Comparative study of automatic and manual planning methods for volumetric modulated arc therapy in patients with intraocular cancer

Xiaomin Zheng | Ce Han | Jinling Yi | Yongqiang Zhou | Yao Ai | Congying Xie | Xiance Jin

Abstract

Objective: To research and assess automatic volumetric modulated arc therapy (VMAT) planning methods for patients with intraocular cancer.

Methods: The mdaccAutoPlan system was added to the Pinnacle3 treatment planning system as a plug-in. Automatic VMAT plans were generated for 10 patients diagnosed with intraocular cancer, and evaluated according to standard dose-volume histogram parameters.

Results: The planning target volume of enrolled patients ranges from 14.24 to 50.69 cm³. Both planning methods lead to acceptable planning target volume target coverage with a V95 of 97.9 ± 1.4% and 96.4 ± 1.5% for manual and automatic plans (P = 0.03), respectively. Automatic planning lowered the dose delivered to the ipsilateral lens and optical nerves, but increased the dose to the brainstem compared with manual planning. Automatic planning significantly prolonged VMAT planning time (3.25 ± 0.53 h vs. 1.02 ± 0.69 h, P < 0.01), but no significant differences were seen in average machine units (474.0 ± 64.8 vs. 502.4 ± 109.5, P = 0.34) compared with the manual planning method.

Conclusions: Automatic VMAT planning achieved acceptable target coverage, and lowered the dose delivered to ipsilateral lens and brainstem in patients with intraocular cancer compared with manual planning. However, the full benefits of automatic VMAT planning require further study with improved performance and treatment planning system capacity.

KEYWORDS
automatic planning, intraocular cancer, target coverage, volumetric modulated arc radiotherapy

1 INTRODUCTION

Intraocular cancer consists of a primary and secondary intraocular malignancy, and is among the most dangerous ophthalmic diseases that threaten people's lives and visual health. Management of orbital lymphoma with radiation therapy (RT) techniques has been well established. Currently, external beam RT (EBRT) has been adapted as one of the most common RT modalities for intraocular cancer...
because of its lower rates of late recurrence compared with radioactive plaque brachytherapy. EBRT also has the advantage of preserving the eye structure, which results in a better appearance after treatment compared with surgery.

One of the major concerns of EBRT is the unnecessary radiation dose delivered to the surrounding normal tissues, which might result in cataracts, retinal detachment, glaucoma, or bleeding into the eye, among other complications. Breakthroughs in EBRT technologies, such as proton therapy, intensity-modulated radiation therapy (IMRT), and volumetric modulated arc therapy (VMAT), have been widely investigated to reduce dose delivery to normal tissues while ensuring tumor coverage. The possibility and advantages of VMAT for the treatment of intraocular cancer were assessed in one of our previous investigations, and it yielded promising results. However, one of the disadvantages of VMAT is the long optimization time required, which is usually four- to fivefold that of IMRT. Furthermore, a significant inter- and intra-institutional variation in planning practice and quality were observed for IMRT and VMAT. The present study aimed to investigate the feasibility and advantages of knowledge-based automatic VMAT planning for the treatment of patients with intraocular cancer. Furthermore, this investigation responds to the increasing demand for automatic VMAT planning for intraocular cancer.

2 | METHODS

2.1 | Patients and target delineation

A total of 10 patients with primary and secondary intraocular cancer who underwent VMAT were enrolled in the present study. Patients underwent simulation in a supine position using a thermoplastic mask with an active fixation spot, and were scanned with a Philips Brilliant spiral computed tomography scanner (Philips Brilliant, Cleveland, OH, USA) following standard procedures. Magnetic resonance images in the T1 and T2 phases were captured at 3-mm slice thickness to facilitate the delineation of target volumes. The overall extent of tumor masses shown on computed tomography and magnetic resonance images were delineated as the gross target volume, and 3 mm were added to the gross target volume to obtain the planning target volume (PTV). No clinical target volumes were generated for intraocular cancer. Normal tissues including the right and left crystals, right and left eyes, optic nerve, optic chiasm, and brainstem were contoured and included in the VMAT optimization.

