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Dosimetric Comparison of IMRT and VMAT Techniquesusing RTOG 0631 Guidelinesin Spine Sterotactic Body Radiosurgery

Hilal Acar[1*], AyseYildirim Altinok[2], Esra Kucukmorkoc[2], Mustafa Caglar[1], Pelin Altınok Sut[3], Nadir Kucuk[2], Mine Doyuran[2] and Hale Basak Caglar[2]

[1]Associate Professor, Medical Physics Department, Institute of Health Sciences, Medipol University, Istanbul, Turkey

[2]Assistant Professor, Department of Radiation Oncology, Medipol University, Istanbul, Turkey

[3]Department of Radiation Oncology, BezmiAlemVakıfÜniversitesi, Istanbul, Turkey

***Corresponding Author**: HilalAcar, PhD, Medical Physics Department, Institute of Health Sciences, Medipol University, Istanbul, Turkey, Zip code: 34075;Tel: +90(535)9395365; Fax: +90 (212) 446 16 08; E-mail:hilalacar@hotmail.com

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Abstract

Purpose: Volumetric modulated arc therapy (VMAT) and intensity modulated radiotherapy (IMRT) techniques were compared in terms of their dosimetric quality and treatment efficiency using Radiation Therapy Oncology Group (RTOG) 0631 guidelines for spine SBRT.

Methods: Ten previously treated patients were replanned. IMRT plans with 7 fields and VMAT plans with 1 and 2 full arcs were generated. All plans were prescribed to deliver 18.0 Gy in a single fraction to 90% of the target volume. RTOG 0631 recommendations were applied for treatment planning. Plans were compared to others based on spinal cord sparing, homogeneity, conformity and gradient indexies, monitor unit (MU) and beam on time (BOT).

Results: 2 arc VMAT plans had better dose coverage and more conformal dose distributions for the target volume than for 1 arc VMAT and IMRT plans. Although there was no difference in terms of homogeneity indexes among the plans, gradient and conformity indexes were improved for 2 arc VMAT techniques. In terms of spinal cord sparing,2 arc VMAT plans were superior to other plans. MU and BOT decreased with the 2 arc VMAT plans when compared to IMRT plans.

Conclusions: 2 arc VMAT plans provide better target volume coverage, favorable dose gradient and conformity and better organ at risk (OAR) sparing when compared to 1 arc VMAT and IMRT plans. 2 arc VMAT plans are also the best in terms of treatment efficiency since they require a much smaller number of MUs and thus a shorter treatment time than IMRT plans.

Keywords: VMAT; IMRT; Spine SBRT; RTOG 0631.

Introductıon

Spine column tumors, both primary and metastatic lesions, are quite often seen in cancer patients. For a variety of tumors, the spine is the most common site of metastatic disease. Radiotherapy has been established as an effective treatment modality for spinal tumors[1-4].

With the advent of image guided radiotherapy, high dose radiation with extremely steep drop off can be delivered to a limited target volume along the spine with very high precision. This procedure is known as Stereotactic Body Radiosurgery (SBRT) and provides a technique to rapidly treat spinal metastasis patients in one to five fractions with the delivery of a higher biologically effective dose of radiation which can provide better local tumor and pain control compared with more established approaches.

Intensity Modulated Radiotherapy (IMRT) is a treatment delivery technique based on inverse planning optimisation to modulate intensity beams by using Multi Leaf Collimator (MLC). During dynamic IMRT, the leaves are adjusted while the beam is on. IMRT allows the possibility of producing concave dose distributions and providing specific sparing of normal tissue.

Volumetric-modulated Arc Therapy(VMAT) is a treatment technique, which delivers the radiation dose during rotation of the gantry of a linear accelerator. The implementation of VMAT available on Varian (Varian Medical Systems, Palo Alto, CA) equipment is called RapidArc®. The radiation intensities depend on the speed of gantry rotation, the motion of MLC and the dose rate modulation.

