The relationship between treatment plan complexity and dosimetry quality: An analysis of three stereotactic treatment planning challenges

Nicholas Hardcastle[1,2,3], Mathieu Gaudreault[1,2], Alisha Moore[4], Benjamin E Nelms[5], Jordi Saez[6], Victor Hernandez[7]

1. Physical Sciences, Peter MacCallum Cancer Centre, Melbourne, Australia
2. Sir Peter MacCallum Department of Oncology, University of Melbourne, Melbourne, Australia
3. Centre for Medical Radiation Physics, University of Wollongong, Wollongong, Australia
4. Trans Tasman Radiation Oncology Group, Newcastle, Australia
5. Canis Lupus LLC, Merrimac, USA
6. Department of Radiation Oncology, Hospital Clínic de Barcelona, Barcelona, Spain
7. Department of Medical Physics, Hospital Sant Joan de Reus, IISPV, Tarragona, Spain

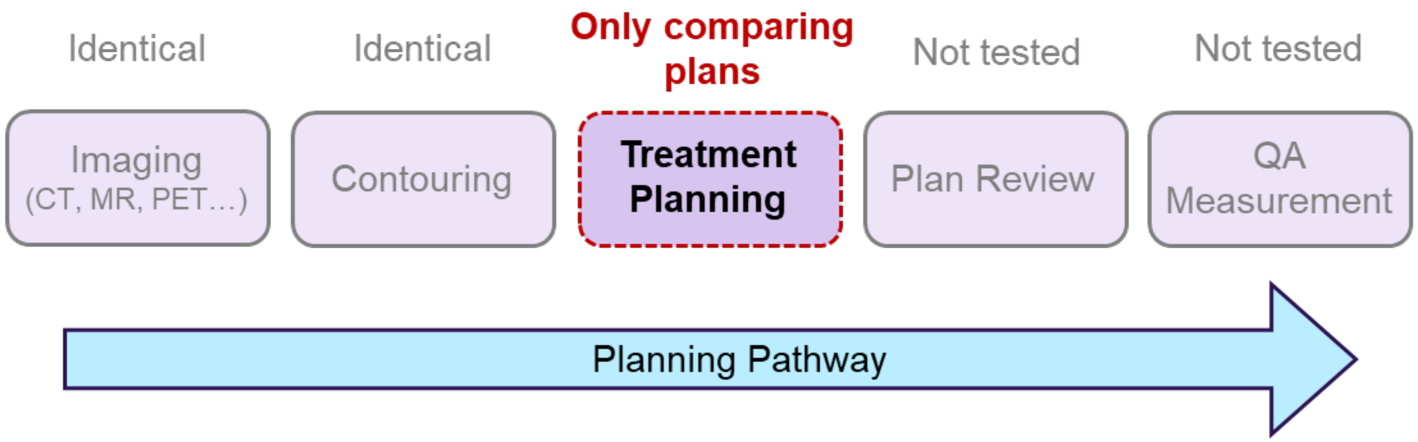
Disclosures

Our research group receives research funding from Varian Medical Systems for unrelated work

I am a paid consultant of SeeTreat Medical

Radiation therapy treatment planning challenges

- Participants are provided with a treatment planning image, with structures, for a given clinical scenario
- Participants generate their best possible plan based on a pre-defined dosimetry scoring matrix

