The Optimal Choice of Technique for Stereotactic Radiosurgery—A LINAC-Based Dosimetric Study between DCA, DCA-SSO, DCA-SSO-VDR, and VMAT

Ramya Venugopal1 Sowmya Narayanan S.1 Richa Tiwari2 Geeta S. Narayanan2 Bhaskar Vishwanathan2

1 Department of Radiation Physics, Vydehi Institute of Medical Sciences and Research Centre, Bangalore, Karnataka, India
2 Department of Radiation Oncology, Vydehi Institute of Medical Sciences and Research Centre, Bangalore, Karnataka, India

Address for correspondence Ramya Venugopal, Post MSc, Dip Rp, Department of Radiation Physics, Vydehi Institute of Medical Sciences and Research Centre, White Field, Bangalore-560066, Karnataka, India (e-mail: kvramyamedphy@gmail.com).

Abstract

Introduction Advanced radiation therapy delivery techniques require greater understanding of various planning sequences and methods. The aim of this study is to determine a class solution that finds the best possible technique to deliver for stereotactic radiosurgery between dynamic conformal arc (DCA) techniques using various options such as DCA, DCA + SSO (segment shape optimization), and DCA + SSO + VDR (variable dose rate) using noncoplanar beam arrangement and volumetric modulated arc therapy (VMAT) using coplanar beams.

Materials and Methods In this dosimetric study, 11 brain cases were retrospectively planned for various techniques and analyzed for the Paddick conformity index (CI), Radiation Therapy Oncology Group homogeneity index (HI), Paddick gradient index (GI), treatment time in terms of monitor units (MU) and normal brain dose (V12Gy). The paired t-test was performed to know the statistical significance between the techniques.

Results In terms of CI, GI, and control of the normal brain dose, the VMAT plan was superior to other techniques. But, HI was found to be better with DCA. Above all, VMAT delivered higher MU than any other technique. The p-values between DCA + SSO and DCA, DCA + SSO + VDR and DCA + SSO, and VMAT and DCA + SSO + VDR are as follows: CI: 0.0004, 0.015, and 0.03; GI: 0.03, 0.33, and 0.29; HI: 0.008, 0.04, and 0.06; V12 Gy of normal brain: 0.1, 0.01, 0.38. VMAT requires approximately 41 ± 17% more MU than DCA + SSO + VDR.

Keywords ► DCA ► SRS ► VMAT

Conclusion VMAT using coplanar beams is preferable among all the techniques, considering the dosimetric parameters studied. If VMAT is not available in the facility, DCA + SSO + VDR technique using non coplanar beams can be used to deliver SRS treatment.

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Introduction

Stereotactic radiosurgery (SRS) of an intracranial lesion combines the stereotactic apparatus and energetic radiation beams to irradiate the lesion with single treatment. SRS is in practice since 1940. Various modalities are used to deliver SRS starting from gamma knife, cyber knife, tomotherapy, and linear accelerator. In linear accelerator, cones or multi-leaf collimators (MLCs) are used to deliver the treatment. Linear Accelerator (LINAC)-based SRS procedure using volumetric modulated arc therapy (VMAT) is newer concept in radiation oncology. Initially frame-based SRS was performed to improve the patient positioning. The recent advancement in imaging allows assessing the feasibility of frameless SRS. SRS and stereotactic radiotherapy (SRT) are different from standard plans not just in terms of fractionation but also allows maximum dose inside the target. These plans have better conformity index (CI) and gradient index (GI). The challenge in SRS and SRT is to accurately and precisely deliver high-dose radiation to the target and minimize dose to organ at risk (OAR).

There are various cases that are treated using SRS technique such as brain metastasis, arteriovenous malformation (AVM), meningioma, pituitary adenoma, and acoustic schwannoma.

While both single-dose SRS and whole brain radiation therapy (WBRT) are effective for treating patients with brain metastasis, single-dose SRS alone appears to be superior to WBRT alone for patients up to three brain tumors in terms of patient survival advantage. SRS is proven to be an effective strategy in the management of AVM over the past three decades. Smaller AVMs receiving higher marginal doses have obliteration rate of 70% and more.

