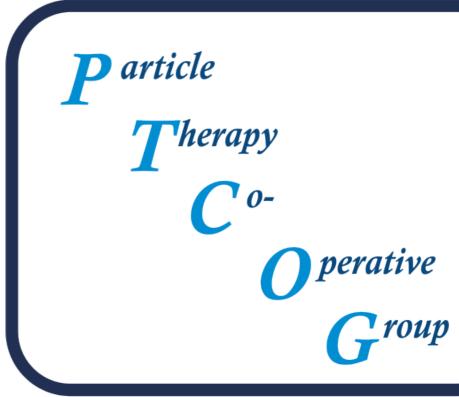
Utilizing piecewise linear DVH based score functions to fully automate FLASH / IMPT dose optimization for objective treatment modality comparison

Anthony Magliari, MS, CMD 2023 PTCOG Annual Meeting

Pierre Lansonneur, Esa Kuusela, Jessica Perez, Miriam Krieger, Lesley Rosa, Wendy Smith, Adam S. Harrington, Karl Bush, Michael Folkerts

FLASH therapy is under development and not available for commercial sale.

MADRID 2023





am employed by Varian on the Medical Affairs team

My job currently includes testing new products and providing feedback including FLASH radiotherapy

I've been creating FLASH treatment plans since 2017

I used development builds of Eclipse and Non Clinical modes of the ProBeam delivery system for examples

FLASH therapy is under development and not available for commercial sale.

DISCLAIMER:

A Siemens Healthineers Company

"The views expressed in this presentation are mine, and mine alone. They do not represent those of Varian, A Siemens Healthineers Company"



Disclaimer 2: FLASH Intellectual Property

- protecting our innovations throughout the world.
- Varian has numerous pending and issued patents worldwide related to FLASH therapy and technology

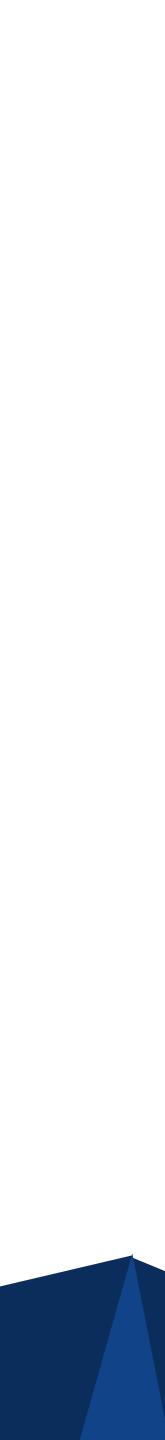
FLASH therapy is under development and not available for commercial sale.

• Varian intends to leverage all intellectual property protections and is committed to

1 2 3

FLASH therapy is under development and not available for commercial sale.

Dosimetric Scorecard Concepts Direct Piecewise Linear Optimization Dosimetric & Doserate Results





Dosimetric Scorecard Concepts Piecewise linear DVH based score functions precisely capture clinical intent



Dosimetric Scorecards: Basic Principles

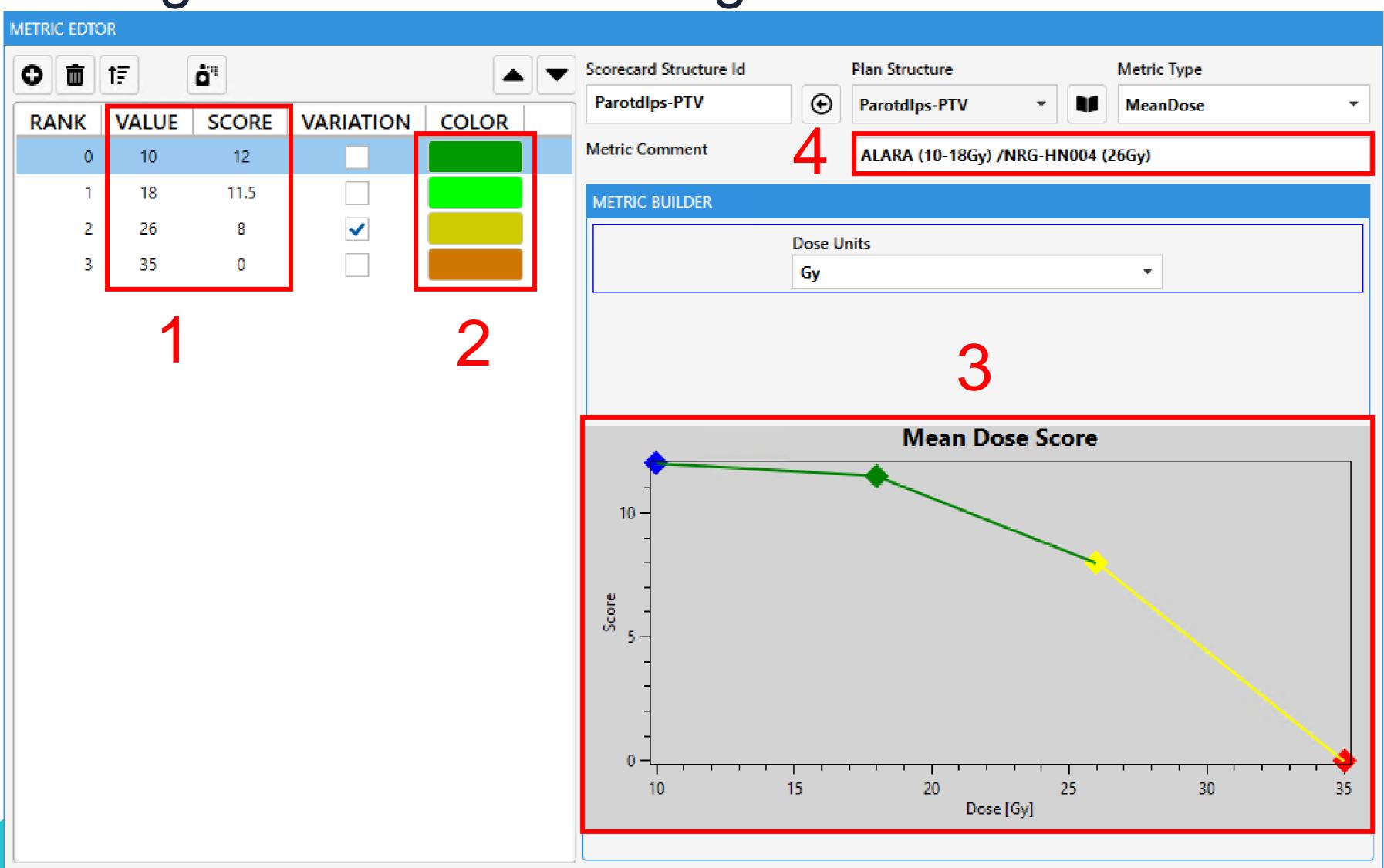
- Between two different patients, scores should not be directly compared
- Designed to analyze multiple plan options for the same patient/case
- Scorecards can be created for a single patient, but better to be created per protocol or class of patients
- Max score should not be achievable
 - Scorecard total
 - Per metric
- Powerful tool for retrospective plan quality analysis

• Create dosimetric wish list to document best achievable today to reexamine in the future

