A COMPREHENSIVE COMPARISON OF VMAT AND DCAT PLAN QUALITY FOR STEREOTACTIC RADIOSURGERY ON ECLIPSE V13.6 AT THE 108 MILITARY CENTRAL HOSPITAL

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Abstract:

- Purpose: Comparing the dosimetric parameters of the DCAT technique with those of the VMAT technique which were used for primary brain tumors and brain metastases stereotactic radiosurgery (SRS)
- Material and Methods: The data of Computed Tomography simulations (CT- sim) of 10 single-lesion patients and 5 patients with single lesion close to OARs treated with DCAT were reused to generate VMAT plans on Eclipse v13.6. Dose coverage at PTV(Q), quality indexes: Conformity Index (CI), Homogeneity Index (HI), Gradient Index (GI), the volume of normal brain receiving 12 Gy (V12) and Beam On Time (BOT) were collected for evaluation and comparison after pretreatment quality assurance (QA).
- Conclusions: In both groups, the DCAT technique performed better in protecting and reducing side effects for healthy organs despite some quality indexes of VMAT were superior.

***Keywords**: SRS, VMAT, DCAT, TrueBeam STx, CI, HI, GI, V12.*

Tóm tắt:

- Mục đích: So sánh, đánh giá các kế hoạch xạ phẫu (SRS - Stereotactic Radiosurgery) điều trị bệnh nhân ung thư sọ não sử dụng hai kỹ thuật Dynamic Conformal Arc Therapy (DCAT) và Volumetric Modulated Arc Therapy (VMAT) bằng phần mềm Eclipse v13.6.
- Đối tượng và phương pháp: Dữ liệu CT mô phỏng của 10 bệnh nhân đơn tổn thương, 5 bệnh nhân đơn tổn thương gần cơ quan nguy cấp đã được điều trị bằng DCAT được sử dụng lại để lập kế hoạch bằng kỹ thuật VMAT trên phần mềm Eclipse v13.6. Độ bao phủ liều Q, các chỉ số chất lượng Comformity Index (CI), Homogeneity Index (HI), Gradient Index (GI), thể tích não lành nhận liều 12 Gy (V12) và thời gian phát tia được sử dụng để đánh giá kế hoạch sau khi đã được kiểm chuẩn.
- Kết luận: Trong cả hai nhóm, kỹ thuật DCAT hoạt động tốt hơn trong việc bảo vệ và giảm tác dụng phụ cho các cơ quan lành mặc dù một số chỉ số chất lượng của VMAT là vượt trội.

***Từ khóa**: SRS, VMAT, DCAT, TrueBeam STx, CI, HI, GI, V12.*

INTRODUCTION

The American Cancer Society has announced guidelines for managing primary brain tumors and brain metastases, in which radiological SRS is considered the main option to improve survivability and possibly the best treatment option for brain metastases when the quality of life is considered the most important result [1].

The Department of Radiation Oncology and Radiosurgery – The 108 Military Central Hospital applied SRS in treating patients with primary tumors and metastases in the brain on TrueBeam STx radiotherapy system (TrueBeam STx machine) with Varian Eclipse Treatment Planning System v13.6 since 2017.

For SRS plans, DCAT and VMAT are the techniques used to deliver better dose distribution in the treatment volume while sparing healthy organs and remained healthy brain areas. This study focused on comparing and evaluating the quality of the DCAT and VMAT plans to find the appropriate and optimal treatment for primary and metastases brain tumor patients. The indicators used to evaluate the plans were the Conformity Index (CI), the Homogeneity Index (HI), the Gradient Index (GI), the volume of healthy brain receiving at least 12 Gy (V12) and Beam On Time (BOT).

MATERIAL AND METHODS

15 patients with primary brain cancer or brain metastases treated with DCAT on TrueBeam Stx were replant with VMAT. Patients had CT simulation in the supine position with a slice thickness of 1 mm. 14 patients were treated using the photon beam 6X-FFF with the dose rate of 1400 MU/minute, 1 patient was planned to treat with the photon beam 10X-FFF, and the dose rate of 2400MU/minute. The tumor volume, location and prescription dose of the 2 groups of patients are presented in Table 1 [14].

