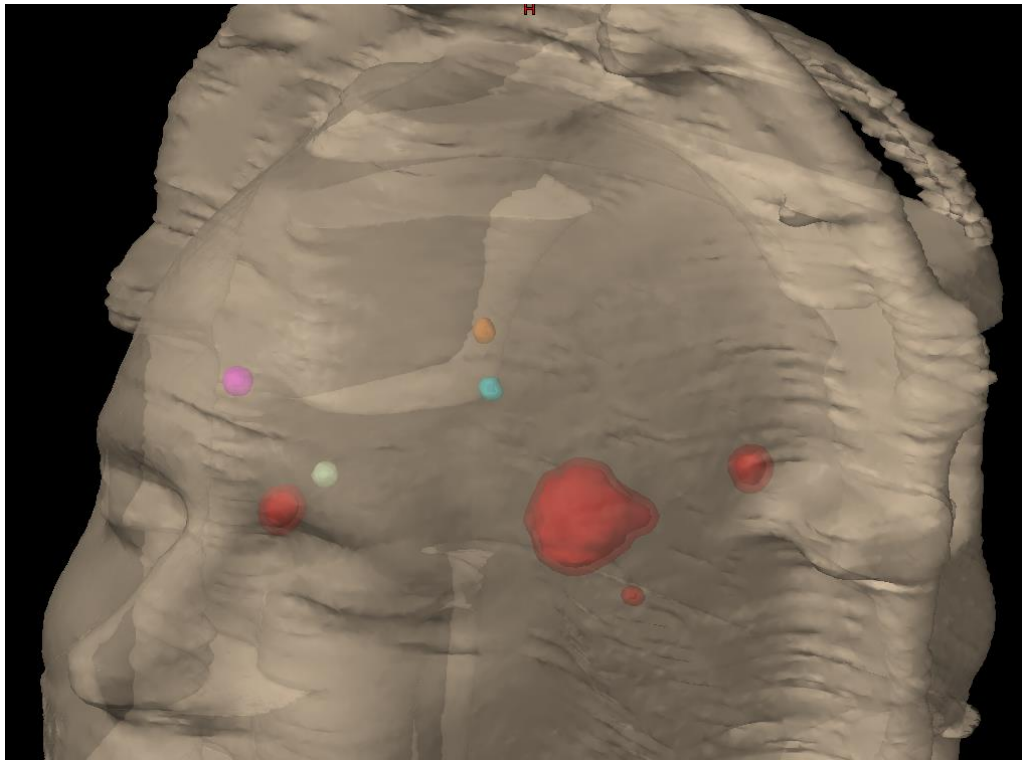
Rex Cardan, Ph.D.
Richard Popple, Ph.D
University of Alabama

