A Preliminary Study on Quality Control for Treatment Planning of Gamma Knife Radiosurgery for Vestibular Schwannoma

Z. Tian, T. Wang, X. Yang, M. Giles, E. Butker, M. Walb, W. J. Curran, S. Kahn, T. Liu

Department of Radiation Oncology, Winship Cancer Institute, Emory University, Atlanta, GA 30322

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INTRODUCTION

Because of the large amount of variables involved in Gamma Knife (GK) manual forward planning, the resulting plan quality heavily depends on planners' skills, experiences and the amount of devoted efforts. Hence, GK plan quality varies significantly among planners and institutions and even for a same planner at different times, particularly for vestibular schwannoma cases which are usually of more challenging geometry (irregularly-shaped target and its proximity to brainstem and cochlea). **Quality control is hence highly desired for GK planning to constantly provide the best treatment for each individual patient**. However, to our knowledge there is no literature focused on quality control for GK planning.

AIM

We propose a quality control method of GK planning for vestibular schwannoma, aiming to help planners to predict achievable plan quality and make quality control decisions to constantly provide high quality treatment plans to each individual patient.

METHODS

Patient anatomy descriptors

We describe patient specific anatomy using 4 terms in order to quantify the difficulty level of GK planning:
1) Target volume size
2) Target SHAPE index[1] (illustrated in Figure 1)
3) Overlap volume histogram[2] between target and brainstem (OVH_{T-BS})
4) Overlap volume histogram between target and ipsilateral cochlea (OVH_{T-CO})

Patient database of high-quality GK plans
- 22 previous vestibular schwannoma cases treated with GK
- Replanned by our multiresolution-level inverse planning (MRL-IP) algorithm[3] to achieve high-quality plans
- Each patient case includes
  - MR images and contours of target, brainstem, ipsilateral cochlea and skull
  - Treatment plan and 3D dose distribution
  - 4 anatomy descriptors
  - 6 plan metrics:
    1) Target coverage
    2) Selectivity
    3) Conformal index at 50% isodose line (CI50)
    4) Brainstem 0.1cc dose ($D_{BS,0.1cc}$)
    5) Cochlea mean dose ($D_{CO,mean}$)
    6) Total beam-on time (BOT)

Plan quality control

When a treatment plan is created for a new patient case, a plan with the closest planning difficulty level will be identified in the database, using
- **Primary criteria**: target volume size and SHAPE index
- **Secondary criteria**: OVH_{T-BS} and OVH_{T-CO}

The identified high-quality plan will serve as a reference for planners to determine whether the query plan needs replanning to further improve its quality.

RESULTS

We tested this plan quality control method on 6 cases. The information of the testing plans and their identified reference plans are listed in **Table 1**. OVH_{T-BS} and OVH_{T-CO} for these cases are shown in **Figure 2**. According to the plan quality control results, our physicist has replanned T1-5 cases (shown in **Table 2**) and all gained significant quality improvement, as expected by our quality control method. Dose distributions of the original plan and the new plan for T4 case are shown in **Figure 3**.
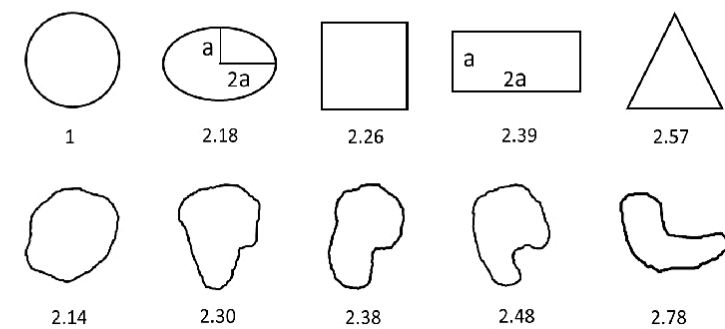

Figure 1. SHAPE values of five 2D shapes (top) and five target contours (bottom).
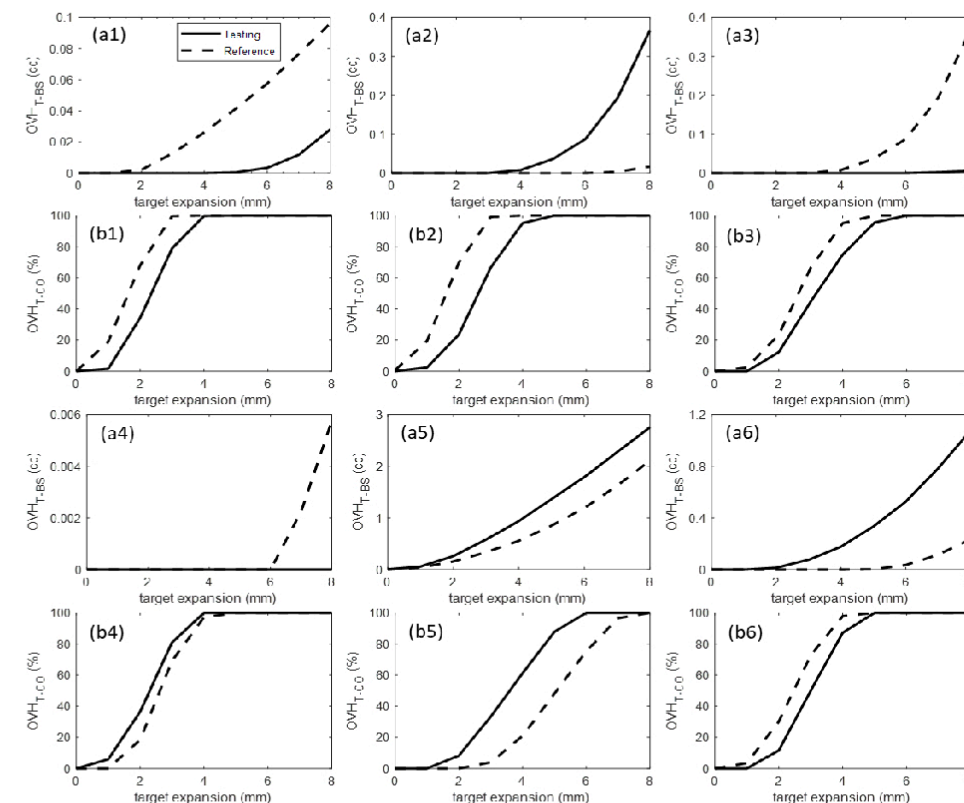