All plans used multiple noncoplanar partial arcs. The arcs and projection field arrangements for the lesions located on the left, center and right side of the brain are shown below:

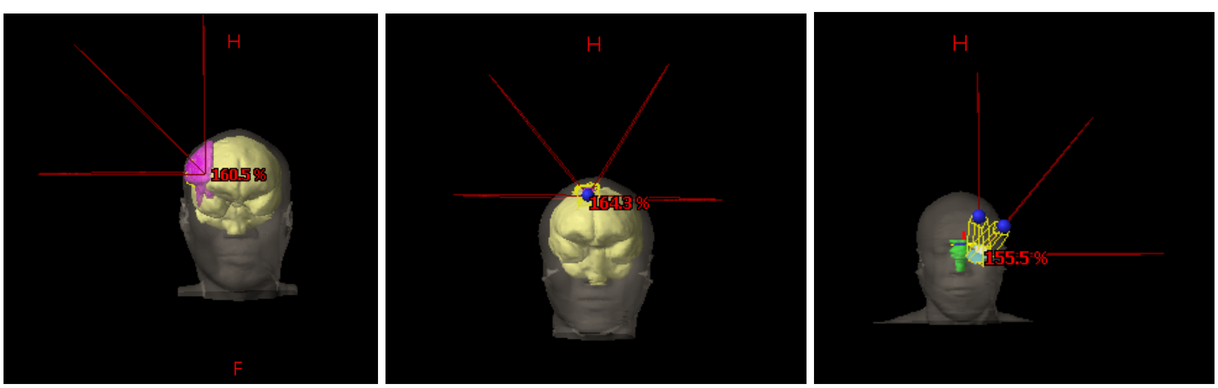

Figure 1. Modalities of noncoplanar partial arcs with the lesion on the left, center and right.

The corresponding VMAT plan with each DCAT plan was optimized with the same parameters of arcs, projection field, energy level and dose rate of each plan. All VMAT plans were performed pretreatment Quality Assurance (QA) using the Electronic Portal Imaging Device (EPID), and the gamma index method was used to qualify the agreement between calculation and measurements. Plan acceptance criterion was the gamma pass rate reaches ≥ 95% (2%/1 mm) [2].

Table 1. Parameter volume, tumor location and prescription dose schedule of stereotactic radiosurgery plans.

Patients	**Case**	**V_{PTV} (cc)**	**Prescription dose**
1	1 lesion	1.80	17Gy/1Fx
2	1 lesion	2.10	22Gy/1Fx
3	1 lesion	0.90	20Gy/1Fx
4	1 lesion	0.60	24Gy/1Fx
5	1 lesion	1.08	24Gy/1Fx
6	1 lesion	2.59	20Gy/1Fx
7	1 lesion	2.45	25Gy/1Fx
8	1 lesion	1.30	25Gy/1Fx
9	1 lesion	4.48	18Gy/1Fx
10	1 lesion	4.94	22Gy/1Fx
11	1 lesion-OARs	1.08	18Gy/3Fx
12	1 lesion-OARs	2.46	18Gy/3Fx
13	1 lesion-OARs	0.74	16Gy/1Fx
14	1 lesion-OARs	0.90	12Gy/1Fx
15	1 lesion-OARs	4.49	20Gy/1Fx

The parameters used for evaluation and comparison included: Conformity Index (CI), Homogeneity Index (HI), Gradient Index (GI), V12 and BOT of all plans. The formulas for indexes CI, HI, and GI are given in Table 2.

Table 2. The formulas of indicators for planning evaluation.

** V_{100}: volume is covered by 100% copper contour, V_{PTV}: PTV volume, V_{PTV100}: PTV volume is 100% indicated dose, V_{100}: volume is covered by 100% isodose line, Dmax : dose maximum, D_P: specified dose, D_5, D_{95}: dose at 5% and 95% volume, V_{PTV50}: volume covered by the 50% isodose line, $R_{Eff,Rx}$ are the radius of the specified volume area, $R_{Eff,\ 50\%Rx}$ is the radius of the volume area covered by the 50% isodose line.*