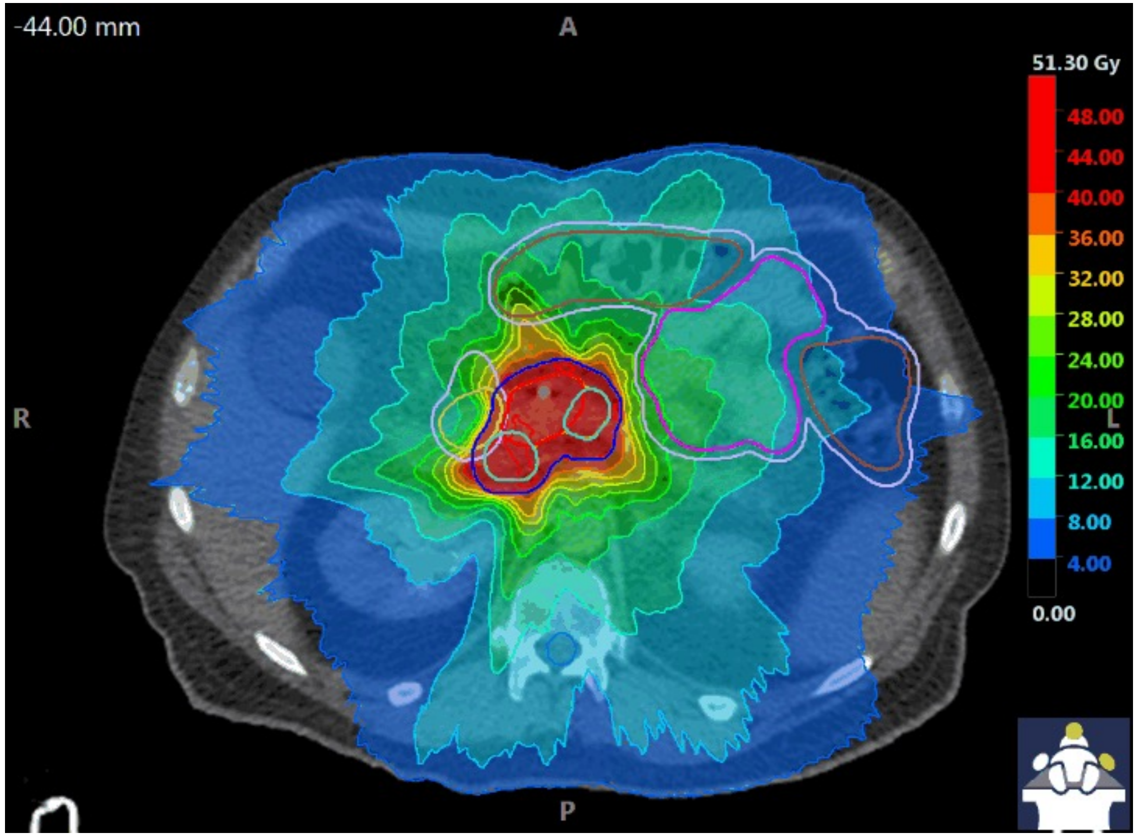


- Treatment planning challenges can be used to quantify variations in dosimetric quality based on technology, software and staff background/training [1, 2, 3]

- Treatment planning challenges can serve as an education tool for a new clinical trials with novel treatment planning scenarios

1. Nelms, B.E., et al., Pract Radiat Oncol, **2** 2012
2. Hardcastle, N., et al., Med Dosim, **45** 2020
3. Moghanaki, D.B., et al., Pract Radiat Oncol, **10** 2020