Advanced radiation therapy delivery techniques require greater understanding of various planning sequences and methods. There are various techniques by which SRS can be delivered such as dynamic conformal arc (DCA) and VMAT. Both DCA and VMAT are rotational techniques. DCA is a forward planning technique where the user defines Gantry start and stop angle, collimator and couch angle. Target remains open inside the field for the entire treatment. This technique is suitable for simple targets. The DCA segment includes the entire target, less than any avoidance structure. When segment shape optimization (SSO) is included in the DCA (DCA + SSO), the small MLC leaf positions adjustments are done in the periphery that improves plan quality without using VMAT-style segmentation. The modern LINACs that are VMAT capable of delivering VMAT can deliver DCA + SSO using variable dose rate (DCA + SSO + VDR) option.

VMAT is an inverse planning technique where the MLC speed, dose rate, and gantry speed are all modulated together to create extremely conformal dose distribution. This technique is suitable for even concave shaped tumors. Actually, VMAT requires a high degree of QA and tighter LINAC tolerances due to smaller fields and variation in dose rate while gantry is moving. Since the size of the tumor is small in SRS, delivering the segments that are produced in VMAT will have uncertainty.

In Elekta Versa HD, there are various options to deliver DCA that are DCA, (DCA + SSO), and (DCA + SSO + VDR). The choice of technique is crucial in SRS since the dose per fraction is high.

With the advancement of technology, there are various ways by which DCA can be delivered and there are only few studies done to know the difference between DCA and VMAT. The aim of the study is to determine a class solution that finds the best possible technique to deliver SRS between DCA among various options using noncoplanar beams and VMAT using coplanar beams. This study also provides reliable guidelines toward establishing viable planning strategies and form a basis of ready reckoning in high-precision radiotherapy planning.

Materials and Methods

Eleven brain cases were taken for the study that include seven solitary metastases, one acoustic schwannoma, two meningioma, one pituitary adenoma of volume ranging from 0.93 to 22.5 cc (median: 4.99 cc) (Fig. 1). Nine SRS and 2 SRT cases were included in the study. The total prescribed dose was in the order of 18 to 30 Gy. Patients were simulated using Fraxion, a unique immobilization device that is a combination of thermoplastic mask and mouth bite in which vacuum is created using negative pressure. A plain computed tomography (CT) scan acquired using 1.25 mm slice thickness. If required, patients were administered contrast material. This plain image is fused with contrast image for better delineation of target and critical structures. Plan was created in plain CT to avoid any change in CT number when contrast material is used.

Planning was done using Monaco TPS (v.5.11.03). Body contour was created using EZ sketch option. EZ sketch is used to contour all image sets that are axial. Magnetic resonance imaging (MRI) and positron emission tomography-computed tomography (PET-CT) images were used to fuse with CT for accurate delineation of the target. Angio images were not used as MRI and PET-CT images were providing information for target delineation. Planning target volume (PTV) is created with 2 mm margin from Gross tumor volume (GTV). Healthy brain volume was defined as a total brain volume excluding PTV. All structures were created according to Radiation Therapy Oncology Group (RTOG) protocols.

MLC used in planning is Agility that has an 80 pair comprising 160 individual leaves, each of 5 mm thickness.

For each patient, four plans were created in Monaco planning system: DCA, DCA + SSO, DCA + SSO + VDR and VMAT. All DCA plans consisted of noncoplanar beams. Couch angle was decided based on the location of the lesion spaced at least 30 degrees. VMAT was planned only with coplanar beams that consisted of either full or partial arc based on the tumor location. The planning objective was 95% volume of PTV that had to be covered by at least 95% of prescription isodose line. The PTV coverage was satisfying the planning objective in all the techniques. All the plans were created using six flattening filter free (FFF). Two-stage optimization
was done using biological optimization parameters. Grid size of calculation was set to be 0.3 cm. The calculation algorithm used in TPS is Monte Carlo. The surface margin of 0.3 cm and beamlet width of 0.2 cm were manually entered in the intensity-modulated radiation therapy (IMRT) parameters column. Both the target and avoidance margin given were very tight (0–1mm). The statistical uncertainty given per calculation was 1%.

DCA was planned using noncoplanar beams. The other dynamic conformal plans were also created to achieve the same coverage using the same beam geometry. The VMAT plan was created using single arc coplanar beam and optimized. The maximum control points per arc was set to be 180.