In this study we aimed to compare VMAT and fixed field IMRT techniques in terms of their dosimetric quality and treatment efficiency in spine sterotactic radiosurgery.

Material and Methods

Ten patients treated with spinal tumor of cervical, thoracic and lumbar region at our institution were selected for this study. Three sets of plans were generated and compared. All IMRT,1 arcVMAT and 2 arc VMAT plans were done using 6 MV photons of a Varian Triology (Varian Medical Systems, Palo Alto, CA).Beam shaping with the Trilogy is achieved with the 120 leaf Millennium MLC.

CT Simulation

All patients had a planning computed tomography (CT) scan for treatment planning. With regards to patient immobilization, for treatment in the mid-lower thoracic and lumber regions, we use a vacuum bed cushion that is set to conform to the patient's treatment position with an overlying plastic wrap that is affixed under vacuum suction over the patient to ensure reproducible setup and reduce potential motion. For treatment in the lower cervical and upper thoracic spine, we use a customized head and shoulder thermoplastic mask with body immobilization. Finally, for treatment in the upper cervical spine, we used a thermoplastic mask that is fitted over the head on an indexed head extender. Patients were scanned in the supine position with 1 mm slice thickness.

Target Volume and OAR Delineation

The delineations of the target volume and OARs were performed for all 10 cases as described in Radiation Therapy Oncology Group (RTOG) 0631 study [5]. All the volumes were defined based on the image fusion of simulation CT and MRI with T2-weighted and T1 weighted images with contrast. The radiosurgery target volume includes only the involved vertebral body and both left and right pedicles and the grossly visible tumor, if a paraspinal or epidural lesion is present. An epidural lesion is included in the target volume provided that there is a $\geq$ 3 mm gap between the spinal cord and the edge of the epidural lesion. A paraspinal mass $\leq$ 5 cm in the greatest dimension contiguous with spine metastasis is included in the target volume.No margin was given to target volume for presumed microscopic extansion. Partial spinal cord were contoured by 6 mm above and below the target volume supposed by the Ryu et al. [6].

Planning Objectives

The prescription was for a total of 18Gy with 1 fraction at 90% iso dose level. RTOG 0631 recommendations were applied for treatment planning. The protocol stipulated that the target volume and not less than 90% of the target volume should receive at least the prescribed dose, i.e. 18Gy. For each technique the same target volume dose constraints and OAR dose constraints were used. The dose constraints for target volume and OARs are listed in Table 1 as recommended by the protocol. The doses except for spinal cord, partial spinal cord and helthy tissue were not given in this paper since different region of target volumes include different OARs (esophagus, lungs, heart. etc, for thoracic vertebral cases and renal cortex, stomach.etc, for lomber vertebral cases). But all the dose constraints were kept within the limits for other OARs. The healthy tissue (Body-PTV) was defined as OAR and it was used to decrease the low and high dose spillage regions. The volumes of $V_{2\ Gy}$, $V_{5\ Gy}$, $V_{10\ Gy}$ and $V_{18\ Gy}$ of the healthy tissue were analyzed between the plans.

Table 1: Dose constraints

Structure	Dose Constraints
PTV	$V_{18Gy} \geq 90$ %
Spinal Cord	$V_{10Gy} \leq 0.35$ cc
	$V_{14Gy} \leq 0.03$ cc
Partial Spinal Cord	$V_{10Gy} \leq 10\%$
Healthy Tissue: Low dose spillage	The falloff gradient beyond the target volume extending into normal tissue structures must be rapid in all directions
Healthy Tissue: High dose spillage	1. To limit dose outside of the target volume to greater than or equal to 105% of the prescription dose to a volume of less than or equal to 3.0 cc. 2. To limit dose of greater than or equal to 105% of the prescription dose to a region within 1.0 cm from the edge of the target volume. 3. To exclude all doses of greater than or equal to 110% of the prescription dose outside of the target volume.

