Biological Plan Evaluation for Linac-based Stereotactic Radiosurgery: Comparison between Single-isocenter and Multiple-isocenter Techniques

HOUSTON Methodist LEADING MEDICINE

國立清華大學 NATIONAL TSING HUA UNIVERSITY

NTHU MP Lab

JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING EASTERN TIME [GMT-4]

MC Lee[1], HC Wang[2] and HY Tsai[1*]

[1]Institute of Nuclear Engineering and Science, National Tsing Hua University, Hsinchu, Taiwan

[2]Department of Radiation Oncology, Houston Methodist Hospital, Houston, USA

*huiyutsai@mx.nthu.edu.tw

INTRODUCTION

Volumetric modulated arc therapy (VMAT) is commonly employed for SRS treatment delivery. Especially the single isocenter techniques were introduced to multiple intracranial lesions for reducing the treatment time in recent years.

The plan quality indices of single isocenter (SI) compared to multiple isocenter (MI) have been proposed[1], however, there has some potential biological effects in single isocenter.

PURPOSE

- To compare the impact of biological effects between multiple-isocenter and single-isocenter treatment plans of SRS.
- We refer to the score formula published by Sánchez-Nieto[2] that could quickly assess the biological effects of two plans.
- We established the biological evaluation program for SRS plans that combined secondary cancer risk assessment and biological models.

METHOD

- All plans were created and exported by Varian Eclipse (Varian Medical Systems, Palo Alto, CA) treatment planning system.
- An in-house MATLAB program imported DICOM and DICOM RT files form TPS.
- Calculate the plan quality indices[3] : Paddick conformity index (CI) 、 Paddick gradient index (GI) 、 V_{12Gy} and V_{5Gy}
- Biological plan evaluation : TCP 、 NTCP and secondary cancer risk which dose relationship proposed by Schneider[4]. All parameter were recorded in reference[5].

TCP

Consider multi-type brain metastasis cell

$$TCP = \prod_{i=1}^{N}\left\{\frac{exp[(D_i - TCD_{50})/k]}{1 + exp[(D_i - TCD_{50})/k]}\right\}^{v_i}$$

NTCP

LKB NTCP Model

$$NTCP = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{t} e^{\frac{-x^2}{2}}dx$$

$$t = \frac{D_{eff} - TD_{50}}{mTD_{50}} \qquad D_{eff} = \left(\sum_i v_i D_i^{1/n}\right)^n$$

Normal tissue	Endpoint
Brain	Necrosis/infarction
Cerebellum	Necrosis/infarction
Brainstem	Cranial neuropathy
Pituitary	Endocrine dysfunction
Hypothalamus	Endocrine dysfunction
Optic nerves	Blindness
Chiasm	Blindness
Cochlea	Tinnitus ≥ grade 2
Eye	Retinopathy

Risk

Secondary Cancer Risk Model

- Schneider et al.

$$RED(D_i) = \frac{e^{-\alpha' D_i}}{\alpha' R}\left(1 - 2R + R^2 e^{\alpha' D_i} - (1-R)^2 e^{-\left(\frac{\alpha' R}{1-R}\right)D_i}\right)$$

- BEIR VII

$$EAR^{org}(D_i, e, a, s) = \varepsilon \times OED(D_i) \times \mu(e, a) \times s$$

$$LAR^{org} = \int_{e+l}^{Ls} EAR^{org}(D_i, e, a, s) \times \frac{s(a)}{a(e)}da$$

RESULTS

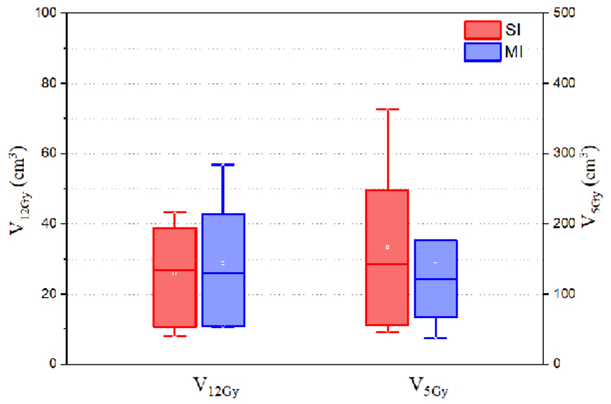
- *Case table*

Case #	Gender	Age (yrs)	# of lesions	Lesions size (cm3)	Prescribed Dose (Gy)
1	M	57	4	1.41-4.45	20
2	M	70	9	0.6-3.05	18
3	M	80	3	2.39-10.91	18
4	F	61	2	0.7-2.48	20
5	F	59	5	0.2-1.17	20
6	M	66	6	0.12-0.27	20

