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Abstract

Purpose: The study was aimed to compare hybrid arc and volumetric-modulated arc therapy treatment plans for fractionated stereotactic radiotherapy of brain tumors. **Methods:** Treatment plans of 22 patients were studied. Hybrid arc and volumetric-modulated arc therapy plans were generated using Brainlab iPlanDose and Varian Eclipse treatment planning systems, respectively, with 6 MV photon beams on a Varian TrueBeam STx linear accelerator (Palo Alto, CA). Prescription dose was 54 Gy. The fractionation was 1.8 Gy per fraction and 30 fractions in total, or 2 Gy per fraction and 27 fractions in total. Planning target volume ranged from 2.4 to 28.6 cm³. Dose conformity index, gradient index, homogeneity index, and maximum doses in organs at risk were compared. Wilcoxon signed rank test was used to determine statistical significance in paired comparison. **Results:** Conformity indexes of hybrid arc and volumetric-modulated arc therapy plans are 1.10 ± 0.10 and 1.14 ± 0.07 , respectively ($P = .4$); gradient indexes are 5.02 ± 1.20 and 5.64 ± 1.28 , respectively ($P = .0001$); homogeneity indexes are 1.02 ± 0.01 and 1.05 ± 0.01 , respectively ($P = .0001$); brainstem maximum doses are 53.87 ± 1.63 Gy and 54.06 ± 3.17 Gy, respectively ($P = .1$); and optic chiasm maximum doses are 53.86 ± 1.28 Gy and 53.95 ± 1.81 , respectively ($P = .4$). The monitor unit efficiencies of hybrid arc and volumetric-modulated arc therapy plans are 2.57 ± 0.25 MU/cGy and 2.68 ± 0.24 MU/cGy, respectively ($P = .2$). The differences of conformity index, gradient index, and homogeneity index between hybrid arc and volumetric-modulated arc therapy plans are small: 0.08 ± 0.05 , 0.65 ± 0.46 , and 0.02 ± 0.01 , respectively. The maximum doses in organs at risks are similar between hybrid arc and volumetric-modulated arc therapy plans. Hybrid arc and volumetric-modulated arc therapy plans, which have similar monitor unit efficiencies, present similar dosimetric results in the fractionated intracranial radiotherapy.

Keywords

hybrid arc, volumetric-modulated arc therapy, treatment plan, intracranial, radiotherapy

Abbreviations

CI, conformity index; DCA, dynamic conformal arc; FSRT, fractionated stereotactic radiotherapy; GI, gradient index; HA, hybrid arc; HI, homogeneity index; IMRT, intensity-modulated radiation therapy; MU, monitor unit; MLC, multi-leaf collimator; OAR, organs at risk; PTV, planning target volume; QA, quality assurance; TPS, treatment planning system; VMAT, volumetric-modulated arc therapy.

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Introduction

Two inverse-planning-based treatment techniques, intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT), are popularly used in radiation therapy.¹⁻³ In IMRT, treatment beams are delivered at fixed linear accelerator gantry angles and beam intensity is

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modulated with multi-leaf collimator (MLC) to generate optimized dose distribution. In VMAT, treatment beams are delivered when machine gantry is rotating and beam intensity is modulated with MLC at the same time to generate optimized dose distribution. Because of inverse planning, compared to regular forward-planning-based treatments, IMRT and VMAT can provide better dose conformity on target and can limit doses on organ at risk (OAR). There have been many studies on comparison of these 2 techniques.⁴⁻⁸ Hybrid arc (HA) is a hybrid technique which combines dynamic conformal arc (DCA; ie, beam is delivered when linear accelerator gantry is rotating in an arc and beam aperture is changed to conform to planning target volume [PTV]) with IMRT beams at fixed gantry angles. A study showed that HA is a good option for treating esophageal cancer with thoracic involvement.⁹ A study of cranial tumor treatment and prostate treatment showed that compared to DCA and IMRT, HA improved dose conformity.¹⁰ A study of rectal cancer treatment showed that compared to VMAT, HA achieved similar target coverage but was less efficient in sparing small bowel and bladder.¹¹

We have been using HA routinely at our institution for fractionated stereotactic radiotherapy (FSRT) of brain tumors. It is of interest to compare the quality of HA and VMAT intracranial treatment plans. To the authors' knowledge, there is no such publication. In this article, we conducted a retrospective dosimetric study to evaluate HA and VMAT for intracranial radiotherapy.