Radiation therapy treatment planning challenges

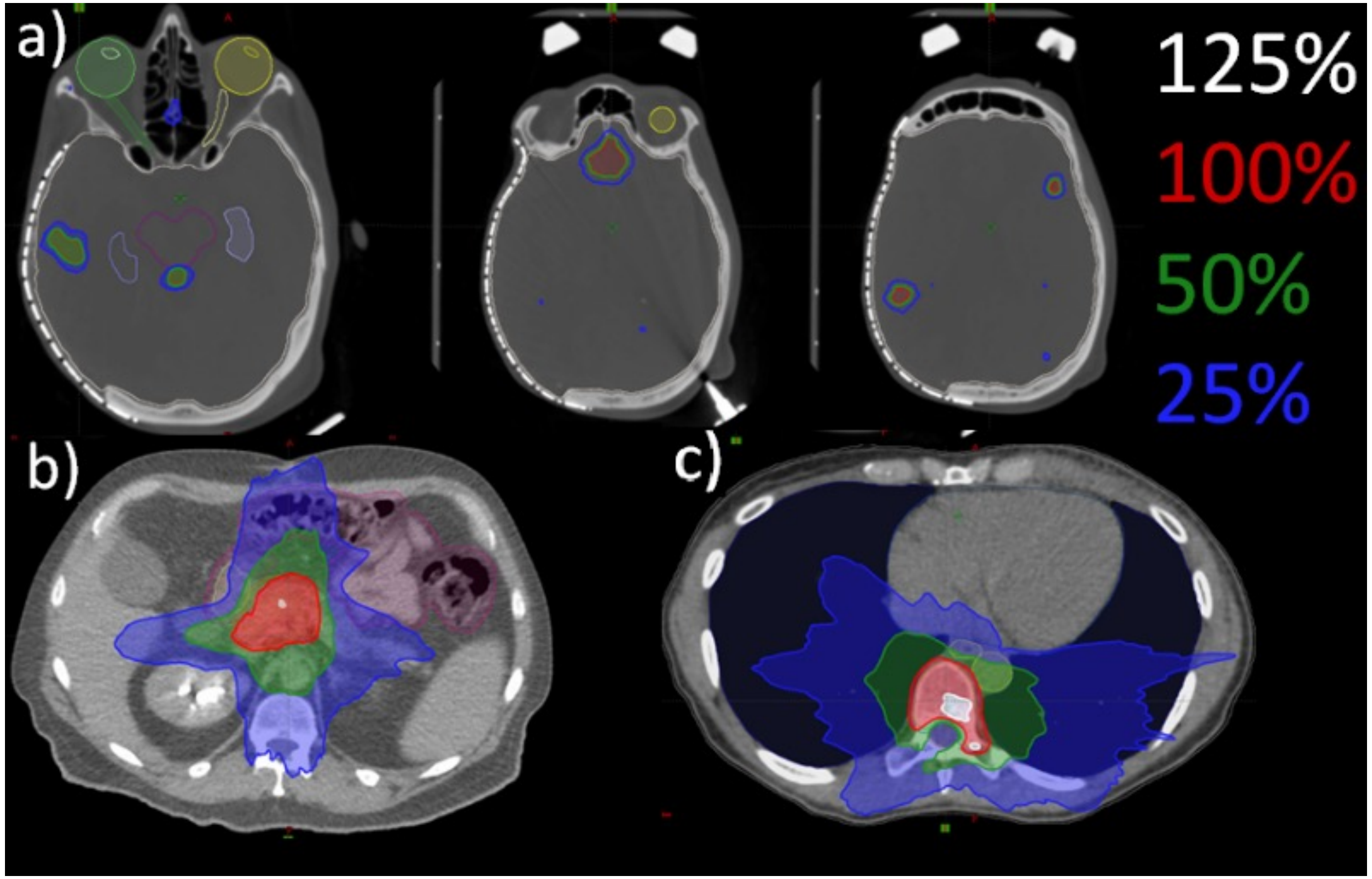


- Planning challenges often provide treatment plans of high dosimetric quality:
  - prescription dose to the target volumes in a highly conformal manner
  - Very low dose to adjacent critical structures.
- These plans may be highly complex:
  - complicated beam geometry
  - small or complicated beam apertures
  - large variations in dose rate and gantry speed
- Modulation complexity may increase uncertainty in delivered dose:
  - Dose calculation accuracy[1, 2]
  - Robustness to intra/inter fraction changes[3, 4, 5]

1. Younge, K.C., et. al. J Appl Clin Med Phys **17** 2016
2. Park, J.M., et. al. J Appl Clin Med Phys **20** 2019
3. May L. et. al. Med. Phys. **51** 2024
4. May L. et. al. EJMP. **124** 2024
5. Burton A. et. al. Phys. Med. **121** 2024

Aim: To evaluate the relationships between treatment plan complexity metrics and dosimetry quality in three stereotactic treatment planning challenges

Methods: Planning challenge data sets



DICOM RTPLAN and dosimetry scoring data available from three TROG stereotactic planning challenges