CI	**RTOG[3]**	**Paddick 2000 [4]**
	$CI_{RTOG} = \frac{V_{100}}{V_{PTV}}$	$CI_{Paddick} = \frac{{V_{PTV100}}^2}{V_{PTV} \times V_{100}} = \frac{V_{PTV100}}{V_{PTV}} x \frac{V_{PTV100}}{V_{100}}$
HI	RTOG [3]	Wu Qiuwen [5]
	$HI_{RTOG} = \frac{D_{max}}{D_P}$	$HI_{Wu} = \frac{D_5 - D_{95}}{D_P}$
GI	Paddick 2006 [6]	Wagner 2003 [7]
	$GI_{Paddick} = \frac{V_{PTV50}}{V_{PTV}}$	$GI = 100 - 100x((R_{Eff,\ 50\%Rx} - R_{Eff,\ Rx}) - 0.3cm)$

- V12 (the healthy brain volume received 12 Gy): Mark et al. and Lawrence et al. [8], [9] had demonstrated that V12 is significant in predicting necrosis in SRS. When assessing treatment plans, this indicator was expected to be as small as possible.

- BOT: the time when the transmitter beams the beam to the patient

$$t = \frac{MUs_{total}}{dose\ rate}(minutes)$$

MU is the unit used to measure radiation dose emitted by LINAC accelerator [10]. The dose rate (MU/minute) is the amount of radiation emitted in a 1-minute period. In this report, 14 patients used a dose rate of 1400 MU/minute, 1 patient used a dose rate of 2400 MU/minute.

Criteria for the plan evaluation:

• Homogeneity Index: Pass if HI ≤ 2, can be accepted if 2 < HI ≤ 2.5.

• Conformity Index: Pass if 1.0 ≤ CI ≤ 2.0, can be accepted if 0.9 ≤ CI ≤ 1 or 2.0 ≤ CI ≤ 3.5.

• Gradient Index: Pass if 3 ≤ GI ≤ 5, can be accepted if GI < 3.

• The volume of healthy brain receiving 12 Gy: Pass if V12 ≤ 10 cc (single fraction).

RESULTS

The obtained data of the two DCAT and VMAT plans showed that the dose coverage of the target volume, as well as the surrounding healthy organs were consistent with the recommendation of the AAPM TG 101 [11].

The quality indicators and physical characteristics of plans for patients with a single lesion and patients with a single lesion close to OARs were summarized in Table 3 and Table 4. Dose of some organs at risk were summarized in Table 5.

V12 was shown in chart 1 and chart 2.

Table 3. Comparison of CI, HI and GI in single lesion cases.

Patient	CI				HI				GI			
	RTOG		Paddick		RTOG		Wu		Paddick		Wagner	
	VMAT	DCAT	VMAT	DCAT	VMAT	DCAT	VMAT	DCAT	VMAT	DCAT	VMAT	DCAT
1	1.17	1.17	0.86	0.89	1.35	1.36	0.26	0.20	4.33	4.33	86.41	86.41
2	1.14	1.14	0.85	0.85	1.33	1.31	0.23	0.23	4.33	4.29	83.53	84.01
3	1.11	1.17	0.88	0.88	1.46	1.47	0.36	0.36	5.44	5.44	86.66	86.66
4	1.17	1.63	0.83	0.83	1.34	1.33	0.25	0.24	6.50	6.50	87.43	87.43
5	1.06	1.45	0.91	0.91	1.40	1.40	0.28	0.28	5.61	5.61	89.13	89.13
6	1.12	1.12	0.87	0.94	1.64	1.46	0.51	0.45	3.55	3.71	88.47	86.61
7	1.06	1.06	0.89	0.89	1.42	1.42	0.34	0.33	3.43	3.47	89.19	88.69
8	1.31	1.31	0.75	0.75	1.41	1.42	0.26	0.26	5.38	5.31	85.36	85.93
9	1.12	1.12	0.88	0.88	1.55	1.55	0.44	0.44	3.15	3.13	86.20	86.56
10	1.01	1.01	0.93	0.93	1.36	1.37	0.30	0.30	3.10	3.10	82.07	82.07

Mean	1.13	1.22	0.87	0.88	1.43	1.41	0.32	0.31	4.48	4.49	86.44	86.35
SD	0.05	0.13	0.03	0.04	0.07	0.05	0.06	0.06	0.91	0.89	1.57	1.28

Table 4. Comparison of CI, HI and GI in the case of single lesion close to OARs.