Material and Method

Patient

Twenty-two brain patients treated with FSRT at our institution under an institutional-review-board approved study were included. The patients were treated on a Varian TrueBeam STx linear accelerator (Palo Alto, California) using 6 MV photon beams, with HA or VMAT plans. The linear accelerator is equipped with high-definition MLC HD120 (central 8 cm of 2.5 mm thick leaf and outer 14 cm of 5 mm thick leaf). The patients had skull-based benign tumors. Total treatment dose was 54 Gy. The fractionation was 1.8 Gy per fraction and 30 fractions in total, or 2 Gy per fraction and 27 fractions in total. Planning target volume ranged from 2.4 to 28.6 cm³. Table 1 lists the patients' tumor locations and PTV sizes.

Treatment Plan

In the study, 2 plans (HA and VMAT plans) were generated for each patient. Hybrid arc plans were generated using Brainlab iPlanDose treatment planning system (TPS; version 4.5.4). The HA plans included 3 to 4 noncoplanar dynamic arcs and 5 to 6 IMRT beams which were located at the beginning or the end of a dynamic arc. The ratio of the weights of dynamic arcs and IMRT beams was chosen based on the idea: to have the dynamic arcs provide most of the dose which is spread out to minimize the entrance dose to reduce hair loss; while to allow

Table 1. Tumor Location and PTV Size of the 22 Patients.

Patient	Tumor Location	PTV (cm ³)
1	Left optic nerve	5.5
2	Right brain/neck region	20.2
3	Left cerebellopontine angle	3.3
4	Right cerebellopontine angle	8.5
5	Sellar region	16.6
6	Right cavernous sinus	28.6
7	Right occipital	24.2
8	Olfactory groove	7.2
9	Brainstem/thalamus region	23.3
10	Left cerebellopontine angle	11.9
11	Right temporal	18.0
12	Right base of skull	20.4
13	Right cerebellopontine angle	22.8
14	Left optic nerve	2.4
15	Right planum sphenoidale	5.7
16	Planum sphenoidale and paranasal sinuses	15.6
17	Right cavernous sinus	24.6
18	Right cerebellopontine angle	13.7
19	Left cavernous sinus	10.3
20	Left cavernous sinus	6.1
21	Right cavernous sinus	14.4
22	Right cavernous sinus	21.3

Abbreviation: PTV, Planning target volume.

the IMRT beams to have enough room to provide modulation for the final plan optimization. Based on our clinical experience, we found the ratio 8:2 or 7:3 led to better planning results, compared to other ratios. Volumetric-modulated arc therapy treatment plans were generated using a Varian Eclipse TPS (Version 11.0) with 3 to 4 noncoplanar VMAT arcs, which were in the same geometry as the dynamic arcs in HA plans. Planning computed tomography image slice thickness was 1.25 mm. Density correction was applied and a grid size of 1 mm was used in both HA and VMAT plan dose calculations. Dose constraints for OAR, for example, 60 Gy for brainstem maximum dose and 56 Gy for optic chiasm maximum dose, were applied in the inverse planning.

BrainLAB iPlanDose TPS provides 4 different options for IMRT portion of the plan. We selected the "PTV only" option, which usually generates a more homogeneous dose distribution than using other options. In VMAT planning, a tuner structure was generated by expanding the PTV with 3 mm uniform outside margin and was used in the optimization to help achieve homogenous dose distribution within the PTV. Planning target volume was generally set to have a lower dose objective to have 100% volume covered by the prescription dose; while the tuner structure was set to have a maximum dose objective no greater than 102% of the prescription dose, and it was given the same level of priority.