Limited to VMAT only

a) Multi-met SRS[1]: 20 Gy in 1 fraction
113 plans, 101 (89%) of which are VMAT

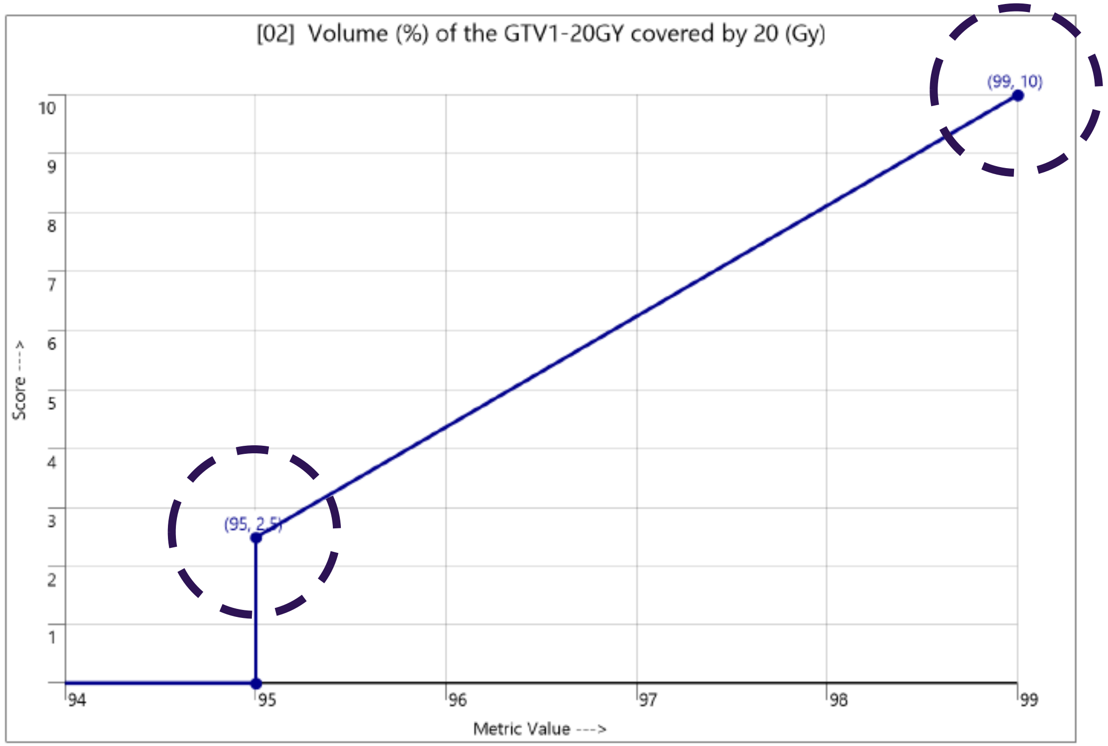
b) Pancreas SBRT: 40 Gy in 5 fractions
150 plans, 134 (90%) of which are VMAT

c) Vertebral SBRT[2]: 20 Gy in 1 fraction
137 plans, 121 (88%) of which are VMAT

1. Hardcastle N. et. al. Radiother. Oncol. **133** 2019
2. Hardcastle N. et. al. Med. Dosim. **45** 2020

Methods: Scoring matrices

Progressive scoring concept



Target dosimetry

#	METRIC	WEIGHT
1	Structure(s) not fully covered by dose grid	---
2	Volume (%) of the GTV1-5 covered by 20 (Gy)	50
7	Conformation Number [20 (Gy), GTV-TOTAL]	10
8	Conformality Index [20 (Gy), GTV-TOTAL]	2.5
9	Conformality Index [10 (Gy), GTV-TOTAL]	7.5
10	Maximum dose (Gy) to the GTV 1-5	---
15	Maximum dose (Gy) to the BODY	2

