Analysis of inhomogeneous dose distribution using volumetric modulated arc therapy (VMAT) for prostate, glioblastoma multiforme, and lung patients and the effect on organs at risk

Stacy Peterson,[1] Pasquale Montanaro, M.S., DABR[2]

[1]The University of Texas MD Anderson Cancer Center School of Health Professions, Houston, TX [2]Texas Oncology – Presbyterian Cancer Center, Dallas, TX

THE UNIVERSITY OF TEXAS MD Anderson Cancer Center

Introduction

The current planning process for prostate, GBM (glioblastoma multiforme) and lung plans may be time consuming due to a process of trial and error. In this study, the user defines objectives in order to obtain adequate coverage of the tumor volume; however, less time is spent on obtaining a maximum value for the prescription dose. The purpose of this study is to allow the maximum dose constraint to be relaxed in several prostate, GBM, and lung plans, while priority is given to the dose constraints of normal tissue. By allowing the computer system to focus less on the maximum dose constraint, the organs at risk are prioritized and the dose constraints to these structures improve, which is an efficient process and advantageous for the patient.

Methods and Materials

The Philips Pinnacle © v.9.6 planning system was used for treatment planning. A total of 11 patients were selected retrospectively for this study including: 4 patients with prostate cancer, 4 patients with glioblastoma multiforme (GBM), and three patients with lung cancer. All the treatment plans were planned with VMAT. In addition, each plan was created to attain the same tumor coverage and constraints on organs at risk. The maximum prescribed dose constraint for each plan, was relaxed from approximately 105% (trial 1) of the prescribed dose to 110% (trial 2), then 115% (trial 3), and 120% (trial 4) of the prescribed dose, while maintaining the adequate coverage of the tumor volumes, and giving priority to lowering the dose to normal tissue. The prostate plans were prescribed to 79.2 Gy in 44 fractions, the GBM plans were prescribed to 60 Gy in 30 fractions, and the lung plan were prescribed to 63 Gy in 35 fractions.

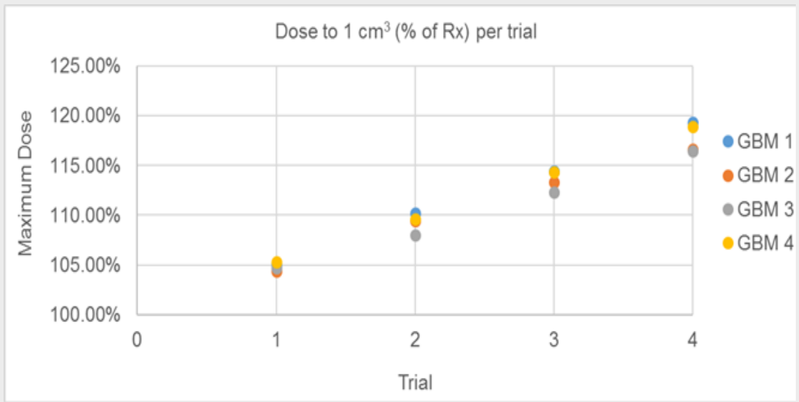

Figure 7. Dose to 1 cm³ (% of Rx) per trial for each GBM plan

Typical results for maximum dose to the PTV for each plan.

Results

The following tables and charts show the decrease in the average mean dose for critical structures per trial.

Table 3. Normalized mean dose per prostate trial

Organ at risk	Trial	Min	Max	Average
Bladder	1	1.0000	1.0000	1.0000
	2	0.8300	0.9956	0.8962
	3	0.8100	0.9993	0.8731
	4	0.8281	0.9217	0.8661
Rectum	1	1.0000	1.0000	1.0000
	2	0.9101	0.9454	0.9263
	3	0.8461	0.9074	0.8811
	4	0.8549	0.9938	0.9013
Femoral Heads	1	1.0000	1.0000	1.0000
	2	0.8301	1.0441	0.9588
	3	0.7842	1.0094	0.9363
	4	0.7445	0.9966	0.8488

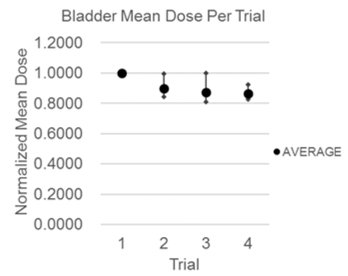

Figure 4. Normalized bladder mean dose for trials 1-4 as defined in methods and materials for each