For comparison, both HA and VMAT plans were normalized to make prescription dose cover 95% of PTV. Dose conformity index (CI; ratio of prescription isodose volume to PTV), gradient index (GI; ratio of 50% prescription isodose

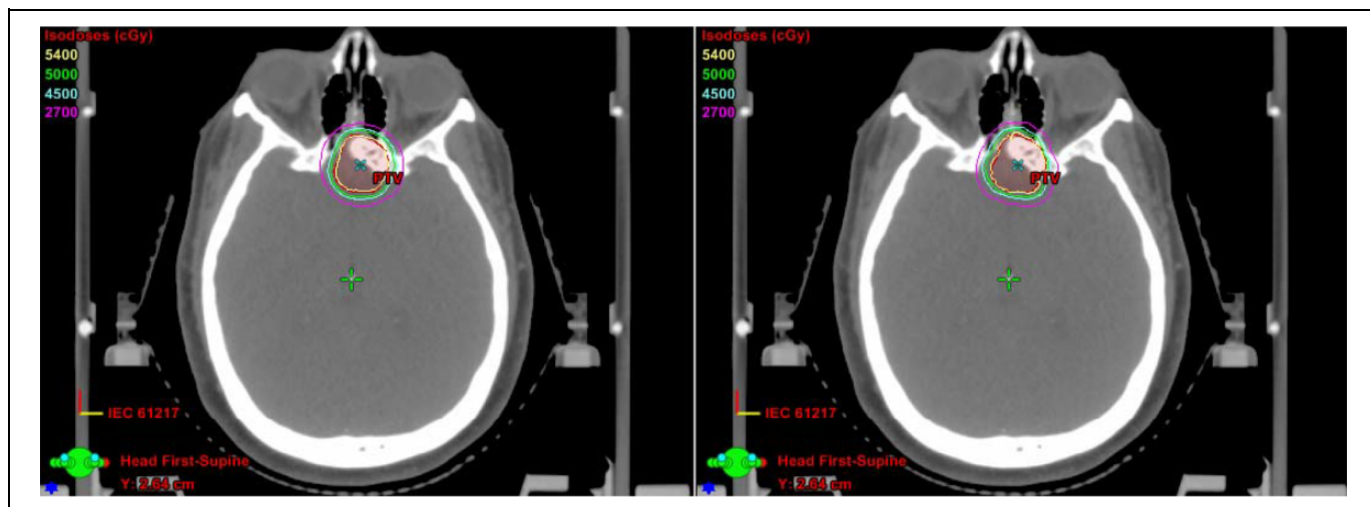


Figure 1. Dose distributions of HA plan (left side) and VMAT plan (right side) of a patient. Planning target volume (PTV) is shown in red line. HA indicates hybrid arc; VMAT, volumetric-modulated arc therapy.

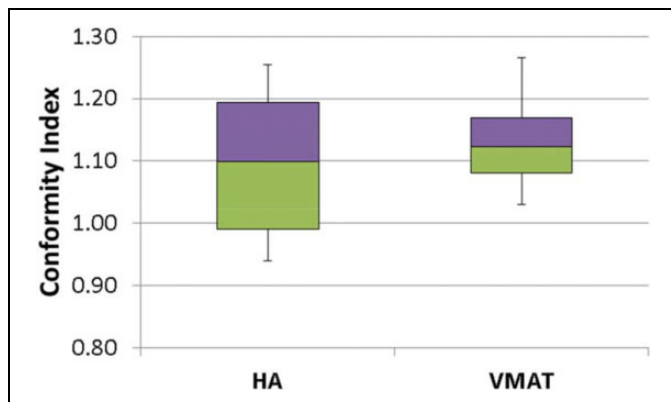


Figure 2. Conformity index of HA and VMAT plans. HA indicates hybrid arc; VMAT, volumetric-modulated arc therapy.

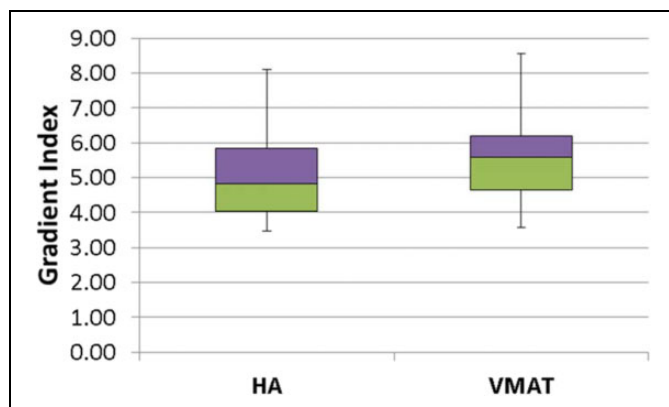


Figure 3. Gradient index of HA and VMAT plans. HA indicates hybrid arc; VMAT, volumetric-modulated arc therapy.