Organ at risk dosimetry

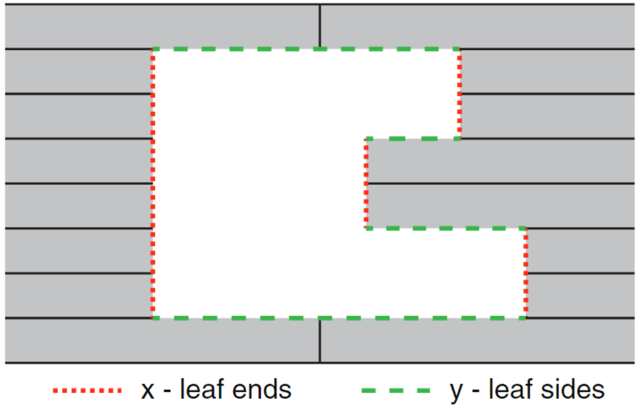
#	METRIC	WEIGHT
16	Structure(s) containing the global max dose point	10
17	Dose (Gy) covering 0.3 (cc) of the BRAINSTEM	10
18	Volume (cc) of the NORMAL BRAIN covered by 10 (Gy)	10
19	Volume (cc) of the NORMAL BRAIN covered by 12 (Gy)	10
20	Volume (cc) of the OPTIC CHIASM covered by 8 (Gy)	5
21	Maximum dose (Gy) to the OPTIC CHIASM	5
22	Volume (cc) of the OPTICNERVE_L covered by 8 (Gy)	5
23	Volume (cc) of the OPTICNERVE_R covered by 8 (Gy)	5
24	Mean dose (Gy) to the HIPPOCAMPUS_L	5
25	Mean dose (Gy) to the HIPPOCAMPUS_R	5
26	Maximum dose (Gy) to the LENS_L	2
27	Maximum dose (Gy) to the LENS_R	2