2 PT/Vno/Hart Volume at 50.6/y [13] PF3Ha48 96.59 % 20.00 20.01 3 PTV Wahme at 52.6/y [13] PF2Ha48 96.59 % 20.00 20.01 4 PTV Wahme at 72.55/y [13] PF2Ha48 51.35 % 0.36 2.00 5 LUNG TOTAL PTV Done at 80.0C [50] RF3Ha48 51.37 % ///////////////////////////////////	Plan Scores	s: [N-Opt] RP3Ha	al6: 133.75/150.00 (89.17%)					
2 PT/Nuclear Volume at 50.60 (PL) 8931abl 96.97 % 20.00 20.00 2 PT/Nuclear Volume at 50.60 (PL) 8931abl 96.97 % 20.00 20.00 3 PTV Volume at 50.60 (PL) 8931abl 96.81 % 0.80 2.00 20.00 4 PTV Down at 0.0152 (PJ) 8931abl 96.81 % 0.80 0.00 2.00 </th <th>ld</th> <th>Structure</th> <th>Score Metric</th> <th>Plan Id</th> <th>Value</th> <th>Score</th> <th>Max</th> <th></th>	ld	Structure	Score Metric	Plan Id	Value	Score	Max	
2 PYNueleast Walaward 35 560 [1] PP31abl 96.09 % 20.00 20.00 3 PYV Volume af 55.60 [1] R65146 0.88 5.00 7.00 7.00 4 PY Daward 65.00 [1] 004.100 PY1448 31.86 6y 6.07 7.00		PTV	Volume at 50.4Gy [%]	RP3Hal6	91.07 %	0.64	3.00	[
2 PYLoofbert Vederer af 50.407 [*] 893446 96.95 % 20.00 20.00 3 PYV Vederer af 70.00 [*] 893446 84.61 % 0.00 2.00 4 PYV Does af 0.00 [6] 873446 51.00 (9) 6.07 7.00 5 LUNG TOTAL PTV Does af 0.00 [6] 873446 51.37 (9) 6.00 6.00 6 LUNG TOTAL PTV Does af 0.00 [6] 873446 51.37 (9) 6.00 6.00 7 LUNG TOTAL PTV Does af 0.00 [6] 873446 1.47 % 7.00 7.00 8 LUNG TOTAL PTV Meandbere [6] 873448 1.47 % 7.00 7.00 7.00 9 LUNG TOTAL PTV Vederer af 300 [%] 873448 7.37 % 1.6.9 7.00		0] IDEAL [3]						90.
3 PTV Wahme et 47.260 [1] BP3Ha66 96.81 % 0.90 2.00 4 PTV Door (11) MCC17964.171 Door (12) RC17966.1 % 0.90 0.00 5 LUNG TOTAL-FTV Door of LD2CC [07] BP3Ha66 5.06 GP 6.00 6.00 6 LUNG TOTAL-FTV Door of LD2CC [07] BP3Ha66 6.09 GP 8.62 10.00 7 LUNG TOTAL-FTV Membrase 100 MCC17964.211 MCC17964.211 RP3Ha66 6.09 GP 8.62 10.00 7 LUNG TOTAL-FTV Wahme et 3000 [15] RP3Ha66 7.78 S 14.69 5.00 6 LUNG TOTAL-FTV Wahme et 3000 [15] RP3Ha66 7.78 S 14.69 7.00 7.00 6 LUNG TOTAL-FTV Wahme et 3000 [15] RP3Ha66 7.78 S 14.69 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 </td <td></td> <td>PTVnoHeart</td> <td>Volume at 50.4Gy [%]</td> <td>RP3Hal6</td> <td>96.99 %</td> <td>20.00</td> <td>20.00</td> <td>ſ</td>		PTVnoHeart	Volume at 50.4Gy [%]	RP3Hal6	96.99 %	20.00	20.00	ſ
3 FV Webers et 7.865 (F) 873466 9.815 0.90 2.00 4 FV Does et 0.0CC (6) 974466 31.85 Gy 6.57 7.00 6 LUNG TOTAL FIV Does et 0.0CC (6) 873446 6.85 Gy 8.62 8.60 6 LUNG TOTAL FIV Maxmate pt maxmate pt maxmate pt maxmate pt 6 LUNG TOTAL FIV Maxmate pt maxmate pt maxmate pt maxmate pt 6 LUNG TOTAL FIV Maxmate pt maxmate pt maxmate pt maxmate pt 7 LUNG TOTAL FIV Webme et 3000 [C] 873446 2.75 % 4.59 7.00 8 LUNG TOTAL FIV Webme et 3000 [C] 873446 2.75 % 4.59 7.00 maxmate pt 9 LUNG TOTAL FIV Webme et 3000 [C] 873446 27.67 % 4.59 7.00 maxmate pt 10 HUNG TOTAL FIV Webme et 3000 [C] R67446 7.00 maxmate pt maxmate pt 11 HUNG TOTAL FIV <t< td=""><td>MARGINAL [0</td><td>0] ACCEPTABLE [10]</td><td></td><td></td><td></td><td></td><td></td><td>90.</td></t<>	MARGINAL [0	0] ACCEPTABLE [10]						90.
4 PTV Does al DECC [Dp] RP3Hade 33.86 Gy 6.67 7.60 FIRE (T) FOOD [S] RC27768.12 [S] RAMINAL [P]	3	PTV		RP3Hal6	98.61 %	0.90	2.00	ſ
Пакада Полов (ст.) <	MARGINAL [0		GOOD [1.5] IDEAL [2]					95.
S LUNG TOTAL FIV Does at 0.01CC [60] BP3Hulb S1.37 Gy 6.00 6.00 6 LUNG TOTAL FIV MeenDore [50] RP3Hulb 6.08 Gy 9.62 10.00 7 LUNG TOTAL FIV MeenDore [50] RP3Hulb 1.47 % 7.00 7.00 7.00 8 LUNG TOTAL FIV Volume at 3007 [%] RP3Hulb 1.47 % 7.00 7.00 7.00 9 LUNG TOTAL FIV Volume at 3007 [%] RP3Hulb 1.47 % 7.00 7.00 7.00 9 LUNG TOTAL FIV Volume at 3007 [%] RP3Hulb 2.17 % 4.69 7.00 7.00 9 LUNG TOTAL FIV Volume at 3007 [%] RP3Hulb 2.17 % 4.59 7.00 7.00 9 LUNG TOTAL FIV Volume at 3007 [%] RP3Hulb 2.16 % 4.59 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00	4	PTV	Dose at 0.03CC [Gy]	RP3Hal6	53.86 Gy	6.07	7.00	ſ
NAME DOOD [SA] PACEFFARE [S] PAADEMAK [B] 6 LUNG TOTAL PTV MeanDose [Gy] RP3Hal6 6.89 Gy 9.62 10.00 7 LUNG TOTAL PTV Velume at 30Gy [S] RP3Hal6 1.47 % 7.00 7.00 8 LUNG TOTAL PTV Velume at 30Gy [S] RP3Hal6 7.78 % 1.4.69 15.00 7.70 9 LUNG TOTAL PTV Velume at 30Gy [S] RP3Hal6 7.78 % 1.4.69 15.00 7.70 9 LUNG TOTAL PTV Velume at 30Gy [S] RP3Hal6 2.767 % 4.99 7.00 7.00 9 LUNG TOTAL PTV Velume at 30Gy [S] RP3Hal6 39.39 % 9.22 10.00 7.70 9 LUNG TOTAL PTV Velume at 50Gy [S] RP3Hal6 30.30 % 9.22 10.00 7.70 9 LUNG TOTAL PTV Velume at 30GY [S] RP3Hal6 5.03 Gy 3.36 5.00 7.70 7.70 7.70 7.70 7.70 7.70 7.70 7.70 7.70 7.70	IDEAL [7]	GOOD [6]						52.
6 LUNG TOTAL PTV MeanDose (fy) RP3Hal6 6.89 Gy 9.62 N0.00 R0.00 PMALEN MeanDose (fy) RP3Hal6 6.89 Gy 9.62 N0.00 R0.00 PMALEN MeanDose (fy) RP3Hal6 L47 % 7.00 7.00 R0.00 PMALEN MeanDose (fy) MeanDose (fy) RP3Hal6 L47 % 7.00 7.00 R0.00 RATION TOTAL PTV Volume at 20Gy (%) RP3Hal6 2.78 % L469 5.00 R0.00 PALENT Volume at 20Gy (%) RP3Hal6 27.67 % 4.99 7.00 R0.00 PALENT Volume at 3Gy (%) RP3Hal6 39.39 % 9.22 N0.00 R0.00 PALENT Volume at 3Gy (%) RP3Hal6 50.32 Gy 3.36 5.00 R0.00				RP3Hal6	51.37 Gy	6.00	6.00	[
IPPAK_[15] DOOD [13] ACCEPTABLE [2] MAXEMAK [2] REAL 7 LUNG TOTAL_PTV Volume at 2000 [13] RE3Hald 1.47 % 7.00 7.00 1.50 8 LUNG TOTAL_PTV Volume at 2000 [13] RE3Hald 7.78 % 1.469 15.00 1.50 9 LUNG TOTAL_PTV Volume at 2000 [13] RE3Hald 27.67 % 4.99 7.00 1.50 9 LUNG TOTAL_PTV Volume at 2007 [13] RE3Hald 39.39 % 5.22 10.00 1.50 11 HEART Doce at 0.32CC [07] RE3Hald 50.32 Gy 3.36 5.00 1.60 11 HEART Doce at 0.32CC [07] RE3Hald 16.76 Gy 10.38 15.00 1.60 12 HEART Montional [01 REAL [01 REAL [01 1.50 1.60 1.50 1.60 13 HEART Montional [01 REAL [01 REAL [01 1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50								52.
7 LUNG TOTAL-PTV Volume at 300y [%] RP3Hal6 L47 % 7.00 7.00 8 LUNG TOTAL-PTV Volume at 200y [%] RP3Hal6 7.78 % H4.69 15.00 9 LUNG TOTAL-PTV Volume at 200y [%] RP3Hal6 7.78 % H4.69 15.00 9 LUNG TOTAL-PTV Volume at 200y [%] RP3Hal6 27.67 % 4.99 7.00 9 LUNG TOTAL-PTV Volume at 300y [%] RP3Hal6 27.67 % 4.99 7.00 9 LUNG TOTAL-PTV Volume at 300y [%] RP3Hal6 39.39 % 9.22 10.00 9 LUNG TOTAL-PTV Volume at 300y [%] RP3Hal6 50.32 Gy 3.36 5.00 9 LUNG TOTAL-PTV Volume at 300y [%] RP3Hal6 50.32 Gy 3.36 5.00 9 LUNG TOTAL-PTV Volume at 400y [%] RP3Hal6 6.18 % 7.88 8.00 9 LUNG TOTAL PTV Volume at 400y [%] RP3Hal6 6.18 % 7.88 8.00 11 HE				RP3Hal6	6.89 Gy	9.62	10.00	[
RK [7] DOOD [5] DOCETTABLE [4] MARGINAL [9] REAL 8 LUNG TOTAL PTV Volume at 206 y [%] RP3Hal6 7.8 % 14.69 15.00 7.6 % 9 LUNG TOTAL PTV Volume at 106 y [%] RP3Hal6 27.6 % 4.49 7.00 7.6 % 10 LUNG TOTAL PTV Volume at 106 y [%] RP3Hal6 39.39 % 9.22 10.00 7.6 % 10 LUNG TOTAL PTV Volume at 106 y [%] RP3Hal6 39.39 % 9.22 10.00 7.6 % 11 HEART Does at 0.032C [6y] RP3Hal6 50.32 G y 3.36 5.00 7.6 % 12 HEART MeanDose [6y] RP3Hal6 16.76 G y 10.30 15.00 7.8 % 13 HEART MeanDose [6y] RP3Hal6 6.18 % 7.8 % 8.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 7.00 <						7.00	7.00	5.0
B LUNG TOTAL-PTV Volume at 20Gy [%] RP3Hal6 7.78 % 14.69 15.00 770 9 LUNG TOTAL-PTV Volume at 10Gy [%] RP3Hal6 27.67 % 4.99 7.00 9 LUNG TOTAL-PTV Volume at 10Gy [%] RP3Hal6 27.67 % 4.99 7.00 00 LUNG TOTAL-PTV Volume at 10Gy [%] RP3Hal6 39.39 % 9.22 10.00 00 LUNG TOTAL-PTV Volume at 500 [%] RP3Hal6 50.32 Gy 3.36 5.00 00 LUNG TOTAL-PTV Volume at 0.03CC [Gy] RP3Hal6 50.32 Gy 3.36 5.00 011 HEART Dose at 0.03CC [Gy] RP3Hal6 5.03 Gy 3.36 5.00 024 HEART MeanDose [Gy] RP3Hal6 5.18 % 7.88 8.00 5.00 13 HEART Volume at 400g [%] RP3Hal6 2.146 Gy 4.89 5.00 5.00 14 KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 0.07 % 6.99 7.00				RP3Hal6	1.47 %	7.00	7.00	•
PEAL [15] GOOD [13] ACCEPTABLE [16] AARGINAL [26]								5.00
9 LUNG TOTAL-PTV Volume at 100g [%] RP3Hal6 27.67 % 4.99 7.00 10 LUNG TOTAL-PTV Volume at 50g [%] RP3Hal6 39.39 % 9.22 10.00 10 LUNG TOTAL-PTV Volume at 50g [%] RP3Hal6 50.32 Gy 3.36 5.00 11 HEART Dose at 0.03CC [Gy] RP3Hal6 50.32 Gy 3.36 5.00 12 HEART MeenDose [Gy] RP3Hal6 16.76 Gy 10.30 15.00 13 HEART Volume at 400g [%] RP3Hal6 6.18 % 7.88 8.00 14 KONEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 0.07 % 6.99 7.00 2.00 14 KONEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 31.39 Gy 6.41 7.00 2.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.39 Gy 6.41 7.00 2.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.39 Gy 6.41 7.00 2				RP3Hal6	7.78 %	14.69	15.00	ľ