volume to PTV), and homogeneity index (HI; ratio of maximum dose in PTV to prescription dose) were compared between HA and VMAT plans of the 22 patients. The OAR doses in some patients were insignificant because the OARs were located far away from the tumors. In the comparison of brainstem maximum doses, only those patients whose brainstem maximum doses were close to or larger than 50 Gy were included. These patients' results may better reflect the capability of treatment planning optimization of the planning systems because the OAR doses were closer to the OAR constraints. Similarly, in comparison of optic chiasm maximum doses, only those patients whose optic chiasm maximum doses were close to or larger than 50 Gy were included. Fifteen patients' brainstem maximum doses from HA and VMAT plans were compared, and 13 patients' optic chiasm maximum doses were compared. Monitor unit (MU) efficiencies, that is, MU/prescription dose, of HA and VMAT plans, were also compared. Wilcoxon signed rank test was used to determine statistical significance in paired comparison with P value threshold of .05.

Results

Figure 1 shows dose distributions of HA and VMAT plans of a patient. The 100% prescription isodose line (5400 cGy) and 50% prescription isodose line (2700 cGy) are shown. In this case, 4 DCAs and 6 IMRT beams were used in the HA plan, and 4 VMAT arcs were used in the VMAT plan. The isodose distributions look similar in the 2 plans.

Figures 2 to 4 show CI, GI, and HI of HA and VMAT plans of the 22 patients, respectively. Conformity indexes of HA and VMAT plans are 1.10 ± 0.10 (range: 0.94-1.25) and 1.14 ± 0.07 (range: 1.03-1.27), respectively; GIs are 5.02 ± 1.20 (range: 3.47-8.11) and 5.64 ± 1.28 (range: 3.57-8.55), respectively; HIs are 1.02 ± 0.01 (range: 1.01-1.05) and 1.05 ± 0.01 (range: 1.03-1.08), respectively. Figure 5 shows brainstem maximum doses of the 15 patients. Brainstem maximum doses in HA and VMAT plans are 53.87 ± 1.63 Gy (range: 49.62-55.14 Gy) and 54.06 ± 3.17 Gy (range: 44.77-56.69 Gy), respectively. Figure 6 shows optic chiasm maximum doses of

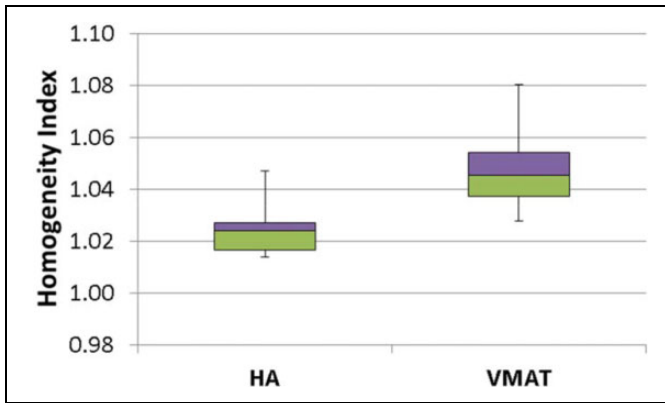


Figure 4. Homogeneity index of HA and VMAT plans. HA indicates hybrid arc; VMAT, volumetric-modulated arc therapy.

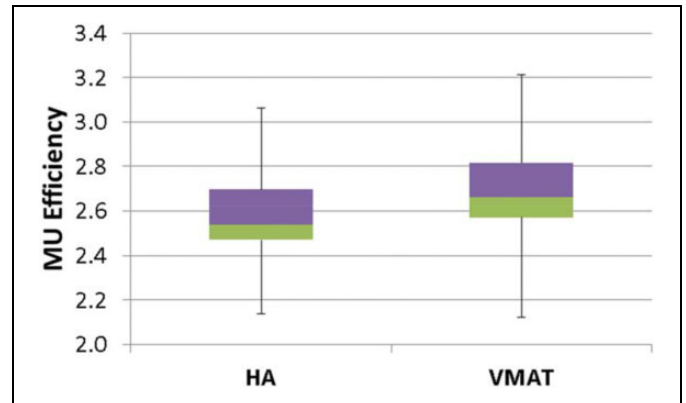


Figure 7. Monitor unit (MU) efficiency of HA and VMAT plans. HA indicates hybrid arc; VMAT, volumetric-modulated arc therapy.