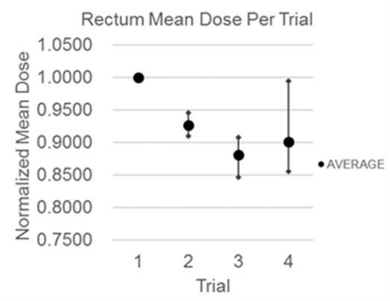

Figure 5. Normalized rectum mean dose for trials 1-4 as defined in methods and materials for each prostate plan

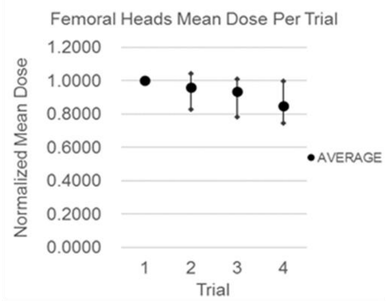

Figure 6. Normalized femoral heads mean dose for trials 1-4 as defined in methods and materials for each prostate plan

Table 6. Average relative change (%) in mean dose of critical structures

Organ at risk	Trial 1	Trial 2	Trial 3	Trial 4
Brainstem	0.000	-7.320	-11.588	-19.159
Chiasm	0.000	-11.110	-21.716	-30.131
Cochlea	0.000	-6.856	-11.038	-20.349
Normal Brain	0.000	-3.728	-4.976	-13.860
Spinal Cord	0.000	-3.385	-3.903	-9.143
Right Optic Nerve	0.000	-10.595	-20.936	-32.329
Right Orbit	0.000	-14.204	-27.967	-16.155
Right Lens	0.000	-18.210	-28.741	-21.702
Left Optic Nerve	0.000	-13.840	-25.766	-32.888
Left Orbit	0.000	-17.419	-25.282	-28.622
Left Lens	0.000	-12.845	-21.499	-18.828

Table 11. Normalized mean dose per lung trial

Organ at risk	Trial	Min	Max	Average
Spinal Cord	1	1.000	1.000	1.000
	2	0.906	0.990	0.954
	3	0.917	0.967	0.936
	4	0.811	0.962	0.896
Total Lung	1	1.000	1.000	1.000
	2	0.816	0.975	0.874
	3	0.737	0.892	0.811
	4	0.644	0.870	0.762
Heart	1	1.000	1.000	1.000
	2	0.887	1.001	0.935
	3	0.825	0.959	0.899
	4	0.807	0.916	0.868
Esophagus	1	1.000	1.000	1.000
	2	0.834	0.992	0.933
	3	0.743	0.985	0.895
	4	0.611	0.975	0.817
Total Lung V5	1	1.000	1.000	1.000
	2	0.850	0.999	0.921
	3	0.740	0.911	0.840
	4	0.634	0.889	0.785
Total Lung V10	1	1.000	1.000	1.000
	2	0.802	0.827	0.816
	3	0.676	0.800	0.741
	4	0.539	0.782	0.680
Total Lung V20	1	1.000	1.000	1.000
	2	0.607	0.983	0.762
	3	0.469	0.887	0.684
	4	0.368	0.850	0.627

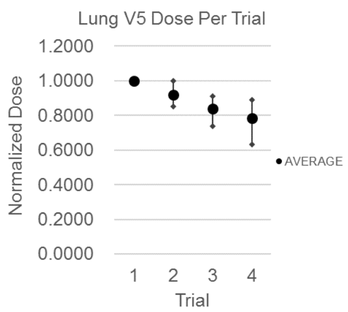

Figure 16. Normalized lung V5 mean dose for trials 1-4 as defined in the methods and materials for each lung plan

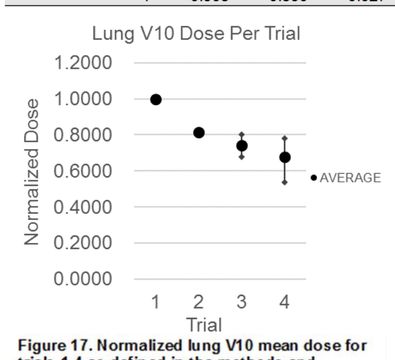

Figure 17. Normalized lung V10 mean dose for trials 1-4 as defined in the methods and materials for each lung plan