Patient	**CI**				**HI**				**GI**			
	RTOG		Paddick		RTOG		Wu		Paddick		Wagner	
	VMAT	DCAT	VMAT	DCAT	VMAT	DCAT	VMAT	DCAT	VMAT	DCAT	VMAT	DCAT
1	1.02	1.00	0.80	0.80	1.32	1.31	0.28	0.28	5.00	4.91	85.20	85.87
2	1.14	1.06	0.86	0.93	1.45	1.39	0.32	0.30	4.11	3.94	83.33	82.99
3	1.08	1.20	0.80	0.80	1.66	1.57	0.53	0.50	4.32	3.92	96.17	96.61
4	1.11	1.09	0.88	0.88	1.59	1.59	0.43	0.43	4.44	4.44	93.55	93.55
5	1.14	1.14	0.86	0.86	1.55	1.56	0.40	0.40	3.30	3.30	84.46	84.46
Mean	1.10	1.10	0.84	0.86	1.51	1.48	0.39	0.38	4.23	4.10	88.54	88.70
SD	0.03	0.05	0.03	0.04	0.09	0.09	0.06	0.06	0.36	0.38	4.21	4.26

Table 5. Dose value of some organs at risk

Organs	**Mean dose**		**Maximum dose**	
	VMAT	**DCAT**	**VMAT**	**DCAT**
Optic chiasm	0.62 ± 0.41	0.63 ± 0.43	1.60 ± 1.16	1.61 ± 1.15
Normal brain	0.57 ± 0.14	0.57 ± 0.14	23.23 ± 3.22	22.98 ± 3.35
Brainstem	1.03 ± 0.83	1.03 ± 0.84	5.94 ± 5.13	5.88 ± 5.11
Left optic nerve	0.38 ± 0.31	0.37 ± 0.31	0.99 ± 0.85	0.96 ± 0.82
Right optic nerve	0.38 ± 0.35	0.37 ± 0.34	0.55 ± 0.49	0.55 ± 0.52

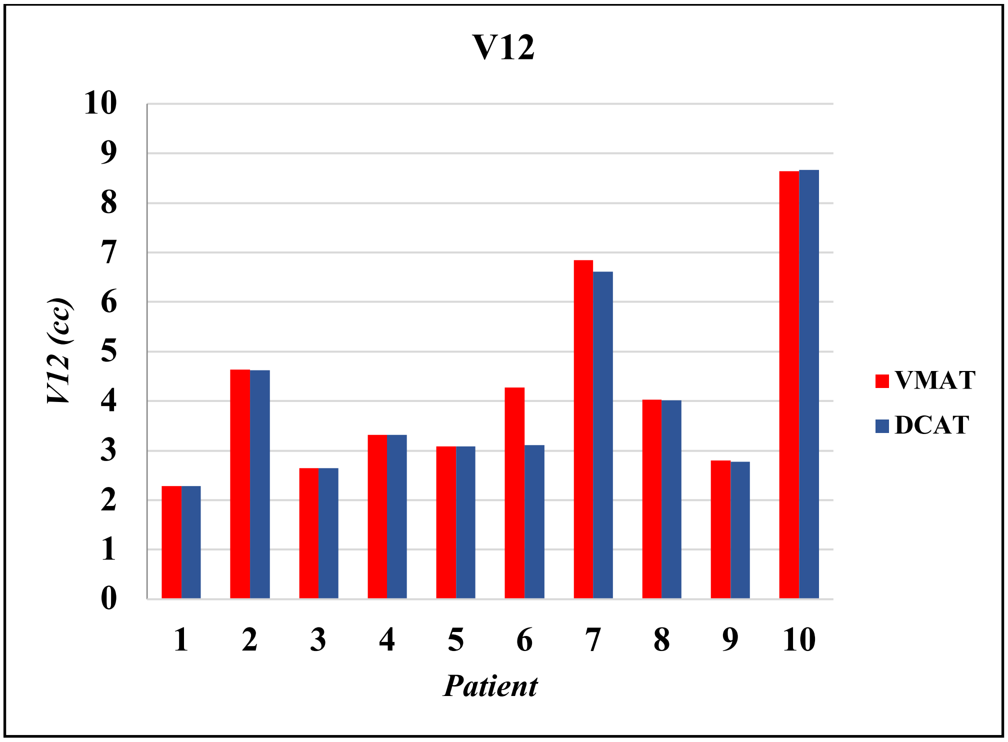

Figure 2. Comparison of V12 in the case of a single lesion.