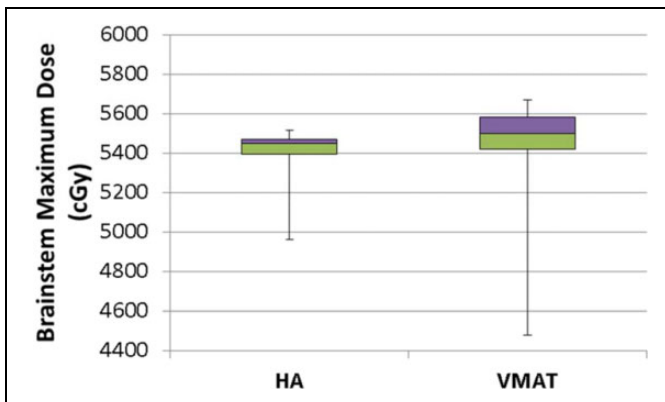


Figure 5. Brainstem maximum dose of HA and VMAT plans. HA indicates hybrid arc; VMAT, volumetric-modulated arc therapy.

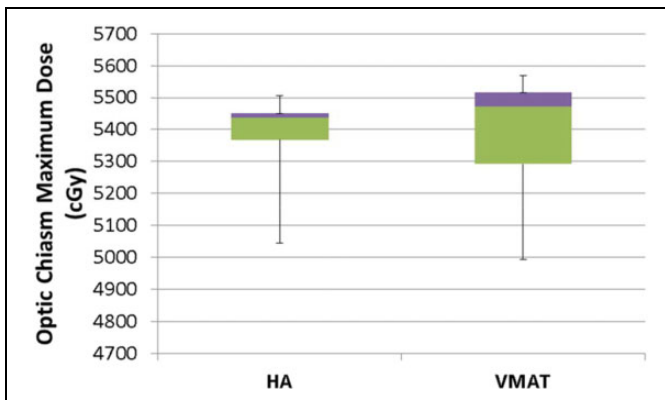


Figure 6. Optic chiasm maximum dose of HA and VMAT plans. HA indicates hybrid arc; VMAT, volumetric-modulated arc therapy.

the 13 patients. Optic chiasm maximum doses are 53.86 ± 1.28 Gy (range: 50.44-55.05 Gy) and 53.95 ± 1.81 Gy (range: 49.93-55.69 Gy), respectively. Figure 7 shows MU efficiencies of HA and VMAT plans of the 22 patients. The MU efficiencies of HA and VMAT plans are 2.57 ± 0.25 (range: 2.14-3.06) MU/cGy and 2.68 ± 0.24 (range: 2.12-3.22) MU/cGy, respectively.

The results show that HA plans have smaller CI ($P = .4$), GI ($P = .0001$), and HI ($P = .0001$), that is, better dose conformity on PTV, faster dose falloff outside PTV, and more homogeneous dose distribution within PTV. Figure 8 shows CI, GI, and HI as functions of PTV volume. The differences of the indexes between HA and VMAT plans do not show PTV-volume dependence. Comparisons of brainstem maximum doses and comparisons of optic chiasm maximum doses do not show significant differences between HA and VMAT plans ($P = .1$ and $P = .4$, respectively). Monitor unit efficiency comparisons show that HA and VMAT plans have similar MU efficiencies ($P = .2$).

Discussion

In our experience, dynamic arcs usually generate such a dose distribution: dose in the center of the target is 20% to 30% higher than the periphery. Therefore in the HA planning, we chose 8:2 to 7:3 ratio between dynamic arc portion and IMRT portion of the HA plan, to let the dynamic arc contribute most of the dose, while there is still room for the IMRT to optimize the intensity, so that the dose in the target can be more uniform. The ratio was selected based on the MLC margin used for the dynamic arcs: by our experience, if a 0 to 1 mm MLC margin is used, the peripheral dose generated by dynamic arcs will be $\sim 70\%$ of the maximum dose, then 7:3 ratio is used; if a 1~2 mm MLC margin is used, the peripheral dose generated by dynamic arcs will be above 80% of the maximum dose, and then 8:2 ratio is used. We plan to further investigate the optimal ratio in HA planning in the future.