28	Maximum dose (Gy) to the EYE_L	2
29	Maximum dose (Gy) to the EYE_R	2

Methods: Complexity calculation

Edge Metric (EM) [1]:

$$M = \sum_{i=1}^{N} W_i \times \frac{C_1 x_i + C_2 y_i}{A_i}$$

A_i is the aperture area, and W_i the aperture weight of aperture *i*



Total modulation index (MI_t) [2]:

$$\text{MLC accel}_i = \frac{|\text{MLC speed}_i - \text{MLC speed}}{\text{Time}_i}$$

$$\text{GA}_i = \left| \frac{\Delta\text{Gantry angle}_i}{\text{Time}_i} - \frac{\Delta\text{Gantry angle}_{i+1}}{\text{Time}_{i+1}} \right|$$

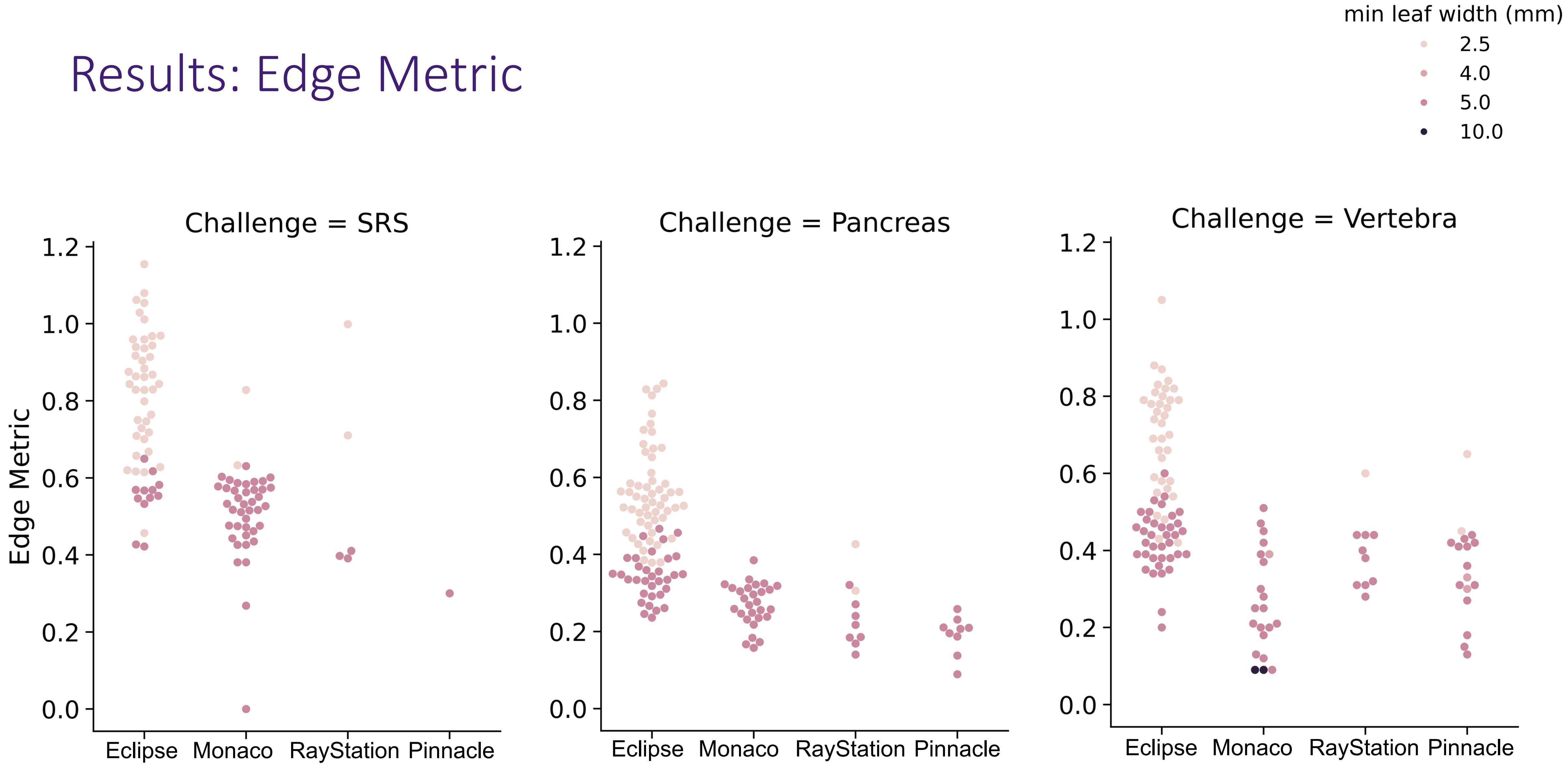
$$\text{MLC speed}_i = \frac{|\text{MLC}_i - \text{MLC}_{i+1}|}{\text{Time}_i},$$