Standardized approach to SRS planning and evaluation

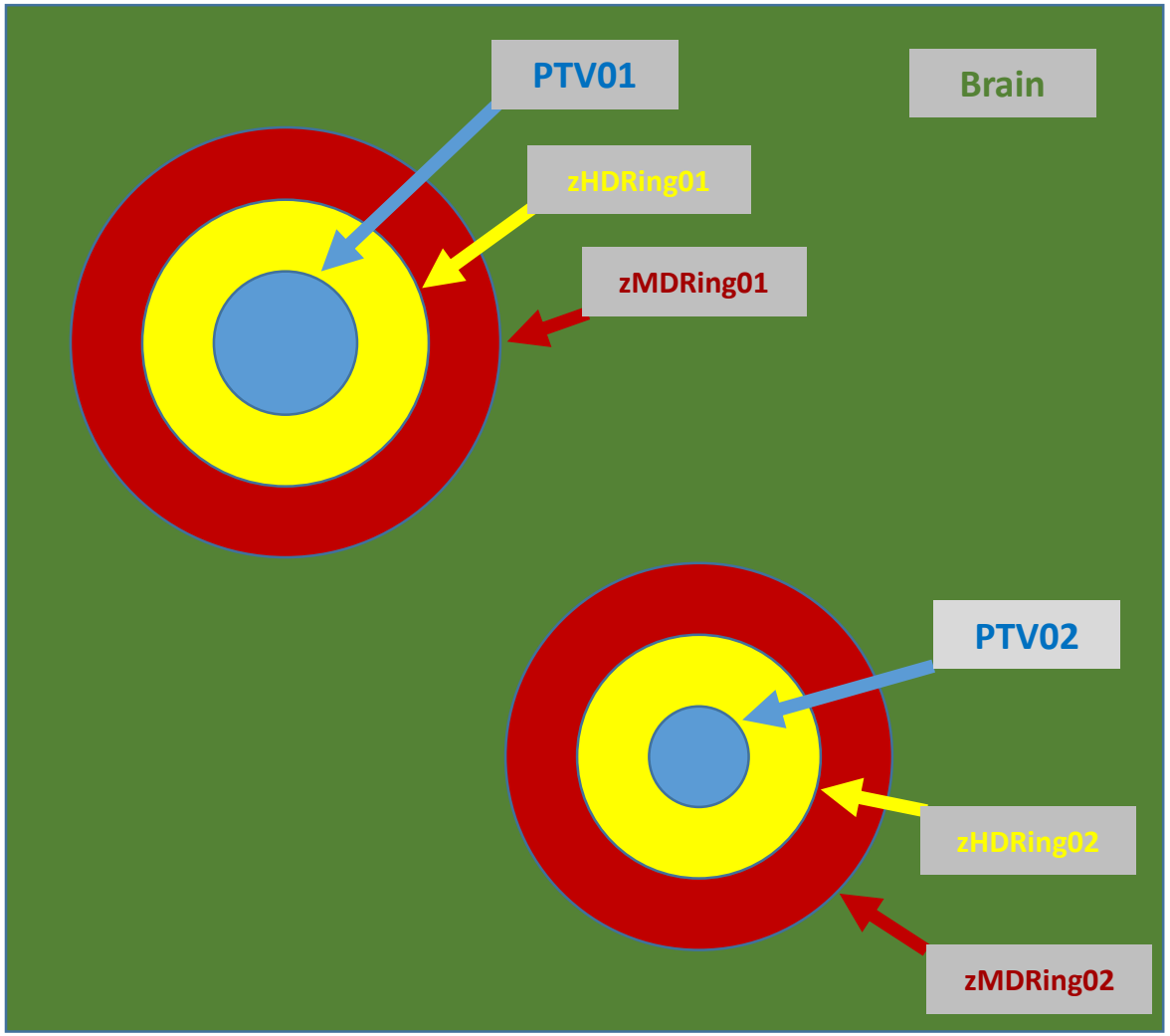
Manual implementation now

Scripted automation with availability of writable scripting





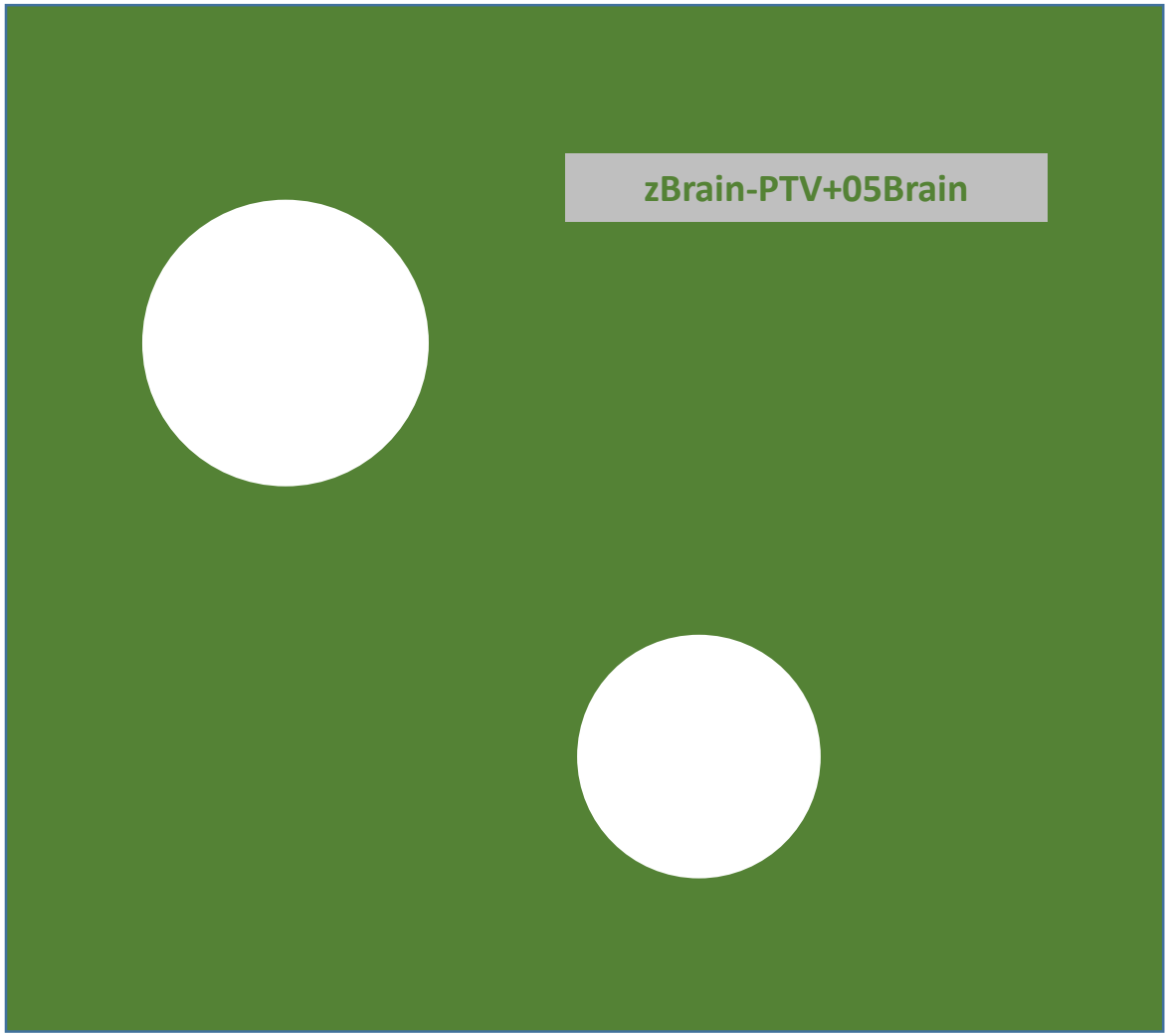
Automation scripting developed in Research Mode



The answer begins with
standardized contouring
and naming

- Targets and rings are sequentially numbered e.g. PTV01, zHDRing01, zMDRing02….
  PTV15, zHDRing15,
  zMDRing15
- Rings are 5 mm thick
- Use zHDRings to control dose gradients and conformality in optimizer
- Use zMDRings to monitor midrange dose falloff