IDEAL [7] GOOD [6] ACCEPTABLE [4] MARCHAR [9] IS 10 LUNG TOTAL-PTV Volume at SGy [5] RP3Hal6 39.39 % 9.22 10.00 IPEAL [19] GOOD [9] ACCEPTABLE [5] MARCHAR [9] 20.00 11 HEART Dore at 0.03CC [Gy] RP3Hal6 50.32 Gy 3.36 5.00 IPEAL [19] ACCEPTABLE [4] MARCHAR [9]	IDEAL [15]							7.00
In LUNG TOTAL-PTV Volume at 56y [%] RP3Hal6 39.39 % 9.22 10.00 IPPAL [19] 6000 [9] ACCEPTABLE [9] MARGINAL [9]				RP3Hal6	27.67 %	4.99	7.00	
PEAL [19] GOOD [5] ACCEPTABLE [5] MARGINAL [9] 20.07 11 HEART Dose at 0.03CC [6y] RP3Hal6 50.32 Gy 3.36 5.00 PEAL [5] ACCEPTABLE [4] MARGINAL [9] 44.00 44.00 12 HEART MeanDose [6y] RP3Hal6 16.76 Gy 10.30 15.00 PEAL [19] GOOD [13] ACCEPTABLE [4] MARGINAL [9] 5.00 5.00 13 HEART Volume at 40Gy [%] RP3Hal6 6.18 % 7.88 8.00 14 KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 21.46 Gy 4.89 5.00 15 KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 0.07 % 6.99 7.00 0.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 0.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 0.00 17 LIVER MeanDose [Gy] RP3Hal6	IDEAL [7]	GOOD [6]						10.0
II HEART Dose at 0.03CC [Gy] RP3Hal6 50.32 Gy 3.36 5.00 IPEAL [5] ACCEPTABLE [4] MARGINAL [0] 44.00 I2 HEART MeanDose [Gy] RP3Hal6 16.76 Gy 10.30 15.00 I2 HEART MeanDose [Gy] RP3Hal6 6.18 % 7.88 8.00 I3 HEART Volume at 40Gy [%] RP3Hal6 6.18 % 7.88 8.00 I4 KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 21.46 Gy 4.89 5.00 I4 KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 0.07 % 6.99 7.00 I5 KIDNEY TOTAL Volume at 20Gy [%] RP3Hal6 31.89 Gy 6.41 7.00 I6 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 I7 LIVER MeanDose [Gy] RP3Hal6 13.94 Gy 4.21 5.00 I8 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66	10		Volume at 5Gy [%]	RP3Hal6	39.39 %	9.22	10.00	
DEAL [5] ACCEPTABLE [4] MARGINAL [0] AUXIMINAL [0]	IDEAL [10]							20.0
I2 HEART MeanDose (Gy) RP3Hal6 16.76 Gy 10.30 15.00 IDEAL [15] GOOD [13] ACCEPTABLE [5] MARGINAL [9] 5.00 13 HEART Volume at 40Gy [%] RP3Hal6 6.18 % 7.88 8.00 DEAL [19] GOOD [17] ACCEPTABLE [2] MARGINAL [9] 5.00 5.00 DEAL [5] GOOD [4] ACCEPTABLE [2] MARGINAL [9] 5.00 5.00 DEAL [5] GOOD [4] ACCEPTABLE [2] MARGINAL [9] 5.00 2.00 14 KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 0.07 % 6.99 7.00 15 KIDNEY TOTAL Volume at 20Gy [%] RP3Hal6 0.07 % 6.99 7.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 17 LIVER MARGINAL [9]	11	HEART	Dose at 0.03CC [Gy]	RP3Hal6	50.32 Gy	3.36	5.00	
12 HEART MeanDose [Gy] RP3Hal6 16.76 Gy 10.30 15.00 IPEAL [13] GOOD [13] ACCEPTABLE [5] MARGINAL [9] 5.00 13 HEART Volume at 40Gy [%] RP3Hal6 6.18 % 7.88 8.00 DEAL [13] GOOD [17] ACCEPTABLE [4] MARGINAL [9] 5.00 5.00 5.00 14 KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 0.07 % 6.99 7.00 6.00 15 KIDNEY TOTAL Volume at 20Gy [%] RP3Hal6 0.07 % 6.99 7.00 6.00 044 [7] GOOD [6] ACCEPTABLE [9] MARGINAL [0] 0.00 0.00 0.00 15 KIDNEY TOTAL Volume at 20Gy [%] RP3Hal6 0.07 % 6.99 7.00 0.00 044 [7] GOOD [6] ACCEPTABLE [9] MARGINAL [0] 0.00 0.00 0.00 0.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 0.00 0EAL [7] GOOD [6] ACCEPTABLE [3] MARGINAL [6] 13.94 Gy	IDEAL [5]	ACCEPTABLE [4]						40.0
13 HEART Volume at 40Gy [%] RP3Hal6 6.18 % 7.88 8.00 DEAL [8] 14 KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 21.46 Gy 4.89 5.00 DEAL [5] 6000 [4] ACCEPTABLE [2] MARGINAL [0] 20.00 14 KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 0.07 % 6.99 7.00 15 KIDNEY TOTAL Volume at 20Gy [%] RP3Hal6 0.07 % 6.99 7.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 17 LIVER Marginal [0] MARGINAL [0] 20.00 18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 DEAL [5] GOOD [4] ACCEPTABLE [3] MARGINAL [0] 10.00 10.00 18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 5.00 DEAL [6] GOOD [5] ACCEPTABLE [3] MARGINAL [0] 5.00 5.00	12	HEART		RP3Hal6	16.76 Gy	10.30	15.00	Γ
13 HEART Volume at 40Gy [%] RP3Hal6 6.18 % 7.88 8.00 DEAL [8] GOOD [7] ACCEPTABLE [4] MARGINAL [9] S.00 5.00 14 KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 21.46 Gy 4.89 5.00 DEAL [5] GOOD [4] ACCEPTABLE [3] MARGINAL [0] 20.00 15 KIDNEY TOTAL Volume at 20Gy [%] RP3Hal6 0.07 % 6.99 7.00 0.00 DEAL [7] GOOD [6] ACCEPTABLE [5] MARGINAL [0] 0.00 0.00 0.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 0.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 13.94 Gy 4.21 5.00 17 LIVER MeanDose [Gy] RP3Hal6 13.94 Gy 4.21 5.00 18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 5.00 DEAL [6] GOOD [5] ACCEPTABLE [3] MARGINAL [0] 5.00 5.00 5.00 5.00	IDEAL [15]	GOOD [13]						5.00
Id KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 21.46 Gy 4.89 5.00 DEAL [5] GOOD [4] ACCEPTABLE [3] MARGINAL [0] 20.00 15 KIDNEY TOTAL Volume at 20Gy [%] RP3Hal6 0.07 % 6.99 7.00 20.00 DEAL [7] GOOD [6] ACCEPTABLE [3] MARGINAL [0] 0.00 0.00 0.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 20.00 17 LIVER MeanDose [Gy] RP3Hal6 13.94 Gy 4.21 5.00 20.00 18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 20.00 DEAL [5] GOOD [6] ACCEPTABLE [3] MARGINAL [0] 10.00 1	13	HEART		RP3Hal6	6.18 %	7.88	8.00	t
14 KIDNEY TOTAL Dose at 0.03CC [Gy] RP3Hal6 21.46 Gy 4.89 5.00 DEAL [5] GOOD [4] ACCEPTABLE [3] MARGINAL [0] RP3Hal6 0.07 % 6.99 7.00 20.00 15 KIDNEY TOTAL Volume at 20Gy [%] RP3Hal6 0.07 % 6.99 7.00 20.00 DEAL [7] GOOD [6] ACCEPTABLE [5] MARGINAL [0] 0.00 0.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 20.00 17 LIVER MeanDose [Gy] RP3Hal6 13.94 Gy 4.21 5.00 18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 DEAL [5] GOOD [5] ACCEPTABLE [3] MARGINAL [0] S.00 20.00	DEAL [8]		ACCEPTABLE [4] MARGINAL [0]					5.00
15 KIDNEY TOTAL Volume at 20Gy [%] RP3Hal6 0.07 % 6.99 7.00 0.00 DEAL [7] GOOD [6] ACCEPTABLE [5] MARGINAL [0] 0.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 0.00 DEAL [7] GOOD [6] ACCEPTABLE [3] MARGINAL [0] 0.00 0.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 0.00 DEAL [7] GOOD [6] ACCEPTABLE [3] MARGINAL [0] 0.00 0.00 17 LIVER MeanDose [Gy] RP3Hal6 13.94 Gy 4.21 5.00 18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 DEAL [6] GOOD [5] ACCEPTABLE [3] MARGINAL [0] 5.00 5.00	14		Dose at 0.03CC [Gy]	RP3Hal6	21.46 Gy	4.89	5.00	ľ
15 KIDNEY TOTAL Volume at 20Gy [%] RP3Hal6 0.07 % 6.99 7.00 DEAL [7] GOOD [6] ACCEPTABLE [5] MARGINAL [0] 0.00 16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 DEAL [7] GOOD [6] ACCEPTABLE [3] MARGINAL [0] 0.00 17 LIVER MeanDose [Gy] RP3Hal6 13.94 Gy 4.21 5.00 DEAL [5] GOOD [4] ACCEPTABLE [3] MARGINAL [0] 10.00 18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 DEAL [6] GOOD [5] ACCEPTABLE [3] MARGINAL [0] 5.00 5.00	DEAL [5]		ACCEPTABLE [3] MARGINAL [0]					20.00
16 SPINAL CORD Dose at 0.03CC [Gy] RP3Hal6 31.89 Gy 6.41 7.00 DEAL [7] 6000 [6] ACCEPTABLE [3] MARGINAL [0] 20.00 17 LIVER MeanDose [Gy] RP3Hal6 13.94 Gy 4.21 5.00 DEAL [5] 6000 [4] ACCEPTABLE [3] MARGINAL [0] 10.00 18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 DEAL [6] GOOD [5] ACCEPTABLE [3] MARGINAL [0] 5.00 5.00	15		Volume at 20Gy [%]	RP3Hal6	0.07 %	6.99	7.00	
DEAL [7] GOOD [6] ACCEPTABLE [3] MARGINAL [0] 20.00 17 LIVER MeanDose [Gy] RP3Hal6 13.94 Gy 4.21 5.00 DEAL [5] GOOD [4] ACCEPTABLE [3] MARGINAL [0] 10.00 18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 DEAL [6] GOOD [5] ACCEPTABLE [3] MARGINAL [0] 5.00	DEAL [7]		ACCEPTABLE [5] MARGINAL [0]					0.00
17 LIVER MeanDose [Gy] RP3Hal6 13.94 Gy 4.21 5.00 DEAL [5] GOOD [4] ACCEPTABLE [3] MARGINAL [0] 10.00 18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 DEAL [6] GOOD [5] ACCEPTABLE [3] MARGINAL [0] 5.00	16	SPINAL CORD	Dose at 0.03CC [Gy]	RP3Hal6	31.89 Gy	6.41	7.00	Γ
DEAL [5] GOOD [4] ACCEPTABLE [3] MARGINAL [0] 10.00 18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 DEAL [6] GOOD [5] ACCEPTABLE [3] MARGINAL [0] 5.00	IDEAL [7]		ACCEPTABLE [3] MARGINAL [0]					20.00
18 LIVER Volume at 30Gy [%] RP3Hal6 8.44 % 5.66 6.00 DEAL [6] GOOD [5] ACCEPTABLE [3] MARGINAL [0] 5.00	17	LIVER	MeanDose [Gy]	RP3Hal6	13.94 Gy	4.21	5.00	
DEAL [6] GOOD [5] ACCEPTABLE [3] MARGINAL [0] 5.00	DEAL [5]							10.00
5.00	18	LIVER	Volume at 30Gy [%]	RP3Hal6	8.44 %	5.66	6.00	
19 PTV03Ring Volume at 50.4Gy [CC] RP3Hal6 0.00 CC 4.93 5.00	DEAL [6]		ACCEPTABLE [3] MARGINAL [0]					5.00
	19	PTV03Ring	Volume at 50.4Gy [CC]	RP3Hal6	0.00 CC	4.93	5.00	t