2.2 | Automatic VMAT planning

The mdaccAutoPlan system developed by Zhang et al. was added to the Pinnacle treatment planning system (clinical version 9.10; Philips Healthcare, Cleveland, OH, USA) as a plug-in. A database for intraocular cancer automatic VMAT planning was generated with 20 manually generated VMAT plans, which were carefully optimized and successfully delivered clinically. The prescription for enrolled patients was 50 Gy in 25 fractions with a 6-MV photon beam. A customized template was generated to define the priority of optimization goals for PTV and organs at risk (OARs) for automatic VMAT planning. The automatic VMAT planning template ran automatically with the contoured targets and OARs after clicking to optimize the desired PTV coverage and OAR sparing with multiple optimization cycles. The automatic model was tested on 10 intraocular cancer patients with previously delivered VMAT plans.

2.3 | Plan evaluation

The automatic VMAT plans were evaluated according to standard dose-volume histogram parameters. D99% and D1% (dose irradiated to 99% and 1% volume) were reported as a measure of the minimum and maximum doses for PTV, and V95% (volume receiving at least 95% of the prescribed dose) defined as the target coverage was reported. The Homogeneity Index (HI), which was defined as the difference between D1 and D99 divided by prescription dose (Dp), was calculated according to the formula shown below, and reported:

$$HI = \frac{D1 - D99}{Dp} \times 100\%$$  \hspace{1cm} (1)

An equivalent uniform dose (EUD) was also calculated and reported for the analysis of radiobiological effects of physics dose resulting from PTV:

$$EUD = \left( \frac{1}{N} \sum_{i=1}^{N} D_i^a \right)^{\frac{1}{2}}$$  \hspace{1cm} (2)

Where N is the number of voxels in the structure of interest, Di is the dose in the i-th voxel, and a is a specific parameter of the normal tumor tissue describing the dose-volume effect. The machine unit of the manual and automatic planning, as well as time of delivery, were also evaluated and compared.

2.4 | Statistical analysis

The evaluation results were described as the mean ± standard deviation. A comparison of the dosimetric and non-dosimetric indices between the two treatment plans was analyzed using the Wilcoxon signed-rank test. All statistical analyses were carried out using SPSS software (version 20.0.0; IBM Corporation, Armonk, NY, USA). Differences were considered statistically significant when $P < 0.05$.

3 | RESULTS

A total of 10 patients (5 men and 5 women) with primary and secondary intraocular cancer were enrolled in this study, with a median age of 52 years (range 33–80 years). Most patients were diagnosed as having mucosa-associated lymphoid tissue lymphoma. The PTVs of these...
The results of OAR comparison between manual and automatic planning were mixed. Automatic planning decreased the dose irradiated to the ipsilateral lens and optical nerves, but it also increased the dose delivered to the brainstem compared with manual planning, as shown in Table 3. No significant differences in contralateral lens, eyeballs, or optic chiasm were seen as a consequence of either planning method. The typical isodose distribution and dose-volume histogram comparison between manual and automatic planning methods is presented in Figures 1 and 2. Automatic planning with the added-in automatic planning algorithm greatly increased VMAT planning time for non-dosimetric parameters compared with manual planning (3.25 ± 0.53 h vs. 1.02 ± 0.69 h, P < 0.01). There were no significant differences in average machine unit between the manual and automatic plans (474.0 ± 64.8 vs. 502.4 ± 109.5, P = 0.34).

4 | DISCUSSION

In the present study, we investigated automatic planning for VMAT in the treatment of intraocular cancer. Automatic planning achieved acceptable target coverage and sparing of OARs compared with manual planning. Nevertheless, the add-in algorithm greatly increased optimization time.