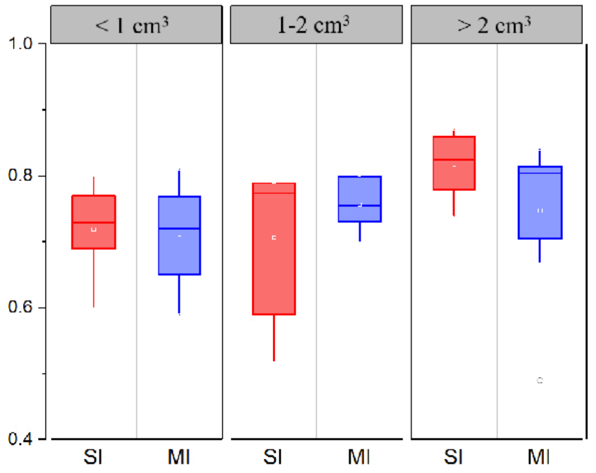
- Plan quality *indices results of every case*

	CI		GI		V_{12Gy}		V_{5Gy}	
Case	SI	MI	SI	MI	SI	MI	SI	MI
1	0.78	0.76	4.647	4.230	35.64	34.59	248.28	176.40
2	0.70	0.59	5.132	6.115	43.55	56.86	364.08	355.12
3	0.88	0.83	3.055	3.179	39.08	42.99	150.68	157.96
4	0.84	0.76	4.103	3.645	10.65	10.68	45.55	37.28
5	0.76	0.67	6.404	5.480	18.08	17.79	133.70	83.31
6	0.73	0.62	6.845	8.664	7.89	10.84	55.78	66.80
Median	0.77	0.72	4.890	4.855	26.86	26.19	142.19	120.64
p-value*	<0.05		<0.05		<0.05		<0.05	

*Wilcoxon signed-rank test



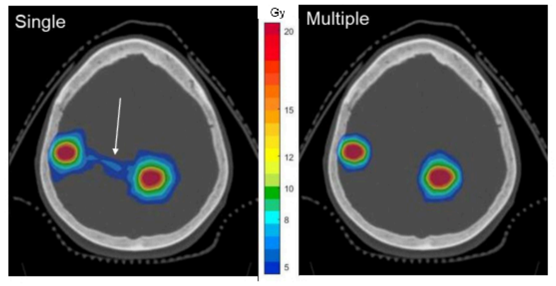
- *Conformity index result of every lesion grouped by lesion size*

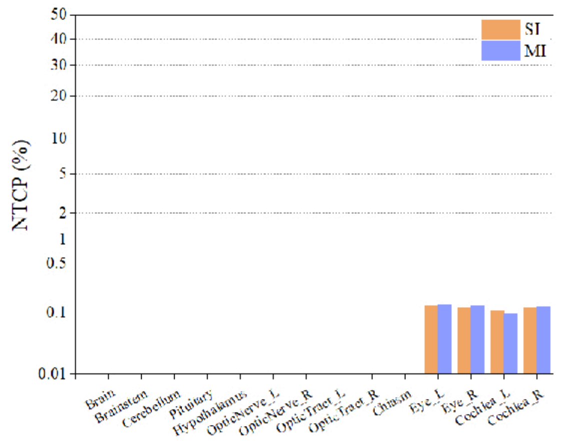


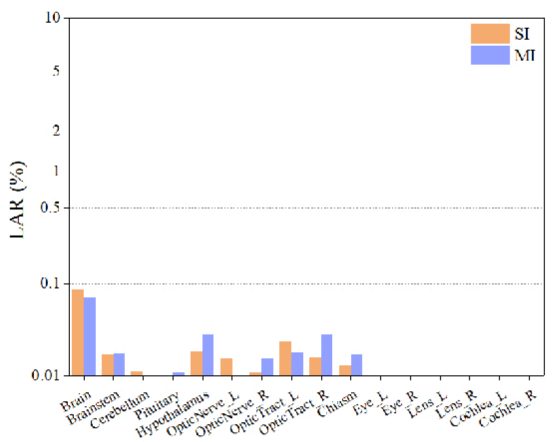
- *Biological evaluation result (case 4)*