Metric Plot	
0 Volume [%]	95.00
	55.00
0 Variation @ 94%	97.00
-	
0 Variation @ 99%	100.00
5 Variation @ 55.44Gy	56.95
- 1	
5 Variation @ 55.44Gy	56.95
1	
Variation @ 20Gy	21.00
1	
Variation @ 20%	25.00
Variation @ 25%	30.00
Variation @ 40%	50.00
+	
Variation @ 50%	55.00
	+
Variation @ 50Gy	52.00
Variation @ 30Gy	31.00
Variation @ 50%	55.00
Variation @ 45Gy	50.00
Variation @ 30%	40.00
Notes of the	
Variation @ 45Gy	50.00
Variation @ 21Gy	
variation @ 21Gy	25.00
Variation @ 20%	
Variation @ 30%	40.00

Building an individual scoring metric



FLASH therapy is under development and not available for commercial sale.

1. Points assigned for mean dose in Gy

2. Metric points scorecard expressed in qualitative colors

- Orange = 0-8 points
- Dark Green = Full points

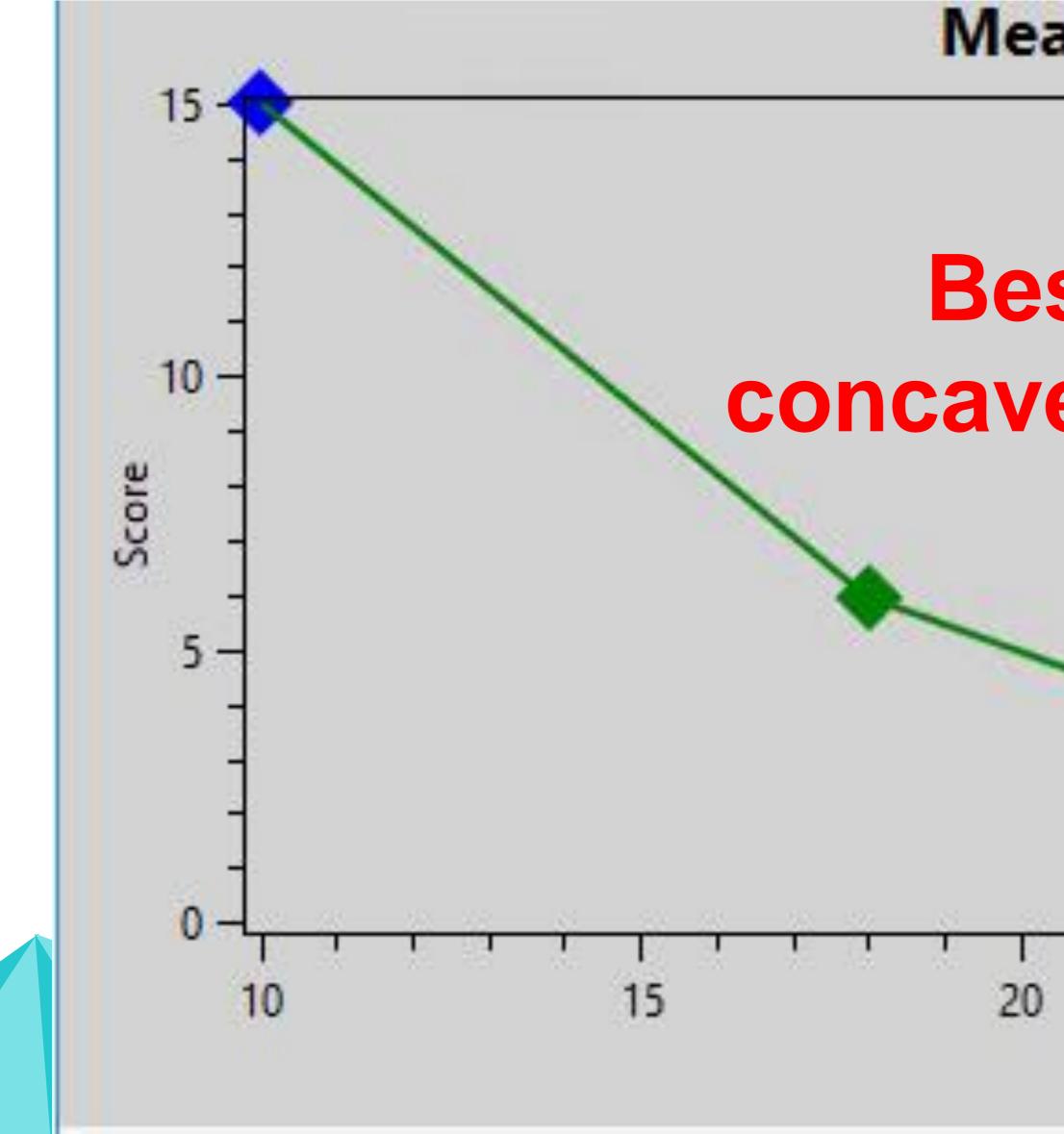
3. Points plotted as a piecewise linear function

Yellow symbolizes variation range

4. Comment box used for referencing protocol



Scoring metrics should not be concave Mean Dose Score



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Best Practice: avoid concave score functions like this