Enucleation, RT, cryotherapy, and laser therapy are common local therapy options for the management of intraocular cancer.1 Lymphoma patients were approximately 14.24–50.69 cm³. Table 1 presents the detailed characteristics of patients and PTV.
accounts for a major portion of patients with intraocular cancer, and Table 1 shows the characteristics of the patients in the present study. RT has become the first choice of treatment for patients with intraocular cancer, because lymphoma cells are very sensitive to radiation.2 The disadvantages of RT include RT-associated complications, such as cataracts, radiation retinopathy,17 optic neuropathy,18 dry eye syndrome, and prolonged corneal epithelial defects.19 Advanced RT technologies, such as IMRT, VMAT, and proton radiation therapy, were introduced to reduce injury to uninvolved structures while achieving appropriate tumor coverage.20

As shown in Tables 2 and 3, automatic planning achieved acceptable target coverage of VMAT without scarifying other PTV parameters compared with the manual plans, which were accepted and delivered in clinical practice. Automatic planning also decreased the dose to ipsilateral lens and optical nerves in terms of OAR sparing. Although the dose irradiated to the brainstem was slightly increased, it was still well within clinical tolerance. Similarly, Della Gala et al. reported a statistically significant improvement in PTV coverage (V95% increased by 1.1 ± 1.1%), higher dose conformity (R50 reduced by 12.2 ± 12.7%), and reduced mean lung, heart, and esophagus doses (reductions of 0.9 ± 1.0 Gy, 1.5 ± 1.8 Gy, 3.6 ± 2.8 Gy, respectively, all P < 0.001) during their full automatic VMAT planning for stage III/IV non-small cell lung cancer patients.21

One of the limitations of knowledge-based automatic planning is the limitation in selecting the training dataset, which is randomly selected from the clinical plans used for previous patient treatments.22,23 The quality of the automatic plans depends on the quality of the plans in the training dataset. Relatively few plans were enrolled in the present study’s training set due to the limited cases of intraocular cancer. Another limitation of this study was the relatively longer optimization time required for automatic planning as an added-in algorithm. One
objective of automatic planning is to decrease planning time and solve the shortage of sufficiently trained personnel. However, automatic planning time was much longer than manual planning in the present study. Further investigation of increased treatment planning system capacity and performance is required to explore the benefits of automatic VMAT plans for intraocular cancer.

Automatic VMAT planning achieved acceptable target coverage and lowered the dose delivered to the ipsilateral lens and brainstem for patients with intraocular cancer in comparison with manual planning. Automatic planning is a promising method for the management of intraocular cancer; however, the full benefits of automatic VMAT planning require further investigation for improved performance and capacity of the treatment planning system.

ACKNOWLEDGMENTS
This investigation was partially funded by the Wenzhou Municipal Science and Technology Bureau (No. 2018ZY016), the Zhejiang Engineering Research Center of Intelligent Medicine (2016E10011), and the National Natural Science Foundation of China (Grant No. 11675122).

CONFLICT OF INTEREST
The authors declare that they have read the article and there are no competing interests.