Single : low dose bridge between two lesions for brain

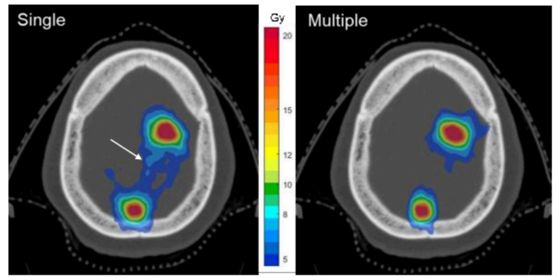
Multiple : different planning skill & less number of non-coplanar arc may produce lower dose for critical organs





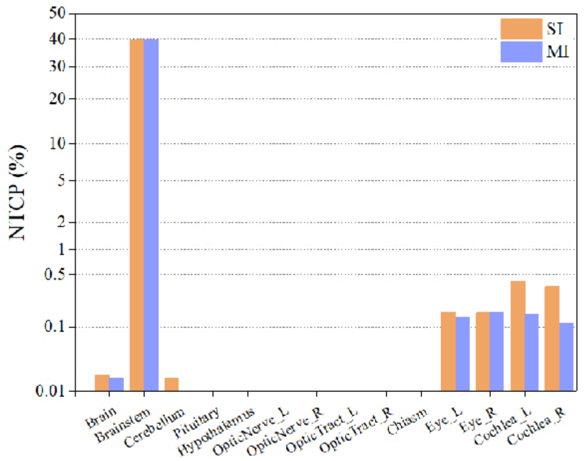


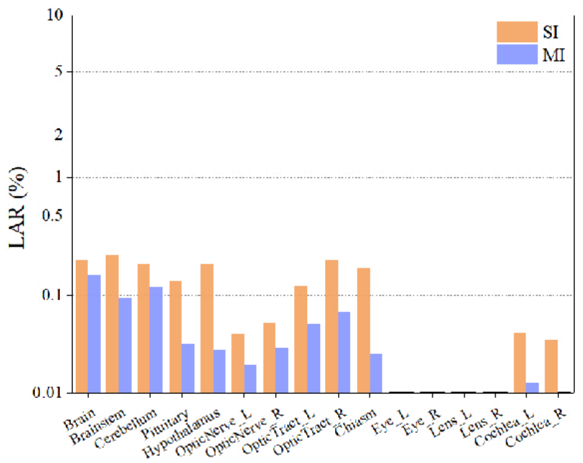
- *Biological evaluation result (case 5)*



Single : more lesion number increase potential biological effect and risk

Multiple : good performance for both NTCP and secondary cancer risk





SCORING RESULTS

The uncomplicated and Cancer-Free tumor Control Probability (UCFCP) proposed by Sánchez-Nieto B et al.

$$UCFCP = TCP \times (1 - SCP) \times \prod_{i=1}^{n}(1 - NTCP_i)$$

		TCP		UCFCP	
Case	# ISO	SI	MI	SI	MI
1	4	0.808	0.799	0.48	0.48
2	7	0.765	0.754	0.43	0.41
3	3	0.762	0.765	0.58	0.45
4	2	0.799	0.804	0.79	0.80
5	5	0.802	0.793	0.47	0.48
6	6	0.827	0.805	0.49	0.48

CONCLUSIONS

- The conformity index of single plans show better than multiple plans, but other plan quality indices have bad performance .
- We found that there is a small difference between the biological evaluation results of two plans, and the UCFCP model could help the evaluation quickly by presenting the score.
- In general, most VMAT single isocenter plans can achieve similar plan quality and biological evaluation results to multiple isocenter plans, however its necessary to evaluate case by case for detail biological information by using our biological evaluation program.

REFERENCES

1 **Liu H.** Interinstitutional Plan Quality Assessment of 2 Linac-Based, Single-Isocenter, Multiple Metastasis Radiosurgery Techniques. Advances in Radiation Oncology 2019

2 **Sánchez-Nieto B.** Uncomplicated and Cancer-Free Control Probability (UCFCP): a new integral approach to treatment plan optimization in photon radiation therapy. Phys Medica 2017;47:35–41.

3 **Paddick I.** A simple dose gradient measurement tool to complement the conformity index. Spec Suppl. 2006;105(7):194-201

4 **Schneider U.** Mechanistic model of radiation-induced cancer after fractionated radiotherapy using the linear-quadratic formula. Med Phys 2009;36:1138–43.

5 **Lee MC.** Biological plan evaluation for stereotactic radiosurgery: a comparison between single isocenter and multiple isocenter techniques