25

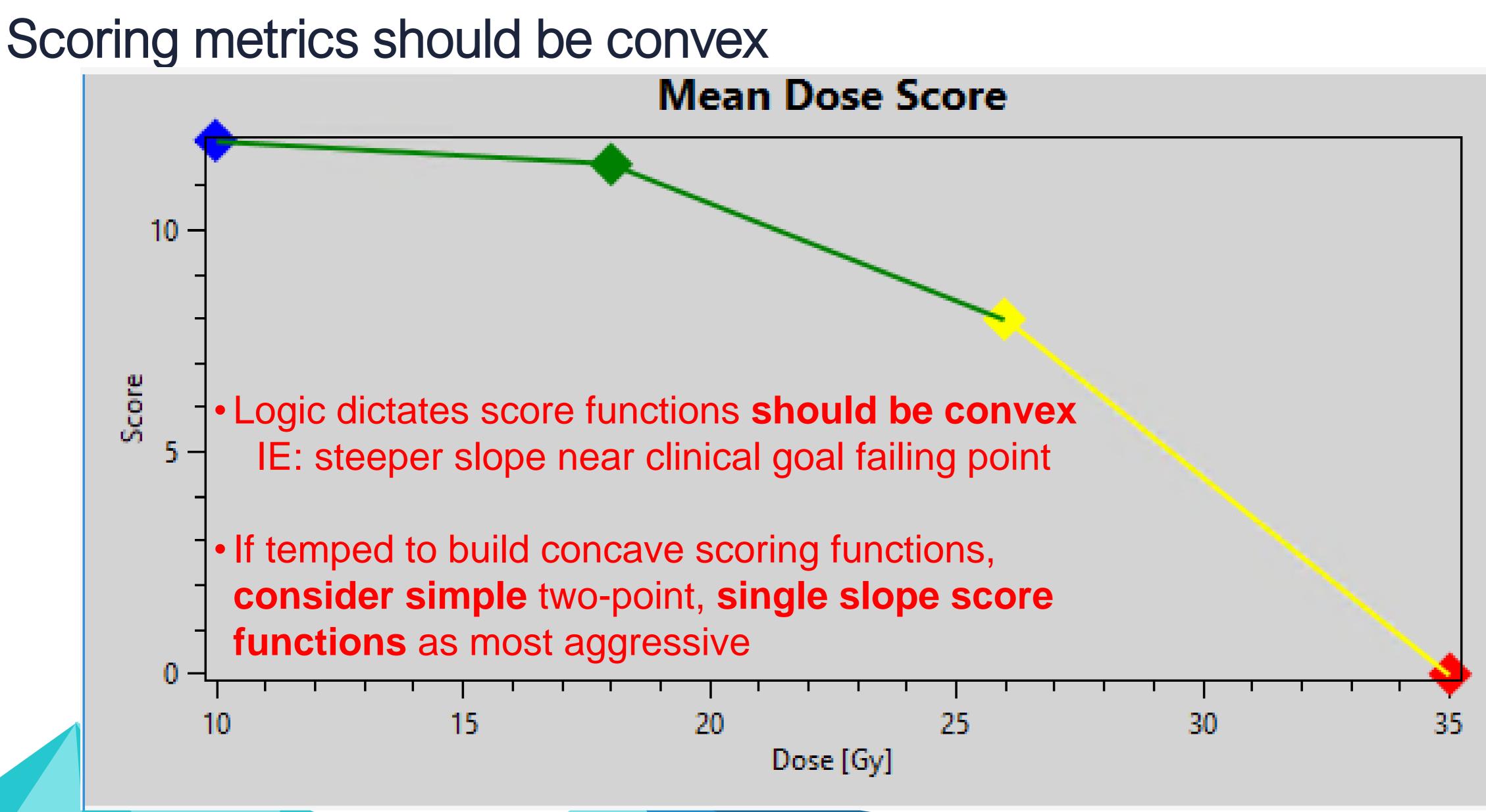
Dose [Gy]



30



35





Scorecard point distribution: Best Practices

- Balance Target metrics (up to 50%)
 - Max/min dose
 - % coverage
 - Homogeneity
 - Conformality
- OAR metrics
 - Volume at Dose
 - Mean dose
 - Dose at Volume (0.03cc)
- Highest points to PTV coverage
- Add multiple dose level rings
- Max is ideal (not achievable)

(10/1	
4		Structure
	1	PTV70OPT
	SUB-OPTIMAL[0]	VARIATION[17]
	3	PTV70OPT
Į	IDEAL[10]	GOOD[9.5]
	47	RingPTV70
	IDEAL[5]	GOOD[4.5]

	34	Mandible-PTV
	IDEAL[2]	GOOD[1.75]
2	29	Lips
	IDEAL[7]	GOOD[6.5]
	37	Esophagus
	IDEAL[3]	GOOD[2.5]
		

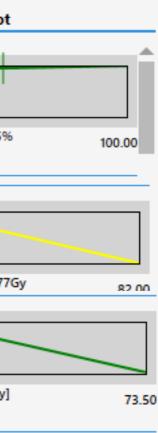
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Target metric examples

Score Metric	Plan Id	Value	Score	Max	Metric Pl	ot
Volume at 70Gy [%]	New HN Model	97.35 %	19.12	20.00		+
IDEAL[20]					93.00 Variation @ 9	5%
Dose at 0.03CC [Gy]	New HN Model	74.33 Gy	8.91	10.00		
SUB-OPTIMAL[0]					71 20 Variation @	770
Dose at 0.03CC [Gy]	New HN Model	71.33 Gy	4.53	5.00	70.00 Dose [0	Gy]
	Score Metric Volume at 70Gy [%] IDEAL[20] Dose at 0.03CC [Gy]	Volume at 70Gy [%] New HN Model IDEAL[20] Dose at 0.03CC [Gy] New HN Model SUB-OPTIMAL[0]	Score MetricPlan IdValueVolume at 70Gy [%]New HN Model97.35 %IDEAL[20]IDEAL[20]Volume at 0.03CC [Gy]New HN ModelDose at 0.03CC [Gy]New HN Model74.33 GySUB-OPTIMAL[0]Volume at 0.03CC [Gy]Volume at 0.03CC [Gy]	Score Metric Plan Id Value Score Volume at 70Gy [%] New HN Model 97.35 % 19.12 IDEAL[20] IDEAL[20] Volume at 0.03CC [Gy] New HN Model 74.33 Gy 8.91 SUB-OPTIMAL[0] SUB-OPTIMAL[0] Value Score Score	Score Metric Plan Id Value Score Max Volume at 70Gy [%] New HN Model 97.35 % 19.12 20.00 IDEAL[20] IDEAL[20] Volume at 0.03CC [Gy] New HN Model 74.33 Gy 8.91 10.00 SUB-OPTIMAL[0] Volume at 0.03CC [Gy] New HN Model 74.33 Gy 8.91 10.00	Score Metric Plan Id Value Score Max Metric Plan Volume at 70Gy [%] New HN Model 97.35 % 19.12 20.00 IDEAL[20] IDEAL[20] 93.00 Variation @ 9 Dose at 0.03CC [Gy] New HN Model 74.33 Gy 8.91 10.00 SUB-OPTIMAL[0] 71.30 Variation @ 71.33 Gy 4.53 5.00

OAR metric examples

VARIATION[0]	Volume at 60Gy [%]	New HN Model	11.26 %	1.80	2.00	0.00	Variation @ 14
VARIATION[5]	MeanDose [Gy]	New HN Model	16.05 Gy	6.19	7.00	10.00	Variation @ 20G
VARIATION[0]	Dose at 0.03CC [Gy]	New HN Model	52.07 Gy	3.00	3.00	56.00	Variation @ 60





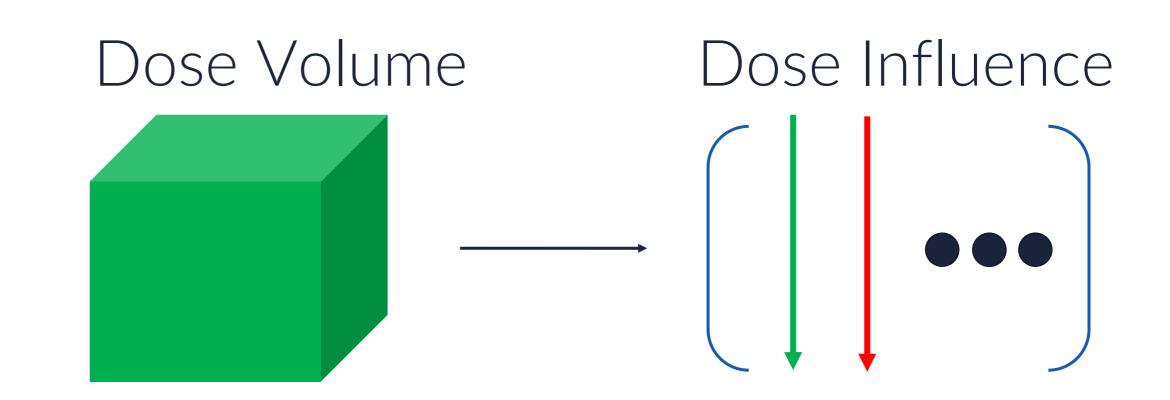


Direct Piecewise Linear Optimization No stretchy quadradic functions: Higher Score = Better Plan

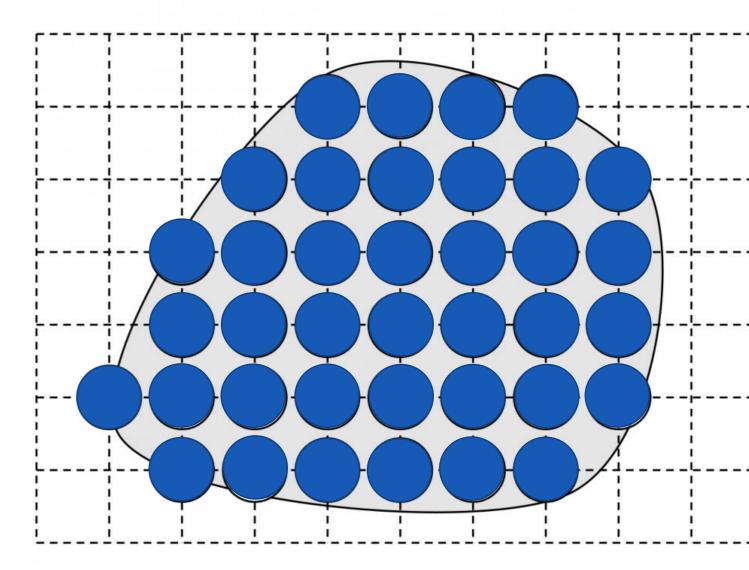
Calculate Dose Influence Matrix

- Turn all but one spot completely off
 - Calculate the final dose
 - Flatten the dose to one dimension
 - Store as a column in 2D array
- Repeat for all spots
- End up with M x N dose influence matrix
 - M is number of pixels in patient volume, N is number of spots
 - Shows contribution of every spot to dose in every pixel

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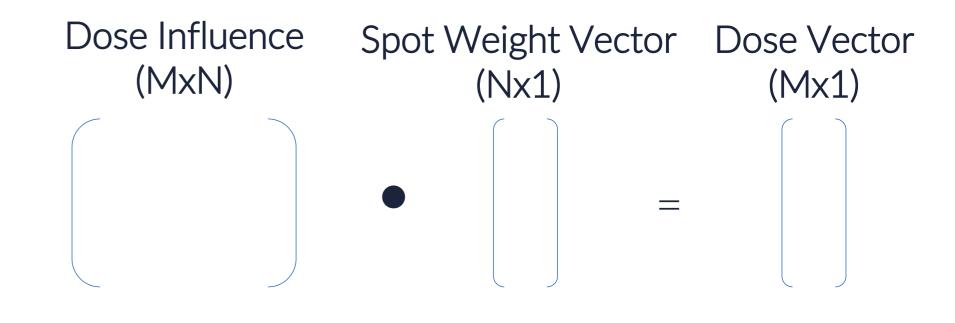
Spot Scanning