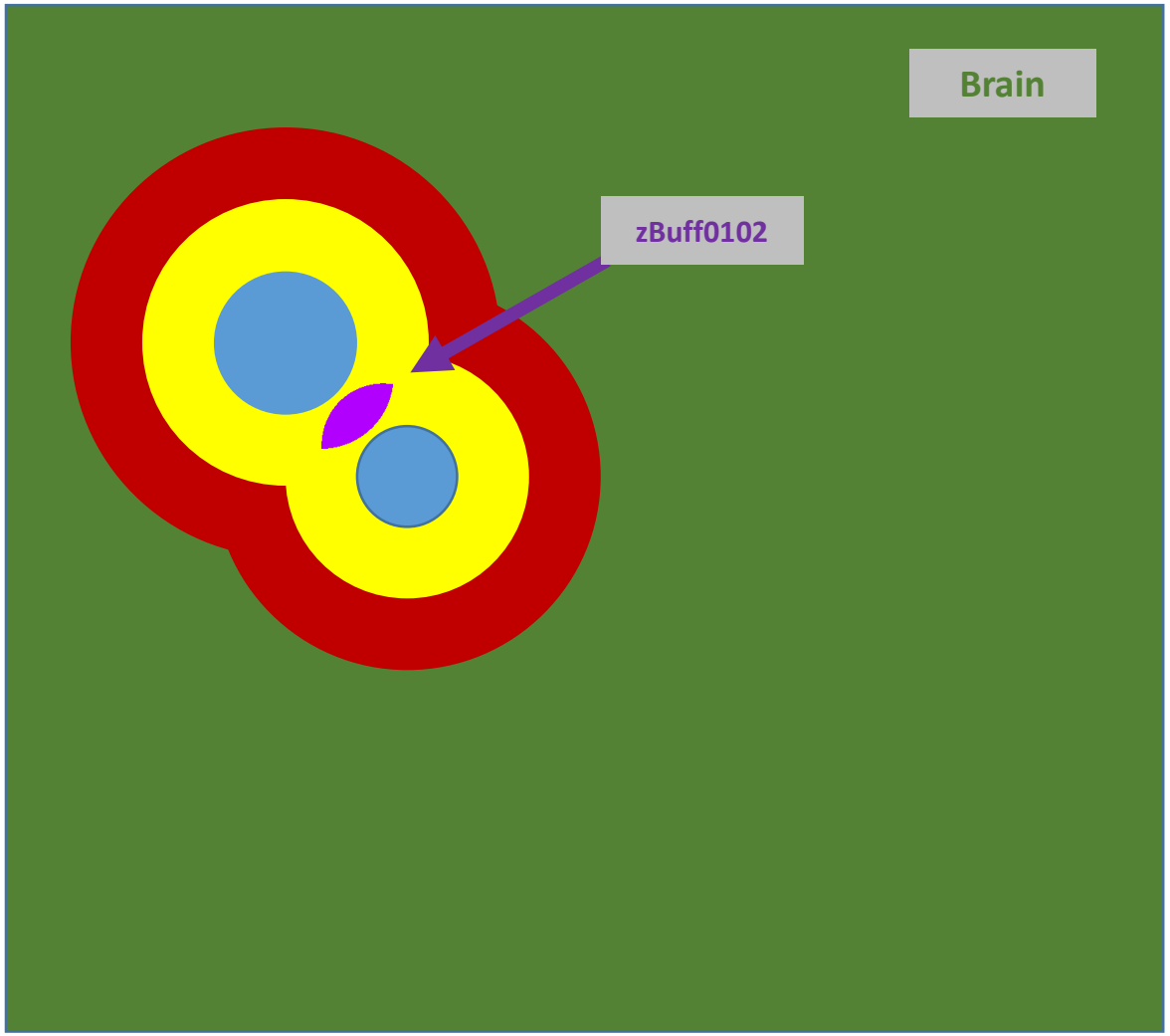
Research mode script – automates creation of all structures for all targets in < 1 sec.



The answer begins with contouring

- Track dose to parts of brain where dose should be low
- Boolean out PTVs and zHDRingxxs from Brain
- zBrain-PTV+05 = Brain-(PTVs+HDRings)
- Use in optimizer to limit low and mid-range dose levels to brain not proximal to targets

Research mode script – automates creation of all structures for all targets in < 1 sec.



The answer begins with contouring

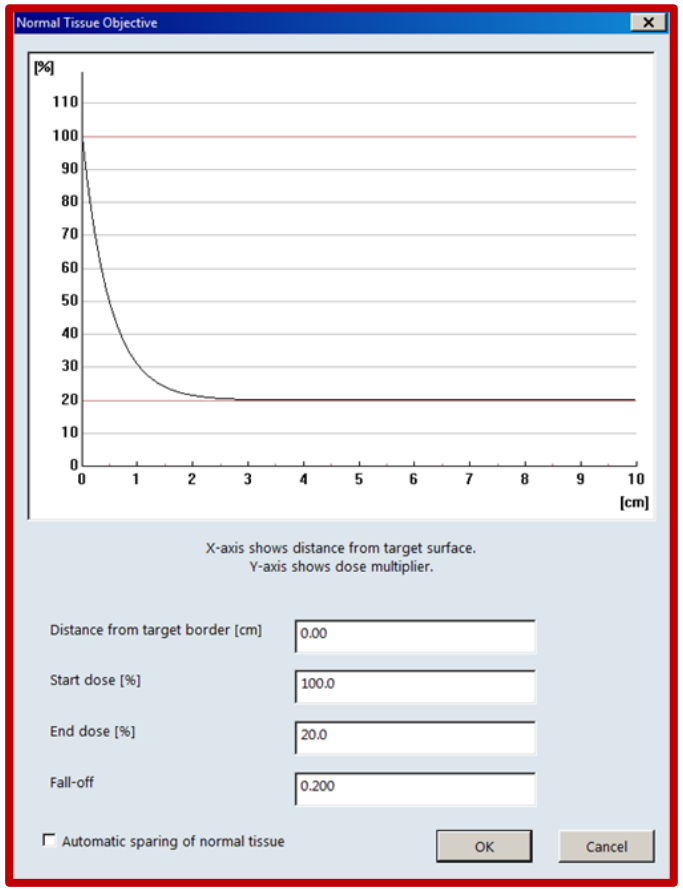
- What if the PTVs are close?
- Boolean PTVs out of Rings
- Create buffer structures from overlap of zHDRingxxs
- Use buffers to “pinch-off” dose in between targets in optimizer

Research mode script – automates creation of all structures for all targets in < 1 sec.