IMRT Plans

IMRT plans were generated using commercial inverse planning software Eclipse, version 10.1(Varian Medical Systems, Palo Alto, CA). Beam geometry consisted of seven coplanar fields with the posterior gantry angles: 105°, 130°, 155°, 175°,200°, 225° and 250°. Default smoothing values were used during optimisation. The normal tissue objective to deliver the highly steep gradient dose to target volume was values of 350 with a 0.5 fall-off between the start dose of the 100% and the end dose of the 50%. The maximum iteration of calculations was limited to 500 times. The MLC motion was optimized using the sliding window technique, resulting in a slightly higher number of monitor units (MUs) and a significantly lower beam on time (BOT). Dose rate of 600 MU/min was selected. The anisotropic analytical algorithm (AAA) was used for dose calculations in the TPS. A grid size of 1 mm and in homogeneity correction were used for calculations. To compare the differences in dose between IMRT and VMAT techniques, the prescription to target was normalized to 90% coverage of the target volume.

VMAT Plans

RapidArc optimisation was performed with the Eclipse. The dose rate was variable with a maximum value of 600 MU/min (averaging around 300 MU/min). Starting optimisation constraints consisted in the results of IMRT plans. 1 arc VMAT corresponded to a single 360° rotation. The gantry rotated from 179.9° to 180.1°. 2 arc VMAT corresponded to two coplanars arcs of 360° sharing the same isocenter and optimised independently and simultaneously. These two arcs were delivered with one arc moving counter clockwise from 179.9° to 180.1° and the second arc moving in the opposite direction and so minimize the off-treatment between the two beams time about 25 seconds.

For the first arc, field size and collimator rotation were determined by the automatic tool from Eclipse to encompass the target volume. The second arc was similar to the first arc except for the rotation of the collimator, which was 360-X for the second arc (X corresponded to the rotation of the collimator of the first arc). We controlled that the collimator was always rotated to a value different from zero in order to avoid tongue and groove effect.

To improve the results, we tried to modify constraints and priority factors on IMRT and VMAT plans. These parameters were evaluated using dosimetric tool Dose Volume Histograms (DVH). DVHs were generated to evaluate the three different plans. All plans were optimized using a standard planning constraint set based on the RTOG0631 protocol.

The constraints of MLC optimization for arc planning were used for the synchronized value of IMRT planning to compare the two treatment modalities under the same conditions. AAA algorithms with a grid size of 1 mm were selected for dose calculations.

Plan Evaluation

1) Plan Quality

The conformity index (CI) was used to assess the quality of target coverage in the respective regions. Paddick conformity index was defined as [7];

Conformity index = $\frac{(PTV \cap V_{100\%})^2}{PTV\ X\ V_{100\%}}$

Where target volume ∩ $V_{100\%}$:target volume covered by the reference isodose, $V_{100\%}$= volume of the reference iso dose and target volume: planned target volume (in this study, reference isodose used for 100%).

Paddick gradient index (GI), defined as [8];

Gradient index =$\frac{V_{50\%}}{V_{100\%}}$

where $V_{50\%}$is the volume that received 50% of the effective prescribed dose and $V_{100\%}$ is the volume that received the 100% of the effective prescribed dose.

Homogeneity index (HI) [9] calculated as;

Homogeneity index =$\frac{D_{2\%}-D_{98\%}}{D_{50\%}}$

where $D_{2\%}$, $D_{50\%}$ and $D_{98\%}$ represent the doses to 2%, 50% and 98% of the target volume, respectively.

For all patients DVH for OAR (spinal cord, partial spinal cord and healthy tissue) were calculated and compared.

2) Plan Efficiency

Treatment efficiency was evaluated based on the comparison of the:
MU defined as the average number of monitor units to required deliver the prescribed dose.
BOT defined as the time the treatment planning system predicts the beam will be "on" to deliver the prescribed monitor units. Does not account for time required to reach each gantry position; as in the case of IMRT.