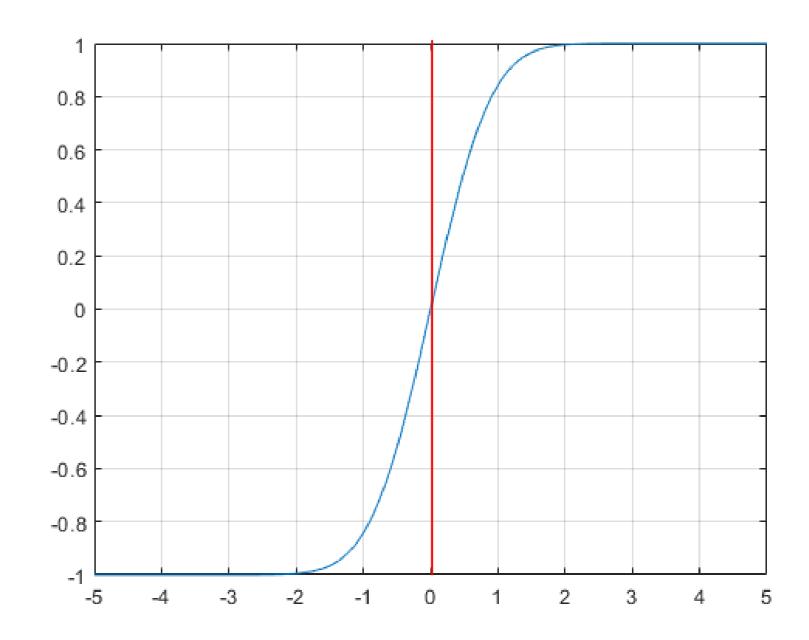


Dose Influence Matrix Optimization

• Simple matrix multiplication to optimize spot weights based on cost function of Dose Vector

- Optimizable VaD and DaV objectives
- Penalizes pixels with dose above threshold
 - Uses smoothed step function
- Essentially analyzes one point/area on DVH
 - Depends on inputs to the smoothing function



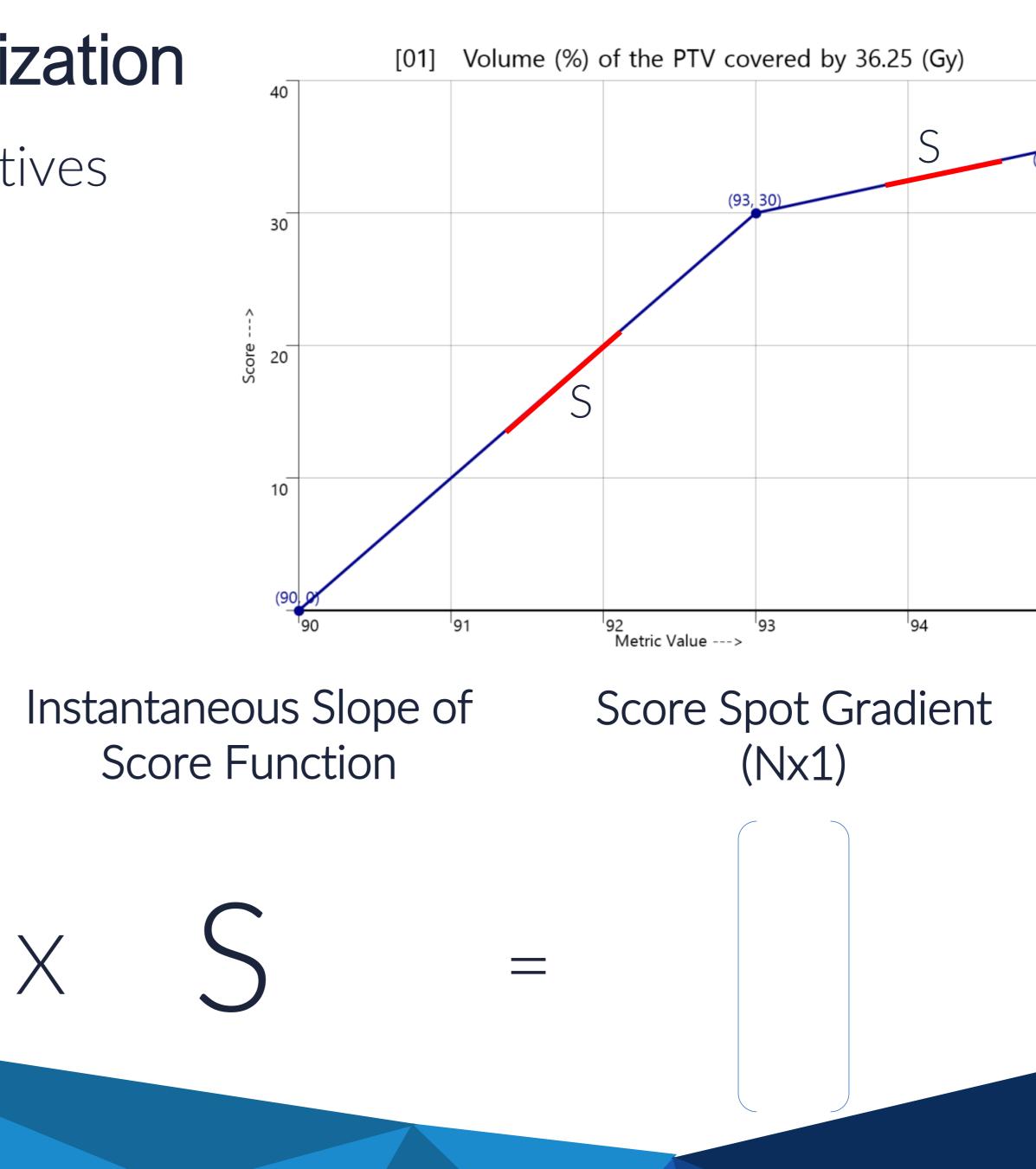


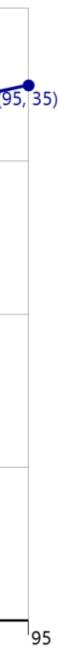
Piecewise linear slopes drive optimization

• Add up costs and gradients from all objectives and optimize

•	For	each	pixel:	ΔVaD
	I UI	Cach	piaci.	∆Dose
•	For	onch	cnot.	ΔVaD
	I UI	Calli	spot:	ΔSpot
	For	onch	cnot.	ΔScore
•	IUI	Call	σροι.	$\frac{\Delta Score}{\Delta Spot}$

[VaD Dose Gradient][⊤] (1xM) Dose Influence (MxN)

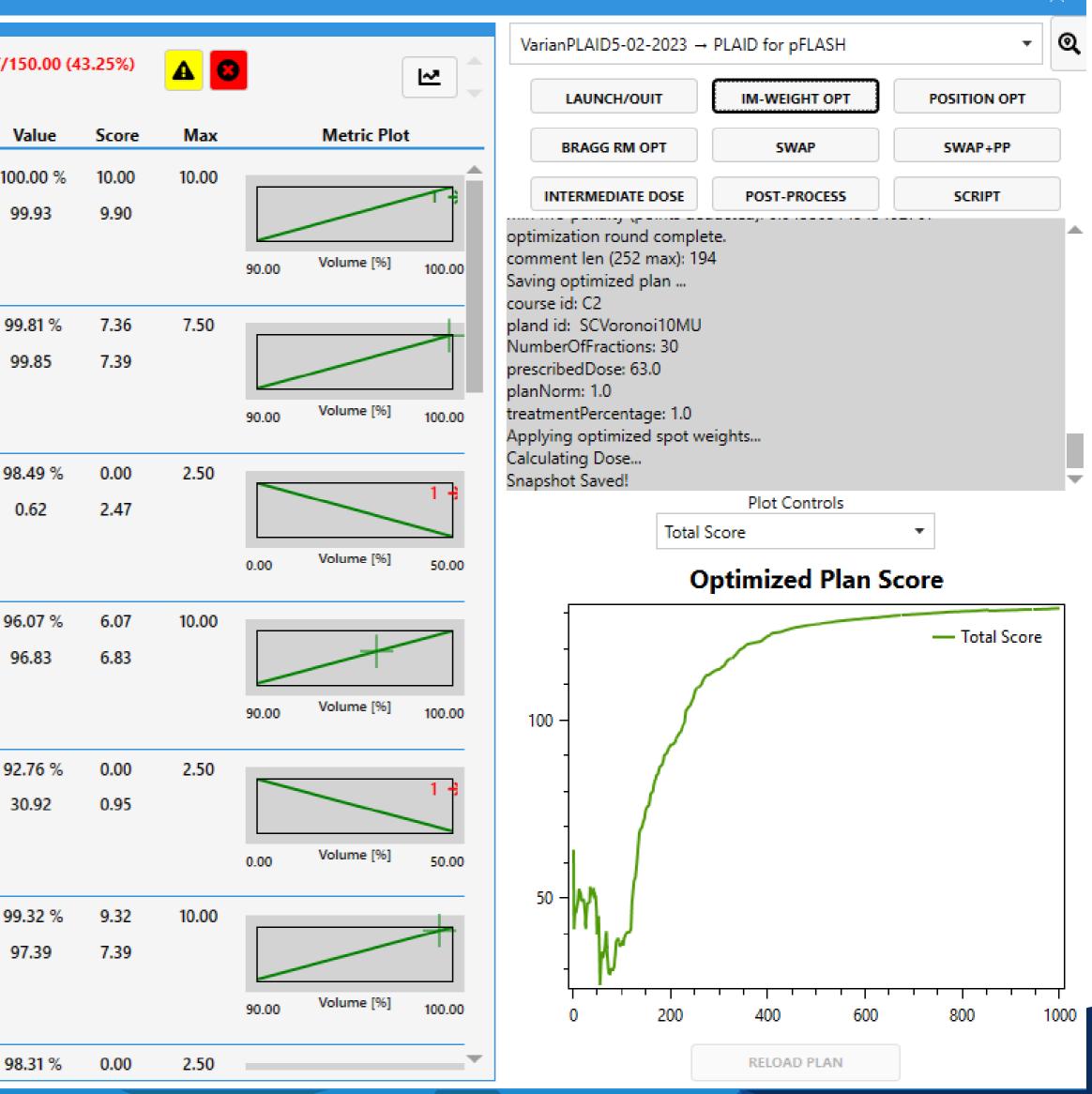


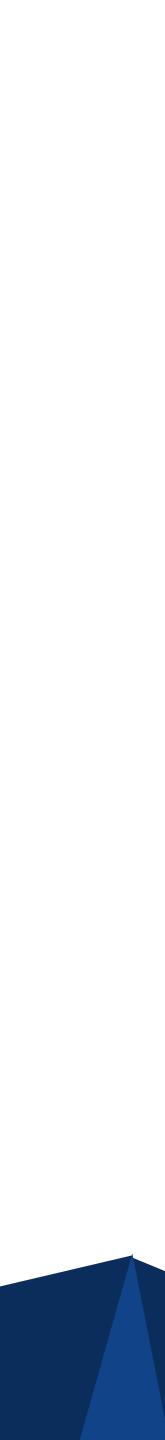


ScoreCard Based Optimization Direct optimization on piecewise linear DVH based score function ranges