Algorithmic approach for planning that can be moved to script automated planning

Optimize starting with these parameters

Structure	Type	Volume[%]	Dose	Priority	Comment
PTVxx	Lower	100	Rx[Gy]	120	
	Upper	0	Rx[Gy]+25%	50	-
GTVxx	Lower	50	Rx[Gy]+8%	50	Push dose higher if needed to reduce horns in dose profile
zHDRingxx	Upper	2	Rx[Gy]	80	
	Upper	70	0.5 * Rx[Gy]	100	Push Volume[%] to < 70% as optimization allows
zBrain-PTV+05	Upper	0	0.5*Rx[Gy]	120	-
	Upper	3	0.25*Rx[Gy]	50	Push dose to < 0.25*Rx[Gy] as optimization allows
zBufxxyy	Upper	20	0.9* Rx[Gy]	50	Push volume[%] to < 20% as optimization allows



Research mode script – automates optimization

Use scripting to calculate standard metrics for plan quality assessment

PTVxx

- Rx[Gy]
- Volume[cc]
- V100%[cc]
- Min[Gy]
- Max[Gy]
- **CI**
- **Greff**

Mayo CS, Ding L, Addesa A, Kadish S, Fitzgerald TJ, Moser R:
Initial experience with volumetric IMRT (RapidArc) for intracranial stereotactic radiosurgery
Int. J. Radiat. Oncol. Biol. Phys. 78(5): 1457-1466

zHDRingxx and zMDRingxx

- V100%[cc]
- V50%[cc]
- **V12Gy[cc]**
- DC5%[cc]
- D5%[cc]

zBrain – PTV+05

- Volume[cc]
- **V12Gy[cc]**
- **V10Gy[cc]**
- **V05Gy[cc]**

SRSMetricCheck.

[redacted] 1 BRAIN SRS ATPS 2.2.0.0

zBrain-PTV-05

Volume[cc]	V12Gy[cc]	V10Gy[cc]	V05Gy[cc]
1523.7	0.0	0.2	67.9

Targets, HDRings and MDRings

Target Name	Rx[Gy]	Volume[cc]	V100%[cc]	Min[Gy]	Max[Gy]	HDRing:V100%[cc]	HDRing:V50%[cc]	HDRing:V12Gy[cc]	HDRing:DC5%[Gy]	HDRing:D5%[cc]	MDRing:V100%[cc]	MDRing:V50%[cc]	MDRing:DC5%[Gy]	MDRing:D5%[cc]	CI	GrEff
PTV01	20	0.42	0.42	20.8	24.4	0.32	2.70	2.03	7.2	21.0	0.00	0.20	2.30	9.1	1.77	137.7
PTV02	18	2.28	2.28	17.8	23.9	0.39	6.14	3.60	7.3	18.0	0.18	2.01	3.64	11.2	1.17	105.2
PTV03	20	1.93	1.93	20.0	26.2	0.25	5.48	3.55	8.8	19.6	0.00	0.34	4.65	9.4	1.13	118.1
PTV04	20	1.31	1.31	19.6	26.4	0.24	4.70	3.14	8.8	19.7	0.02	0.92	4.47	11.5	1.18	108.1
PTV05	20	0.73	0.73	20.1	26.2	0.16	3.35	2.07	7.8	19.6	0.00	0.18	3.50	9.3	1.22	122.6

Write To File

Approaches for actualizing standards to reduce variability and improve evaluation

Book of Policies

Enforcement

Writeable scripting will enable automating creating policy compliant plans

Summary

- Advanced scripting is being used by many groups to address all components of plan evaluation

- Un-necessary variability and inconsistency undermine potential of scripting to automate

  Start now with standardizing

  - process
  - nomenclatures
  - plan policies