The plan quality was evaluated using CI, HI, GI, dose to normal brain, MU delivered. Plan evaluation was performed using CI and GI as proposed by Paddick.\(^6\)

\[ \text{Paddick CI} = \frac{(TVPIV)^2}{(TV \times PIV)} \]

\[ TVPIV = \text{target volume covered by prescription isodose volume} \]
\[ TV = \text{target volume} \]
\[ PIV = \text{prescription isodose volume} \]
\[ CI_{\text{Paddick}} \text{ will have an ideal value of 1 and plan quality decreases with decreasing CI value.} \]
\[ GI \text{ was calculated using Paddick GI formula.} \]
\[ \text{Paddick GI} = \frac{V_{50}}{V_{100}} \]
\[ V_{50} = \text{Volume receiving 50\% of prescription dose} \]
\[ V_{100} = \text{Volume receiving 100\% of prescription dose} \]

A perfect plan will have a Paddick GI that approaches 1. Homogeneity index was calculated using RTOG formula

\[ HI = \frac{I_{\text{max}}}{RI} \]
\[ I_{\text{max}} = \text{Maximum dose in the target.} \]
As per guidelines, less than or equal to 2 is considered as normal value.

Results

In terms of conformity, the VMAT shows superiority than other DCA techniques. CI of DCA was 0.6, whereas for VMAT, it was 0.78. Out of 11 patients, 2 patients had VMAT plan CI just same as DCA + SSO + VDR.

Considering dose gradient, both the DCA + SSO + VDR technique and VMAT showed better results than simple DCA or DCA + SSO. The GI of DCA + SSO + VDR and VMAT was found to be 1.20 and 1.17, respectively.

To analyze the dose homogeneity, DCA shows homogeneous dose compared with other techniques. HI of DCA and VMAT was estimated as 1.17 and 1.28, respectively.

Treatment time required to deliver the technique was measured in terms of MU and it was found that VMAT was the highest among all other technique. The average MU to be delivered for DCA technique was 2507, whereas for VMAT, it was 4040.

Normal brain dose (V12Gy) was also analyzed between all the techniques. VMAT is capable of delivering lowest dose than any of the DCA techniques. The V12Gy of brain in VMAT was calculated as 11.14cc and in DCA as 16.75cc.

Refer \(\text{Table 1}\) for all the average value and \(p\)-value compared between various techniques.
Table 1  Average, standard deviation of different techniques and p-values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DCA (average)</th>
<th>DCA + SSO (average)</th>
<th>DCA + SSO + VDR (average)</th>
<th>VMAT (average)</th>
<th>p-Value (DCA vs. DCA + SSO, SSO vs. VDR, VDR vs. VMAT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>0.6 ± 0.14</td>
<td>0.69 ± 0.15</td>
<td>0.75 ± 0.15</td>
<td>0.78 ± 0.15</td>
<td>p = 0.0004, 0.015, 0.03</td>
</tr>
<tr>
<td>HI</td>
<td>1.17 ± 0.03</td>
<td>1.22 ± 0.05</td>
<td>1.26 ± 0.05</td>
<td>1.28 ± 0.07</td>
<td>p = 0.008, 0.04, 0.06</td>
</tr>
<tr>
<td>GI</td>
<td>1.35 ± 0.16</td>
<td>1.21 ± 0.07</td>
<td>1.20 ± 0.05</td>
<td>1.17 ± 0.04</td>
<td>p = 0.03, 0.33, 0.29</td>
</tr>
<tr>
<td>MU (avg)</td>
<td>2507 ± 954</td>
<td>2724 ± 1035</td>
<td>2818 ± 1094</td>
<td>4040 ± 1618</td>
<td>p = 0.001, 0.20, 0.0007</td>
</tr>
<tr>
<td>Brain dose (V12Gy)</td>
<td>16.75 ± 8</td>
<td>14.13 ± 6.6</td>
<td>11.75 ± 5.62</td>
<td>11.14 ± 6.67</td>
<td>p = 0.10, 0.01, 0.38</td>
</tr>
</tbody>
</table>

Abbreviations: CI, conformity index; DCA, dynamic conformal arc; GI, gradient index; HI, homogeneity index; MU, monitor unit; SSO, segment shape optimization; VDR, variable dose rate; VMAT, volumetric modulated arc therapy.