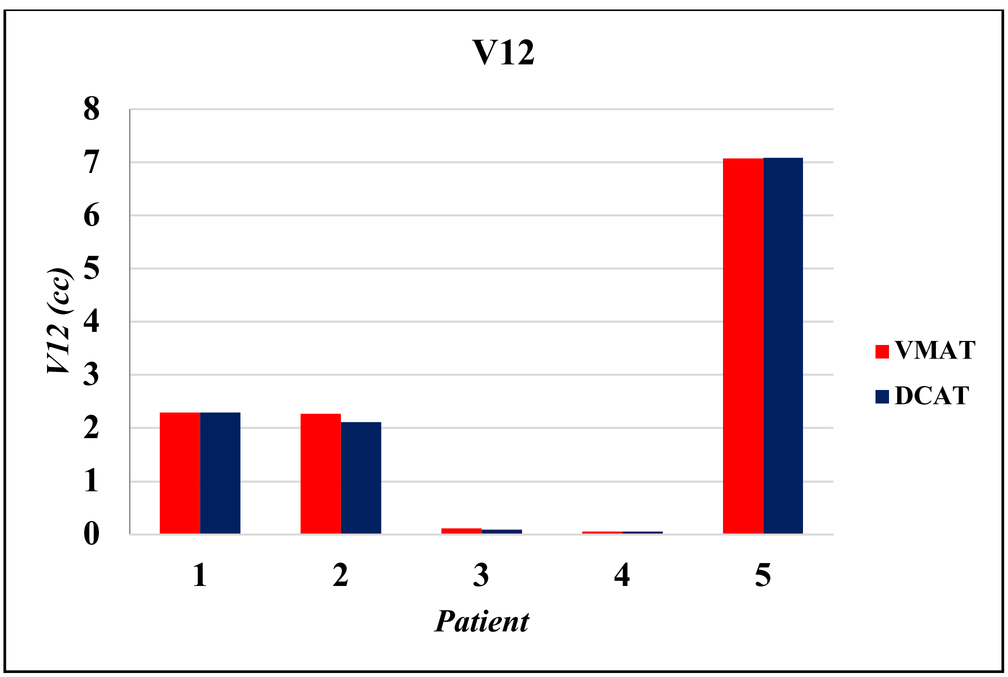

Figure 3. Comparison of V12 in the case of a single lesion close to OARs patient.

A. The cases of single lesion

The VMAT technique gave dose coverage (91.76 ± 2.91) in PTV was 1.4% better than DCAT (90.47 ± 3.95). The CI_{RTOG} index of VMAT (1.13 ± 0.05) was closer to the ideal value (the ideal value = 1) than DCAT (1.22 ± 0.13). The ability to reduce the volume of surrounding healthy organs receiving high doses of both techniques was good and relatively equal considering $CI_{Paddick}$ index (ratio V_{PTV100}/V_{100} is 0.88 ± 0.03 and 0.88 ± 0.04 in VMAT and DCAT respectively). Regarding the HI index, the DCAT technique by RTOG [3] and Wu Qiuwen [5] was better than VMAT (HI_{RTOG}: 1.41 ± 0.05 compared to 1.43 ± 0.07 and HI_{Wu}: 0.31 ± 0.06 compared to 0.32 ± 0.06). DCAT and VMAT provided similar GI according to the Paddick's formula [6] (VMAT: 4.48 ± 0.91 and DCAT: 4.49 ± 0.89) and Wagner [7] (VMAT: 86.44 ± 1.57 and DCAT: 86.35 ± 1.28). DCAT was superior to VMAT in the ability to control cerebral necrosis because the healthy brain volume received 12Gy of DCAT (4.12 ± 1.37) was 3.29% smaller than that of VMAT (4.26 ± 1.34). The emission time of both techniques was equivalent (4.95 ± 0.53 in VMAT and 4.90 ± 0.60 in DCAT).