$$\text{DRV}_i = |\text{DR}_i - \text{DR}_{i+1}|.$$

- Complexity metrics were calculated with in-house code developed in Matlab[3]
- Complexity metric values were compared between different TPS using the two-sample Kolmogorov-Smirnov test
- The relationship between plan dosimetry score and plan complexity was assessed using the Spearman correlation coefficient

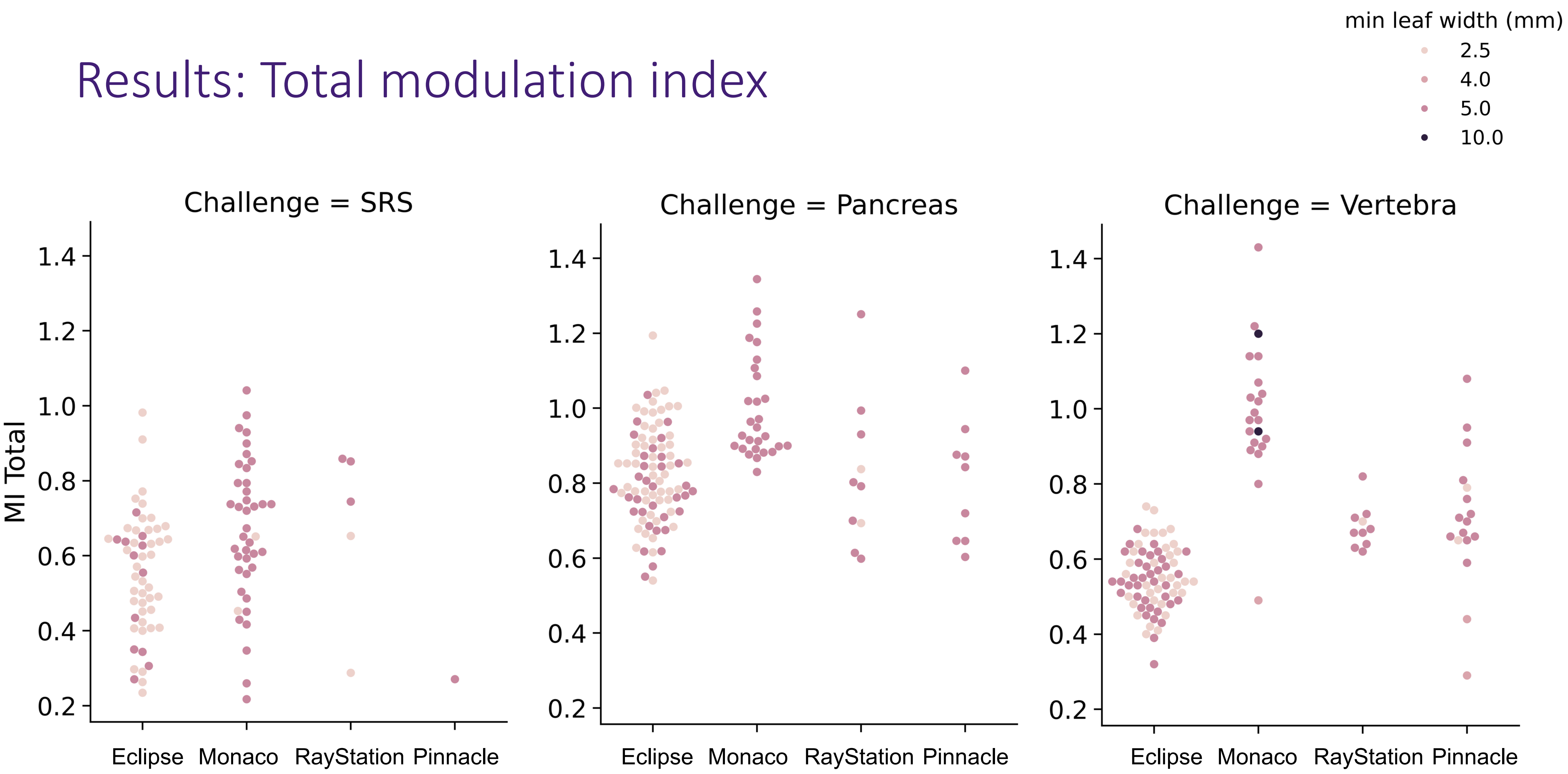
1. Younge, K.C. et. al. Med Phys **39** 2012
2. Park, J.M. Et. al. Phys Med Biol **59** 2014
3. Hernandez, V., et. al. PhIRO **5** 2018