Fig. 2  Dose distribution of DCA, DCA + SSO, DCA + SSO + VDR, and VMAT plans. DCA, dynamic conformal arc; SSO, segment shape optimization; VDR, variable dose rate; VMAT, volumetric modulated arc therapy.
Discussion

All the 11 patients were planned for DCA using three different options (DCA, DCA + SSO, DCA + SSO + VDR) and VMAT. Hence, total four plans will be created per patient. The plan quality was analyzed using various parameters such as CI, HI, GI, beam ON time using MU, and normal brain dose. These parameters were compared between all four techniques.

Student paired t-test was performed in Excel Sheet to find the difference between the techniques. p-Value of 0.05 was considered to be significant. Therefore, 95% confidence interval was applied.

The Conformity Index

The average CI of different techniques was found separately. The p-value between DCA and DCA-SSO was found to be 0.0004. Between DCA-SSO and DCA-SSO-VDR, p-value was found to be 0.015. Between DCA-SSO-VDR and VMAT, p-value was found to be 0.03. Statistically, there was significant difference found between different methods of DCA and VMAT. But the CI is better with VMAT. The average value of CI of DCA, DCA + SSO, DCA + SSO + VDR, VMAT follows the order as 0.6 < 0.69 < 0.75 < 0.78. These results are matching with Jessica et al.2 which shows for single and multiple brain lesions CI is better in VMAT than DCA. Lagerwaard et al7 have performed a study on vestibular schwannoma. They compared the plan quality between DCA with single arc, DCA with five noncoplanar arc and VMAT and reported that VMAT is superior to DCA-single arc and DCA-5 arc.2,5,7 This could be because of the inverse optimization of the VMAT plans that adjusts the dose to the target (Figs. 4 and 5).

The Gradient Index

The GI is complementary to the CI. The reason being GI considered for analysis is high dose per fraction in stereotactic techniques. The GI average values of DCA, DCA + SSO, DCA + SSO + VDR, VMAT are as follows: 1.35 > 1.21 > 1.20 > 1.17. p-Value of DCA + SSO against DCA is 0.03 that shows
**Fig. 4** Conformity index of various techniques.

**Fig. 5** Correlation between PTV volumes and CI of different techniques. CI, conformity index; DCA, dynamic conformal arc; SSO, segment shape optimization; VDR, variable dose rate; VMAT, volumetric modulated arc therapy.
**Fig. 6** Gradient index (GI) of various techniques. DCA, dynamic conformal arc; SSO, segment shape optimization; VDR, variable dose rate; VMAT, volumetric modulated arc therapy.

**Fig. 7** Correlation between PTV volumes and GI of different technique. DCA, dynamic conformal arc; GI, gradient index; SSO, segment shape optimization; VDR, variable dose rate; VMAT, volumetric modulated arc therapy.
statistically there is difference between the methods. $p$-Value of DCA + SSO + VDR against DCA + SSO is 0.33. GI value of VMAT compared against DCA + SSO + VDR is found to be 0.29. The above result shows statistically no difference between DCA + SSO and DCA + SSO + VDR method and DCA + SSO + VDR and VMAT. And above all VMAT shows superiority than all other methods in terms of dose gradient. These results are same as Chang et al who compared the dosimetric parameters of DCA, intensity modulated radiosurgery (IMRS), and VMAT and showed that significant improvement in GI for VMAT and IMRT than DCA and concluded that VMAT is superior to the other two techniques in GI.\(^8\)

On the contrary, in stereotactic techniques the accuracy of the patient set up for treatment is crucial irrespective of the planning method. Even though the steep dose gradient in VMAT could be advantageous, the resulting deviation due to any treatment setup could result in significant dose error. But in case of DCA, there is less chance of deviation from the prescription dose due to setup error\(^9\)(\textit{Fig}. 6 and 7).

**The Homogeneity Index**

The HI explains the dose homogeneity within PTV. The average values found between the different techniques are shown in the order of DCA, DCA + SSO, DCA + SSO + VDR and VMAT 1.17 < 1.22 < 1.26 < 1.28. The $p$-value between DCA + SSO + VDR and VMAT alone shows 0.06 that shows statistically no significant difference. The other DCA methods show significance difference in homogeneity. Rudd et al who studied the difference between the modulated radiotherapy and DCA therapy concluded that DCA has better HI than modulated therapy for tumors smaller than 92 mL\(^10\)(\textit{Fig}s. 8 and 9).