PLAN SCORECARD **NOT VALIDATED FOR CLINICAL USE**

SCORE CARD SELECTION Score Card ID Plan Rx matches scorecard.	Plan Sco	res: AAM	D2023PLANSTUDY: [C2] V	oronoi10MU: 64.	87/
SC_HeadAndNeck-AAMD2023_PlanStud	ld	Structure	Score Metric	Plan Id	
PLAN SELECTION	1	PTV63	Volume at 63Gy [%]	Voronoi10MU Voronoi10MU	1(
Patient ID	MARGINAL	L[0] IDEA	L[10]		
AAMD2023PLANSTUDY					
Patient Course Plan	2	PTV60	Volume at 60Gy [%]	Voronoi10MU	9
AAMD2023PLANSTUDY C2 'oronoi10Ml				Voronoi10MU	
	MARGINAI	L[0] IDEAI	L[7.5]		
	3	PTV60	Volume at 63Gy [%]	Voronoi10MU	9
				Voronoi10MU	
	IDEAL[2.5]	MAR	GINAL[0]		
	4	PTV57	Volume at 57Gy [%]	Voronoi10MU	9
				Voronoi10MU	
	IDEAL[0]	IDEA	L[10]		
	5	 PTV57	Volume at 59.85Gy [%]	Voronoi10MU	9
				Voronoi10MU	
	IDEAL[2.5]	IDEA	L[0]		
	6	PTV54	Volume at 54Gy [%]	Voronoi10MU	9
				Voronoi10MU	
Norm	MARGINAI	L[0] IDEA	L[10]		
Bound by the terms of the VarianLUSLA	7	PTV54	Volume at 56.7Gv [%]	Voronoi10MU	9





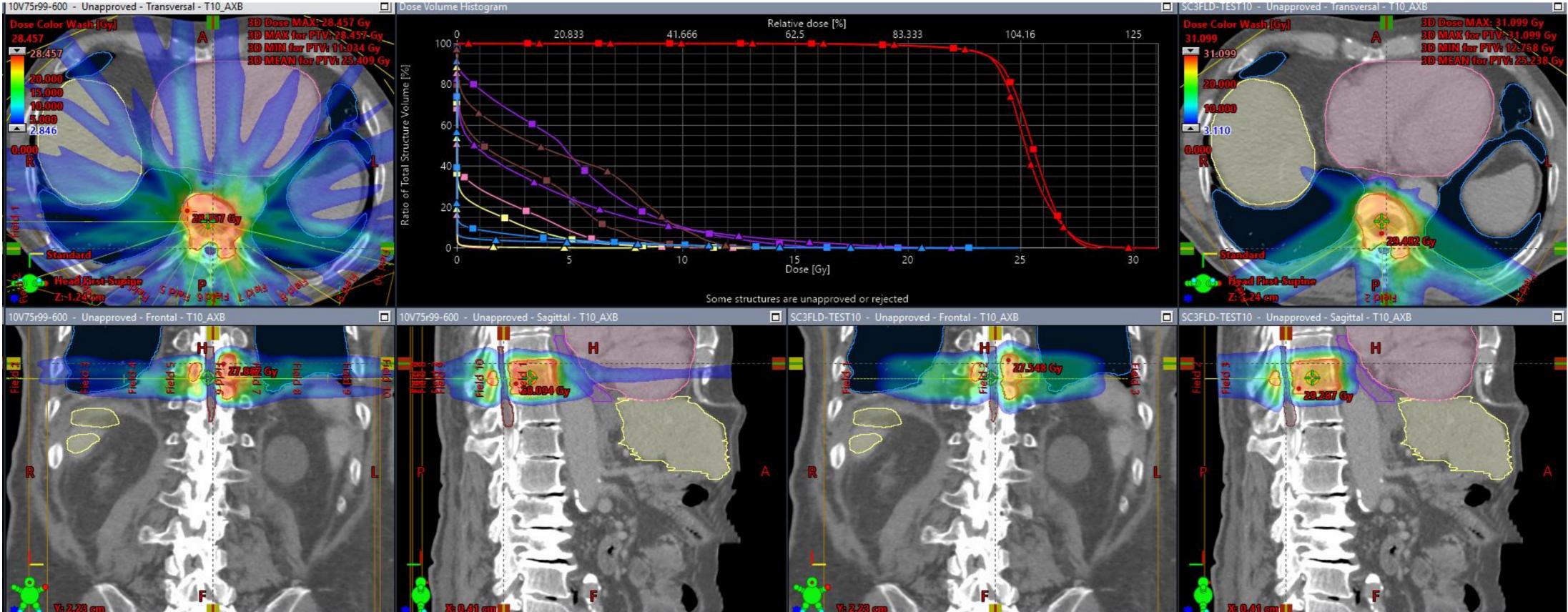


Spine Dosimetric & Doserate Result

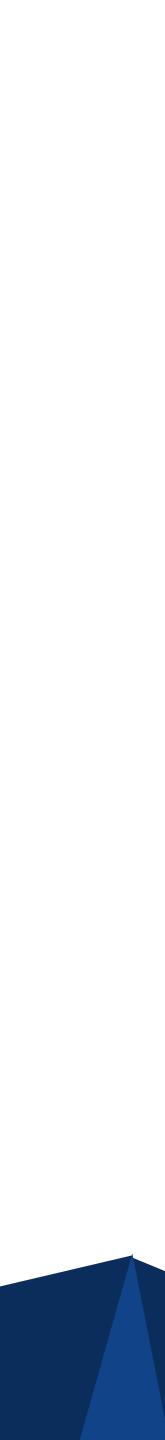
FLASH compared to IMPT standard of care via Scorecard Optimization



SBRT spine 24Gy 1fx 10 field transmission flash vs. 3 field IMPT



ow DVH 🛛 Structure	Approval Status	Plan	Course	Volume [cm ³]	Dose Cover.[%]	Sampling Cover.[%]	Min Dose [Gy]	Max Dose [Gy]	Mean Dose [Gy]
SpinalCord	Unapproved	10V75r99-600	FlashST-SCtest9	2.6	A REAL PROPERTY AND A REAL			11.329	
SpinalCord	Unapproved	SC3FLD-TEST10	N-Opt	2.6	100.0	101.9	0.000	13.212	4.405 💌
PTV	Unapproved	10V75r99-600	FlashST-SCtest9	55.7	100.0	100.0	11.034	28.457	25.409 💌
PTV	Unapproved	SC3FLD-TEST10	N-Opt	55.7	100.0	100.0	12.758	31.099	25.238
Lungs	Unapproved	10V75r99-600	FlashST-SCtest9	3045.2	100.0	100.0	0.000	24.948	0.521 💌
Lungs	Unapproved	SC3FLD-TEST10	N-Opt	3045.2	100.0	100.0	0.000	23.441	0.323 💌
Liver	Unapproved	10V75r99-600	FlashST-SCtest9	1914.6	100.0	100.0	0.000	14.312	0.773 💌
Liver	Unapproved	SC3FLD-TEST10	N-Opt	1914.6	100.0	100.0	0.000	8.037	0.024 💌
Heart	Unapproved	10V75r99-600	FlashST-SCtest9	947.0	100.0	100.0	0.000	12.768	1.196 💌
Heart	Unapproved	SC3FLD-TEST10	N-Opt	947.0	100.0	100.0	0.000	1.854	0.009 👻
Esophagus	Unapproved	10V75r99-600	FlashST-SCtest9	12.7	100.0	100.3	0.000	18.810	4.780 💌
Esophagus	Unapproved	SC3FLD-TEST10	N-Opt	12.7	100.0	100.3	0.000	22.466	3.126 💌 🗙



SBRT spine 24Gy 1fx 10 field transmission flash vs. 3 field IMPT

Plan Scores: [N-Opt] 10V75r99-600p: 277.31/310.00 (89.45%) [N-Opt] SC3FLD-TEST9: 257.38/310.00 (83.02%) Score Metric Structure Plan Id Id CTVEVAL Dose at 99.9% [Gy] 10V75r99-6 SC3FLD-TE 2 PTVEVAL Volume at 24Gy [%] 10V75r99-6 SC3FLD-TE PTVEVAL Dose at 0.035CC [Gy] 10V75r99-6 SC3FLD-TE Dose at 0.35CC [Gy] 10V75r99-6 18 SpinalCord SC3FLD-TE 24 10V75r99-6 Heart Dose at 0.035CC [Gy] SC3FLD-TE Dose at 99.9% [Gy] CTV 10V75r99 8 SC3FLD-FLASH therapy is under development and notvavailable for commercial sale. 10V75r99

Scorecard metrics (5 of 33 total)