Results: Edge Metric



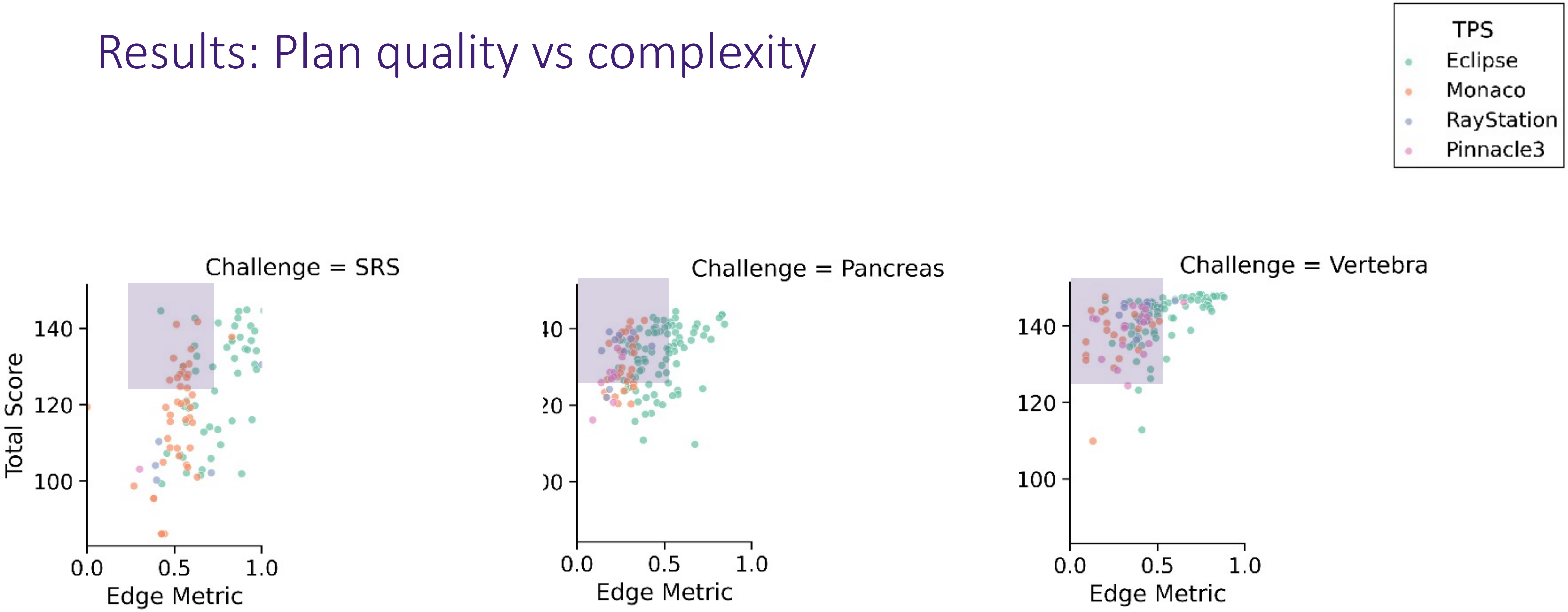
Higher value is more complex

Results: Total modulation index



Higher value is more complex

Results: Plan quality vs complexity



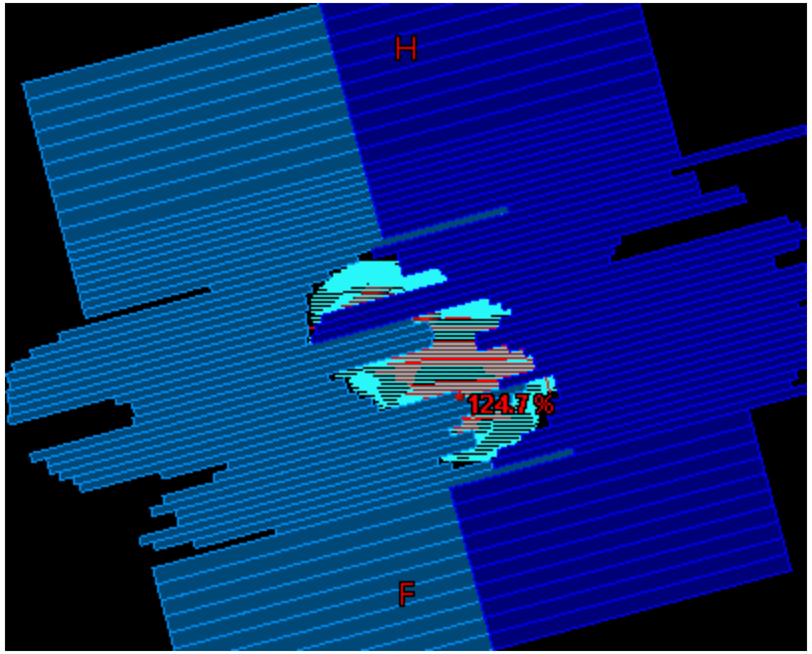
r = 0.48
p < 0.005

r = 0.38
p < 0.005

r = 0.59
p < 0.005

Discussion and conclusion

- Plan complexity is controlled differently depending on the TPS: aperture modulation vs gantry speed and dose rate modulation
- Aperture complexity was associated with high plan score, but was not a necessity for a high scoring plan
- Plan complexity taking into account aperture, gantry and dose rate was not associated with improved dosimetric scores
- Dosimetric improvement must be balanced against the pitfalls of increased complexity
- Plan complexity should however not be prioritised over dosimetric quality; in many cases some complexity is expected and necessary to ensure high quality dosimetry
- It remains a challenge to determine the optimal trade-off between these two components for routine treatment plan optimization. This is likely vendor specific



nick.hardcastle@petermac.org