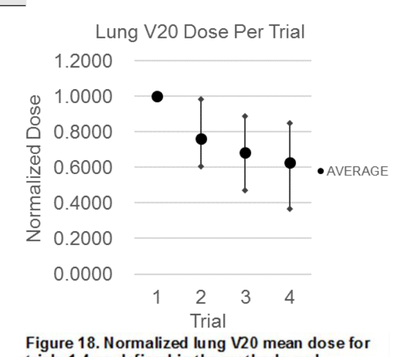

Figure 18. Normalized lung V20 mean dose for trials 1-4 as defined in the methods and materials for each lung plan

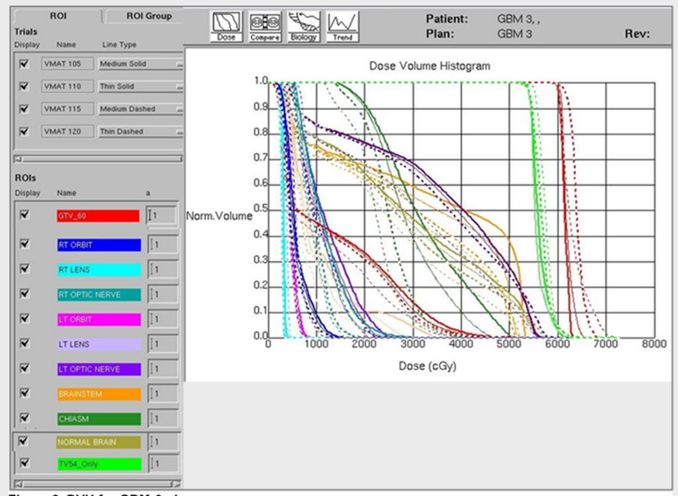

Figure 8. DVH for GBM 3 plan

Discussion/Conclusion

In the prostate plans, the average mean dose for the bladder, rectum, and femoral heads was reduced in trial 4 in comparison to trial 1 by a significant margin which would ultimately be advantageous to the patient in reducing toxicity to the bladder and rectum, and reducing the occurrence of negative side effects. In the GBM plans, the most significant change can be seen in the data for the right and left optic nerves and the chiasm, in which the dose to these structures was reduced about one third in trial 4 when compared to trial 1. In addition, each trial indicated a reduction in dose for normal brain tissue, which further reduces the risk of radiation induced necrosis[3]. Finally, in analyzing the data for each lung plan, the results indicated a substantial reduction in dose to the total lung volume for each constraint (V5, V10, and V20) as the maximum dose was escalated for trial 4 (about a third less dose when compared to trial 1). Considering that many alternative treatment options result in successful treatment outcomes while utilizing heterogeneous dose distributions, this research shows that there may be opportunity to lower doses to nearby organs at risk by relaxing maximum dose constraints within the PTV. It is likely that this is more appropriate for certain anatomical sites and is based on the ability to define and localize to the area of interest.

References

1. Y. Yu, L. Anderson, Z. Li, D. Mellenberg, R. Nath, M. Schell, F. Waterman, A. Wu and J. Blasko, “Permanent prostate seed implant brachytherapy: Report of the American Association of Physicists in Medicine task group no. 64,” Medical Physics **26** (10), 2054-2076 (1999).

2. Grills, A. Martinez, M. Hollander, R. Huang, K. Goldman, P. Chen and G. Gustafson, “High dose rate brachytherapy as prostate cancer monotherapy reduces toxicity compared to low dose rate palladium seeds”, The Journal of Urology **171**,1098-1104 (2004).

3. M. Hingorani, W. Colley, S. Dixit and A. Beavis, “Hypofractionated radiotherapy for glioblastoma: Strategy for poor risk patients or hope for the future?” The British Journal of Radiology **85**, 770-781 (2012).

4. N. Mehta MD, C. King MD, Phd, N. Agazaryan PhD, M. Steinberg MD, A. Hua, BA and P. Lee MD, “Stereotactic body radiation therapy and 3dimensional conformal radiotherapy for stage I non small cell lung cancer: A pooled analysis of biological equivalent dose and local control,” Practical Radiation Oncology **2** (4), 288-295 (2012).

5. B. Yao, Y. Wang and Q. Liu, Radiation pneumonitis in non-small-cell lung cancer patients treated with helical tomotherapy,” Nigerian Journal of Clinical Practice **19** (1), 25-29 (2016).