ORCID
Xiance Jin https://orcid.org/0000-0002-4117-5953

REFERENCES
1. Burch HB, Wartofsky L. Graves' ophthalmopathy: current concepts regarding pathogenesis and management. Endocr Rev. 1993;14:747-793.
2. Bolek TW, Moyes HM, Marcus Jr RB, et al. Radiotherapy in the management of orbital lymphoma. Int J Radiat Oncol Biol Phys. 1999;44(1):31-36.
3. Chao CK, Lin HS, Devineni VR, Smith M. Radiation therapy for primary orbital lymphoma. Int J Radiat Oncol Biol Phys. 1995;31:929-934.
4. Char DH, Kroll S, Phillips TL, Quivey JM. Late radiation failures after iodine 125 brachytherapy for uveal melanoma compared with charged-particle (proton or helium) therapy. Ophthalmology. 2002;109(10):1850-1854.
5. Munier FL, Verwey J, Pica A, Balmer A, Zografos L, Abouzeid H, et al. Knowledge-based algorithms in nasopharyngeal cancer patients using comparison of planning quality and efficiency between conventional and intensity-modulated radiation treatment planning for lung cancer. Pract Radiat Oncol. 2012;2(4):296-305.
6. Bogner J, Petersch B, Georg D, Dieckmann K, Zehetmayer M, Pöttler R. A noninvasive eye fixation and computer-aided eye monitoring system for linear accelerator-based stereotactic radiotherapy of uveal melanoma. Int J Radiat Oncol Biol Phys. 2003;56(4):1128-1136.
7. Zhang X, Li X, Quan EM, Pan X, Li Y. A methodology for automatic intensity-modulated radiation planning for lung cancer. Phys Med Biol. 2011;56(13):3873-3893.
8. Eldebawy E, Parker W, Abdel Rahman W, Freeman CR. Dosimetric study of current treatment options for radiotherapy in retinoblastoma. Int J Radiat Oncol Biol Phys. 2012;82(3):e501-e505.
9. Deng ZX, Shen LX, Zheng XM, et al. Dosimetric advantage of volumetric modulated arc therapy in the treatment of intraocular cancer. Radiat Oncol. 2017;12(1):83.
10. Jin X, Yi J, Zhou Y, Yan H, Han C, Xie C. Comparison of whole-field simultaneous integrated boost VMAT and IMRT in the treatment of nasopharyngeal cancer. Med Dosim. 2013;38(4):418-423.
11. Nelms BE, Robinson G, Markham J, et al. Variation in external beam treatment plan quality: an inter-institutional study of planners and planning systems. Pract Radiat Oncol. 2012;2(4):296-305.
12. Iori M, Cattaneo GM, Cagni E, et al. Dose-volume and biological-model based comparison between helical tomotherapy and (inverse-planned) IMAT for prostate tumours. Radiat Oncol. 2008;88(1):34-45.
13. Niemierko A, Goiten M. Modeling of normal tissue response to radiation critical volume model. Int J Radiat Oncol Biol Phys. 1993;25(1):135-145.
14. Archer DB, Amoaku WMK, Gardiner TA. Radiation retinopathy-clinical, histopathological, ultrastructural and experimental correlations. Eye. 1991;5:239-251.
15. Brown GC, Shields JA, Sanborn G, et al. Radiation optic neuropathy. Ophthalmology. 1982;89:1489-1493.
16. Chan RC, Shukovsky LJ. Effects of irradiation on the eye. Ther Radiol. 1976;120:673-675.
17. Mouw KW, Sethi RV, Yeap BY, et al. Proton radiation therapy for the treatment of retinoblastoma. Int J Radiat Oncol Biol Phys. 2014;90:863-869.
18. Yuan L, Ge Y, Lee WR, et al. Quantitative analysis of the factors which affect the interpatient organ-at-risk dose sparing variation in IMRT plans. Med Phys. 2012;39:6868-6878.
19. Chang AT, Hung AW, Cheung FW, Lee MC, Chan OS, Philips H. Comparison of planning quality and efficiency between conventional and knowledge-based algorithms in nasopharyngeal cancer patients using intensity modulated radiation therapy. Int J Radiat Oncol Biol Phys. 2016;95:981-990.
20. Shikama N, Tsujino K, Nakamura K, Ishikura S. Survey of advanced radiation technologies used at designated cancer care hospitals in Japan. Jpn J Clin Oncol. 2014;44:72-77.

How to cite this article: Zheng X, Han C, Yi J, et al. Comparative study of automatic and manual planning methods for volumetric modulated arc therapy in patients with intraocular cancer. Pract Radiat Oncol. 2020;4:68–72. https://doi.org/10.1002/pro.6.1099