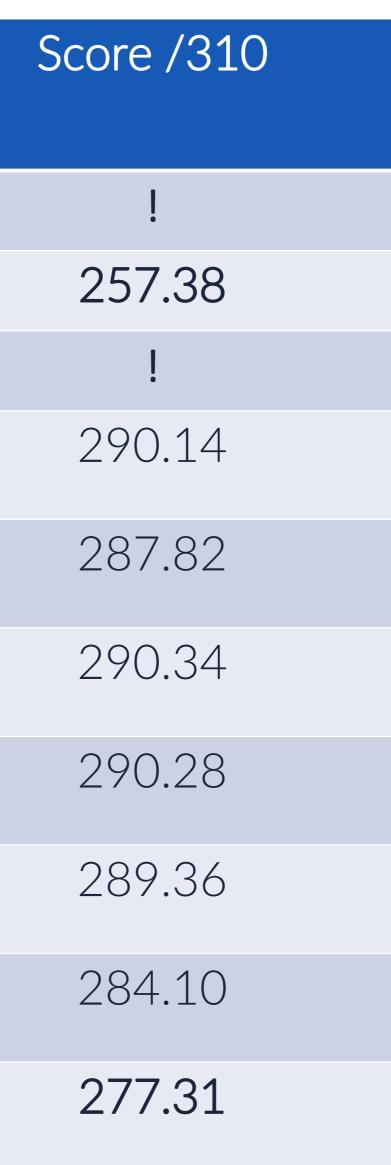
ł	Value		Score	Max	Metric Plot
600p	22.10 Gy		23.42	25.00	
EST9	22.34 Gy		23.62	Score Stats Max=23.62 Mean=23.52 Min=23.42	19.20 Dose [Gy]
600p	88.58 %		12.86	20.00	
EST9	89.99 %		14.98	Score Stats Max=14.98 Mean=13.92	Variation @ 90%
				Min=12.86	80.00 Variation @ 50%
600p	28.80 Gy		13.00	15.00	
EST9	30.25 Gy		5.15	Score Stats Max=13.00	
				Mean=9.07 Min=15.10	27.12 Dose [Gy]
600p	6.19 Gy		15.81	17.00	
EST9	9.29 Gy		3.55	Score Stats Max=15.81	
				Mean=9.68 Min=3.55	5.00 Dose [Gy]
600p	11.76 Gy		6.80	8.00	
EST9	1.44 Gy		7.91	Score Stats Max=7.91	
			Min=7.26	Mean=7.35	0.00 Variation @ 16Gy 50.00
99-600p	19.44 Gy	1.00	1.00		2 >
D-TEST9	20.43 Gy	1.00	Score Stats Max=1.00 Mean=1.00 Min=1.00	15.00 Varia	ation @ 16Gy 16.00
99-600p	86.80 %	0.68	1.00		



SBRT spine 24Gy 1fx 10 field transmission flash vs. 3 field IMPT vs. failed options and non-FLASH

Number of fields	Min MU score assigned	Min MU target	
2 (ML-IMPT)	0	_	
3 (ML-IMPT)	0	_	
5 (250MeV)	0	_	
10 (250MeV)	0	_	
10 (250MeV)	40	150	
10 (250MeV)	40	300	
10 (250MeV)	40	450	
10 (250MeV)	80	450	
10 (250MeV)	r99	600	
10 (250MeV)	r99*	600	

FLASH therapy is under development and not available for commercial sale.



PTCOG 2022 Poster:

A novel IMPT optimization method enforcing a minimum spot MU per energy layer for FLASH

P. Lansonneur*, T. Leinonen, M. Ropo, L. Rosa, A. Magliari, M. Folkerts

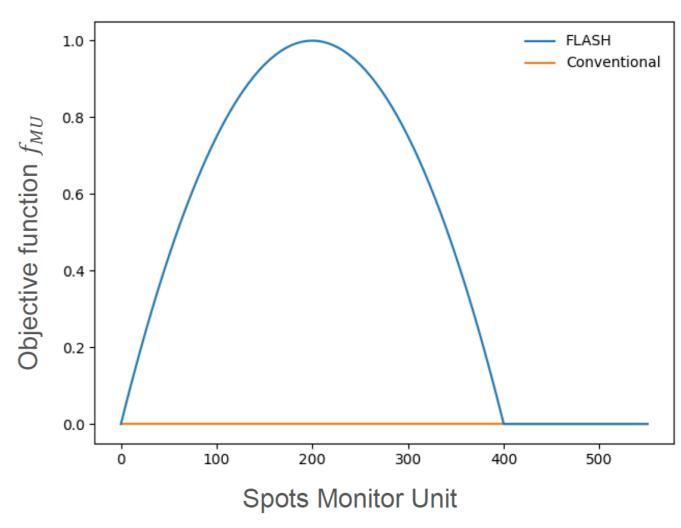
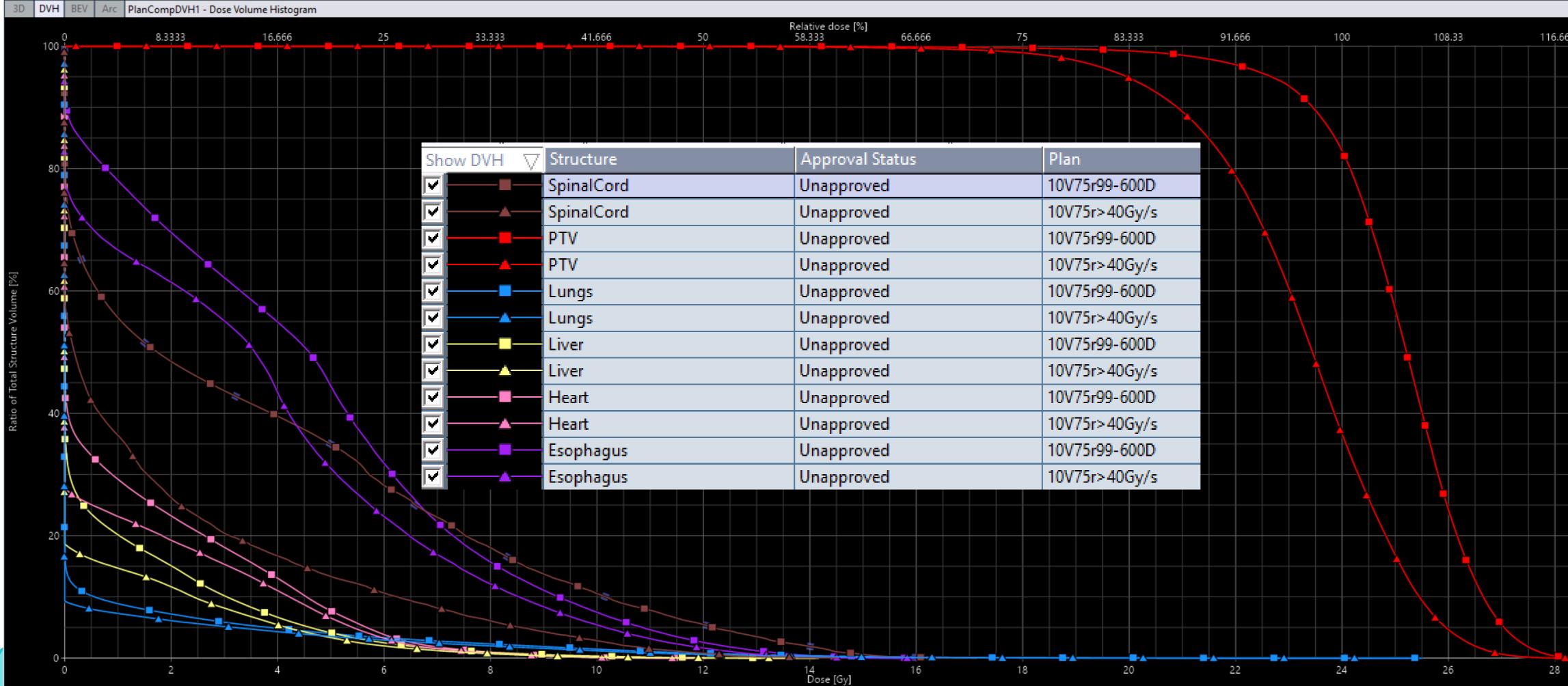


Fig. 1. Example of a minimum MU objective function, for a minimum MU $MU_{min} = 400$. Spots MUs above 200 tend to get increased to 400 while spots MUs below 200 tend to get reduced to zero and removed.

SBRT spine 24Gy 1fx PBS Dose Rate analysis: Minimum MU=600 (Dose Rate Threshold DVH >40Gy/sec)



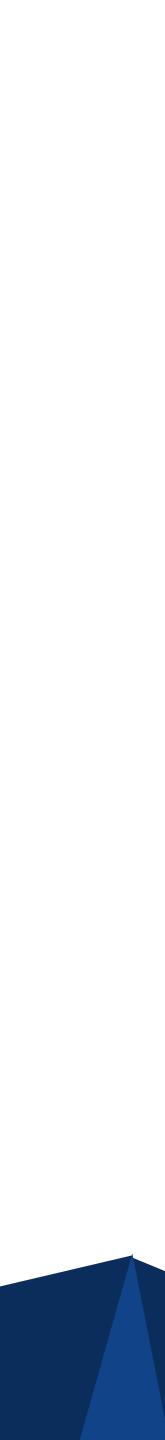
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Scorecard Utility Dosimetric Scorecards have great potential

- Current uses
 - Scoring treatment planning competitions
 - Quantifying dosimetric quality improvements of various techniques
 - energies, collimation devices, modalities, field arrangements
 - Tuning the inputs to common automated quadratic DVH point optimizers
 - RapidPlan and Ethos
 - Guiding manual treatment planning, even for novices
- Future uses
 - Published prospectively with popular trials to reduce variability for manual plans
- Dosimetric Scorecard evaluation tools have high availability
 - Varian MAAS GitHub, Elekta ProKnow, Sun Nuclear PlanIQ, etc.

FLASH therapy is under development and not available for commercial sale.

• Directly input to dose optimizers so only variability is technical limitation of hardware



Thank you!

Special Thanks to:

- Michael Folkerts
- Pierre Lansonneur
- Jessica Perez
- Miriam Krieger
- Lesley Rosa
- Alexander Katsis