**Treatment Time (MU)**

The treatment time is measured in terms of monitor units (MU). The average percentage of difference in MU delivered to DCA + SSO to DCA is 19.14 ± 5.56%. Difference between DCA + SSO + VDR to DCA + SSO is 3.61 ± 2.76%. On an average, VMAT delivers 41 ± 17% more MU than DCA + SSO + VDR. In VMAT, MUs are high due to many small segments used in the beam\(^1\).\(^8\)(\textit{Fig}s. 10 and 11).

Chang et al have measured the difference in MU between IMRS and VMAT from DCA and concluded that VMAT requires higher MU than DCA by a factor of 2.37.

In DCA, the delivery time will be faster since the MUs required to deliver are less than VMAT and hence DCA reduces the likelihood of intrafraction motion. On the other hand, DCA requires noncoplanar beams which requires the technologist to enter the treatment room in between the couch rotations. This increases the total time of delivery and
Correlation between PTV Volumes and HI of various techniques

**Fig. 9** Correlation between PTV volumes and HI of various techniques. DCA, dynamic conformal arc; HI, homogeneity index; SSO, segment shape optimization; VDR, variable dose rate; VMAT, volumetric modulated arc therapy.

Treatment time comparison between various techniques in terms of MU

**Fig. 10** Treatment time comparison between various techniques in terms of MU. DCA, dynamic conformal arc; MU, monitor unit; SSO, segment shape optimization; VDR, variable dose rate; VMAT, volumetric modulated arc therapy.
also intrafraction motion. This is imperative when the OAR is close to the PTV.

In terms of radiobiology, delivering the total dose in as short a time period possible is thought to be more effective, since this will minimize the time available for repair of radiation-induced DNA damage.\(^\text{11}\) From the radiobiological aspect, DCA has the advantage of less repair in tumor than other techniques.

**Normal Brain Dose**

Normal brain dose was evaluated as per RTOG protocol. V12Gy was compared between the techniques and tabulated. Out of 11 patients, 9 patients had VMAT dose less than any other DCA technique.\(^\text{2,8}\) Among DCA techniques, DCA shows highest dose than DCA + SSO or DCA + SSO + VDR techniques. A paired \(t\)-test performed between the techniques shows that statistically there is no significant difference between DCA versus DCA + SSO and DCA + SSO + VDR versus VMAT. There is significant difference between DCA + SSO and DCA + SSO + VDR in terms of brain dose.

Molinier et al have studied the difference in normal brain (\(V_{10\ Gy}\)) rapid arc noncoplanar (RANC), rapid arc coplanar (RAC), and rapid arc with table rotation (RA\(_t\)) of \(\pm 10\) degrees introduced for the same RA\(_c\) plan. And they have found that even though DCA enhances the healthy brain protection, RANC is best at it.\(^\text{2}\) Chang et al have studied the normal brain dose of \(V_{2Gy}\) between IMRT, VMAT, and DCA and found that VMAT has better sparing than IMRT or DCA\(^\text{8}\) (\(\rightarrow\) Fig. 12).

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**TYPICAL SEGMENT SHAPE OF VARIOUS TECHNIQUES OF DCA & VMAT**

![Typical segment shape of various techniques of DCA and VMAT. DCA, dynamic conformal arc; SSO, segment shape optimization; VDR, variable dose rate; VMAT, volumetric modulated arc therapy.](image-url)
Conclusion

A dosimetric comparative study was performed between DCA, DCA + SSO, DCA + SSO + VDR, and VMAT techniques. VMAT using coplanar beams shows superiority than other techniques. In VMAT, even though the MU was found to be high, the overall treatment time was less, as the plans were done using FFF beams having higher dose rate. In case, VMAT is not available, DCA + SSO + VDR using noncoplanar beams can be used to deliver SRS treatments as the plan quality is comparable with VMAT. Delivery of noncoplanar beams require robust mechanical QA verifications.

Conflict of Interest

None declared.

References


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