Although the statistical analyses show that CI, GI, and HI favor HA plans, the amounts of the differences of CI, GI, and HI between HA and VMAT plans are small, which are 0.08 ± 0.05 , 0.65 ± 0.46 , and 0.02 ± 0.01 , respectively. Both HA and VMAT plans are clinical acceptable.

The results show that HA and VMAT plans have similar dosimetric results. For clinics where both HA and VMAT modalities are available, either HA or VMAT can be used for intracranial radiotherapy. In our clinical practice, since the PTV and

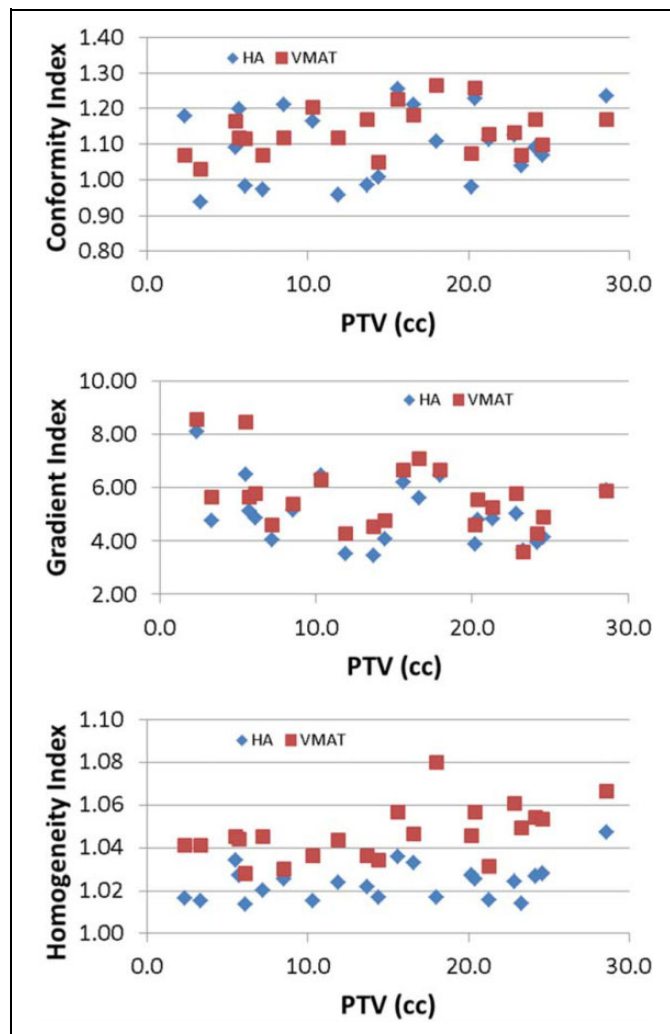


Figure 8. Conformity index, gradient index, and homogeneity index versus PTV volume. PTV indicates planning target volume.

OARs are drawn in iPLAN image (version 4.1), from the operation perspective, it is easier to generate an HA plan in iPlanDose TPS. According to our experience, if HA and VMAT have the same number of arcs, the delivery time of HA plan is slightly longer than that of VMAT plan because HA has IMRT beams in addition to arc beams. But the total treatment time of an HA treatment is similar to that of a VMAT treatment because the majority of the treatment time is spent on patient setup and image verification and the difference in beam delivery time between HA and VMAT plans is minimal. In our study, a HA plan has 5 to 6 IMRT beams and a VMAT plan has 3 to 4 VMAT beams. We found that the time spent on plan quality assurance (QA) measurement of a HA plan and a VMAT plan was similar when we used the same device, such as a ScandiDos Delta4 phantom (Uppsala, Sweden), for both plan QA.

As HA can be implemented on any linear accelerator equipped with DCA and IMRT techniques, in clinics where DCA and IMRT are available but VMAT is not, HA can be used.

Conclusions

Hybrid arc plans demonstrate slightly better dose conformity and dose homogeneity, and slightly steeper dose falloff outside PTV. The differences are however clinically insignificant. Brainstem maximum doses and optic chiasm maximum doses are similar between HA and VMAT plans. Hybrid arc and VMAT plans, which have similar MU efficiencies, present similar dosimetric results in the fractionated intracranial radiotherapy.

Authors' Note

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Declaration of Conflicting Interests

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