B. The cases of single lesion close to OARs

PTV dose coverage was found better with the VMAT technique (87.00 ± 3.39) than the DCAT technique The CI index of VMAT technique (85.22 ± 3.94). The CI_{RTOG} index of VMAT (1.10 ± 0.03) and DCAT (1.10 ± 0.05) were the same and close to the ideal value. Considering the $CI_{Paddick}$ index, the ability to reduce the volume of surrounding healthy organs receiving a higher dose of DCAT better than VMAT (ratio V_{PTV100}/V_{100} is 0.86 ± 0.02 and 0.87 ± 0.03 in VMAT and DCAT respectively). Regarding the HI index, DCAT by RTOG [3] and Wu Qiuwen [5] produced better dose homogeneity than VMAT (HI_{RTOG}: 1.48 ± 0.09 compared to 1.51 ± 0.09 and HI_{Wu}: 0.38 ± 0.06 compared to 0.39 ± 0.06). DCAT provided the GI index 3.07% better than that of VMAT according to the Paddick's formula [6] (VMAT: 4.23 ± 0.43 and DCAT: 4.10 ± 0.46). According to Wagner [7], DCAT and VMAT introduced the similar GI (VMAT: 88.54 ± 5.05 and DCAT: 88.70 ± 5.11). For healthy brain protection, both techniques were equivalent (VMAT: 2.19 ± 1.58 and DCAT: 2.17 ± 1.59). The BOT of both plans was similar (VMAT: 2.65 ± 1.09 and DCAT: 2.61 ± 1.08).

DISCUSSIONS

With the collected data, the study demonstrated that both VMAT and DCAT plans achieved dose coverage at PTV greater than 0.8 (within the small limit). The VMAT technique provided better PTV dose coverage than DCAT in both groups.

In terms of dose uniformity, there was a difference between the two groups of patients. For the patients with a single lesion, the CI_{RTOG} indicated that the VMAT technique was more optimized than DCAT. While for the patients with a single lesion close to OARs, there was no difference in CI_{RTOG} values between the two techniques (1.10 ± 0.03 versus 1.10 ± 0.05). The CI results were similar to the CI_{RTOG} values in the study of Haisong Liu et al (1.19 ± 0.14) [12].

Statistics of 15 patients showed that the DCAT technique provided a smaller maximum dose point and better dose uniformity in comparison to VMAT. Gevaert et al. [13] investigating the dosimetric performances of Novalis-Tx (with dynamic conformal arcs), CyberKnife and GammaKnife for 15 patients with arterious malformation and acoustic neuromas gave a HI index of 0.30 ± 0.03 for DCAT. This result was similar to the HI_{Wu} value in this report (0.31 ± 0.06 in single lesion patient group).

This study also compared the GI values of two VMAT and DCAT techniques. With the group of patients with a single lesion, the GI values according to Paddick and Wagner areWERE the same. However, for patients with a single lesion close to OARs, DCAT provided a dose reduction from 100% to 50% better than VMAT according to Paddick's formula (GI_{VMAT}: 4.23 ± 0.43 and GI_{DCAT} is 4.10 ± 0.46).

According to the statistics, the DCAT technique reduced the incident of brain necrosis with V12 was smaller than that of the VMAT technique (3.53 ± 1.67 opposed to 3.63 ± 1.72). Therefore, the brain function was maintained better with DCAT.

Statistical results showed that the monitor unit numbers of both plans were almost the same. Based on statistics, the average emission time of the two techniques was small, with BOT_{VMAT} and BOT_{DCAT} were 4.95 ± 0.53 and 4.90 ± 0.60 respectively for the single lesion patient group and 2.65 ± 1.09 and 2.61 ± 1.08 for the single lesion close to OARs patient group.

This study only concentrated on the VMAT and DCAT techniques for cranial tumor treatment. In the future we will conduct surveys on other areas of the body, other techniques with a larger number of patients to ensure the statistical reliability of the results, thereby giving recommendations on the use of modern radiotherapy techniques to conduct treatment for cancer patients.

CONCLUSIONS

The study confirmed that both VMAT and DCAT outcomes satisfied the recommendations of AAPM TG 101 [11]. However, in both groups, the DCAT technique surpassed the VMAT technique in the reduction of dose for the brain and other healthy organs even if some VMAT quality indicators were better. Therefore, the DCAT technique have been giving priority for cranial stereotactic radiosurgery on TrueBeam STx in the 108 Military Central Hospital

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