Figure 2. OVH_{T_BS} for the testing cases T1-6 (in solid line) and their corresponding reference cases R1-6 (in dashed line) are shown in subfigures (a1-a6), and OVH_{T_CO} for these cases are shown in subfigures (b1-b6). Please note that OVH_{T_BS} is shown in absolute volume to correspond to $D_{BS,0.1cc}$, and OVH_{T_CO} is shown in percentage volume to correspond to $D_{CO,mean}$.

Table 1. Information of the testing plans (T_i, i=1,2,...,6) and the corresponding reference plans (R_i, i=1,2,...,6) identified in the patient database.

	TARGET SIZE (CC)	TARGET SHAPE	COVERAGE	SELECTIVITY	CI50	BOT* (MIN)	$D_{BS,0.1CC}$ (GY)	$D_{CO,MEAN}$ (GY)	EXPECT BIG QUALITY IMPROVEMENT
T1	0.777	2.34	1.00	0.69	4.01	61.0	2.8	4.2	YES
R1	0.790	2.64	1.00	0.71	3.94	43.0	7.6	8.0	
T2	0.289	2.46	1.00	0.56	5.29	41.2	2.5	3.7	YES
R2	0.303	2.45	1.00	0.71	4.18	31.9	2.0	6.9	
T3	0.280	2.31	1.00	0.58	5.14	26.7	2.4	3.6	YES
R3*	0.289	2.46	1.00	0.69	5.04	29.8	3.4	3.6	
T4	0.283	2.59	0.99	0.43	7.05	42.4	1.8	4.0	YES
R4	0.284	2.56	0.99	0.70	5.30	23.7	1.8	3.4	
T5	2.784	2.20	1.00	0.79	3.20	52.4	10.4	5.1	YES
R5	2.779	2.14	1.00	0.81	3.30	37.1	10.0	4.0	
T6	0.415	2.62	1.00	0.67	4.73	39.7	5.5	4.0	NO
R6	0.418	2.54	1.00	0.65	4.66	36.5	2.5	4.9	

*R3 Is the high-quality plan obtained by replanning for T2 (i.e., T2-RE in Table 2) and added to patient database
*BOT listed here is normalized to the initial dose rate 3.534Gy/min.

Table 2. Plan metrics of the new plan obtained by replanning for T1-5 cases.

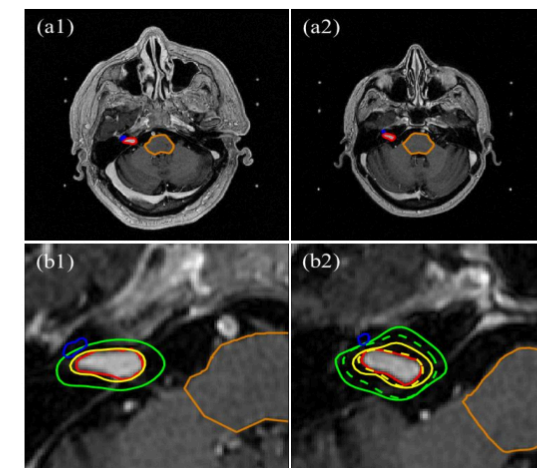|	COVERAGE	SELECTIVITY	CI50	BOT* (MIN)	$D_{BS,0.1CC}$ (GY)	$D_{CO,MEAN}$ (GY)
T1-RE	1.00	0.74	3.82	43.0	2.6	4.2
T2-RE	1.00	0.69	5.04	29.8	3.4	3.6
T3-RE	1.00	0.70	4.56	25.9	2.3	3.4
T4-RE	0.99	0.68	4.82	30.2	1.3	3.6
T5-RE	1.00	0.81	3.20	37.8	10.4	4.1

Figure 3. Replanning results of T4 case. (a1-2) shows a transvers slice of MR image for R4 and T4 cases, respectively. Contours of target, brainstem and ipsilateral cochlea are shown in red, orange and blue, respectively. Target regions of (a1-2) are zoomed in and shown in (b1-2), with the isodose lines of the prescription dose (in yellow) and half of the prescription dose (in green). In (b2), the isodose lines of the original T4 plan are shown in solid lines and those of the new plan T4-re are shown in dashed lines.

CONCLUSIONS

- We proposed a quality control method for GK planning for the first time, by building a database of high-quality GK treatment plans of same disorder type and quantifying the planning difficult level using 4 anatomy descriptors.
- Our experimental results on 6 testing cases have demonstrated the efficacy and feasibility of our quality control method.
- This method may also be used as a plan quality prediction method for GK planning, facilitating the development of automatic treatment planning for GK radiosurgery.
- We will keep adding new high-quality plans into our patient database to increase its diversity.

ACKNOWLEDGEMENTS

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CONTACT INFORMATION

Zhen Tian, PhD
Assistant Professor
Department of Radiation Oncology
Winship Cancer Institute, Emory University
Email: zhen.tian@emory.edu