For each one of the above parameters, the average value and the standard deviation (SD) were calculated.

Data and Statistical Analysis

The average cumulative DVHs for PTV and OARs were plotted based on the average corresponding volumes at the interval of every 2Gy for all patients. The representative isodose distribution displays, which were presented in a 2-D manner, were also displayed to evaluate the target coverage and conformity. For statistical analysis, the paired t-tests were performed to compare the results between IMRT and RapidArc plans for parametric datas. Wilcoxon signed rank test was performed for the nonparametric datas. The data were tested by the Statistical Package of Social Sciences (SPSS v16.0) with statistical significance level setatp < 0.05.

Plan Verification

Radiation therapy requires delivery quality assurance to ensure that treatment is accurate and closely follows the plan. The patient specific QA of the plans were made using ArcCheck (Sun Nuclear Corporation, Melbourne, USA) to compare the dose distribution calculated by TPS with experimental distribution in 3D phantom. For all patient-specific IMRT and VMAT QA, the pass rates exceeded 95% and 98%, respectively.

Results

1. Plan Quality

The ten patients in this study were aged between 42 to 61. Table 2 shows volume range and mean volume of target volume and partial spinal cord volume. The mean volume was 36.31 ± 13.48 cm^3 for target volume and 6.93 ± 1.83 cm^3 for partial spinal cord.

Table 2: Average volumes and volume ranges of target volume and OAR

Structure	Mean Volume ± S.D (cm^3)	Volume Range (cm^3)
Target volume	36.31 ± 13.48	68.19 - 23.15
Partial Spinal Cord	6.93 ± 1.83	4.02 – 9.24

Figure 1 shows the typical isodose distribution of the IMRT, 1 arc VMAT and 2 arc VMAT techniques in the transverse, sagital and coronal planes. The cyan lines outline the target volume for the tumor target in one patient and red and green lines represent 90% and 50% isodose lines of the prescribed dose in the tumor. In comparing the discrepancy between the 90% isodose lines isodose distribution in VMAT plan was more conformal to the target volume especially in the sagital plane.

Figure 1a: Typical isodose distribution of the 1 arc VMAT plan in the transverse, sagital and coronal planes.

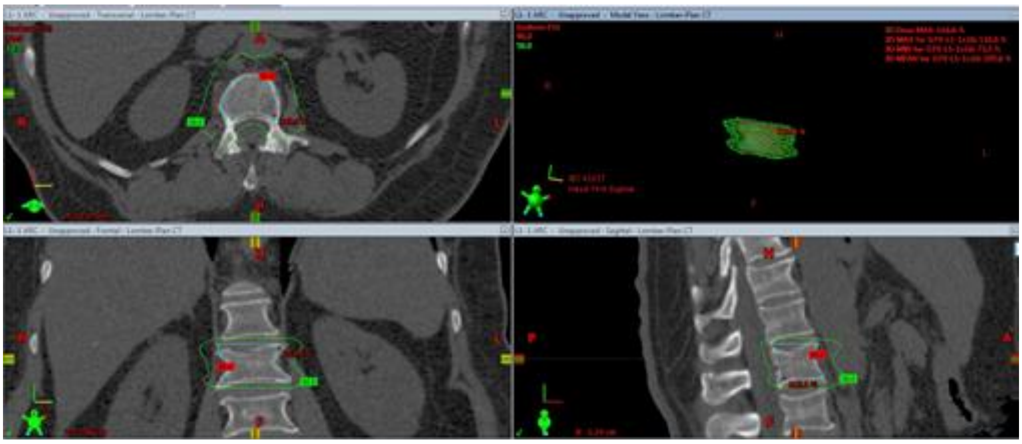


Figure 1b: Typical isodose distribution of the 2 arc VMAT plan in the transverse, sagital and coronal planes.

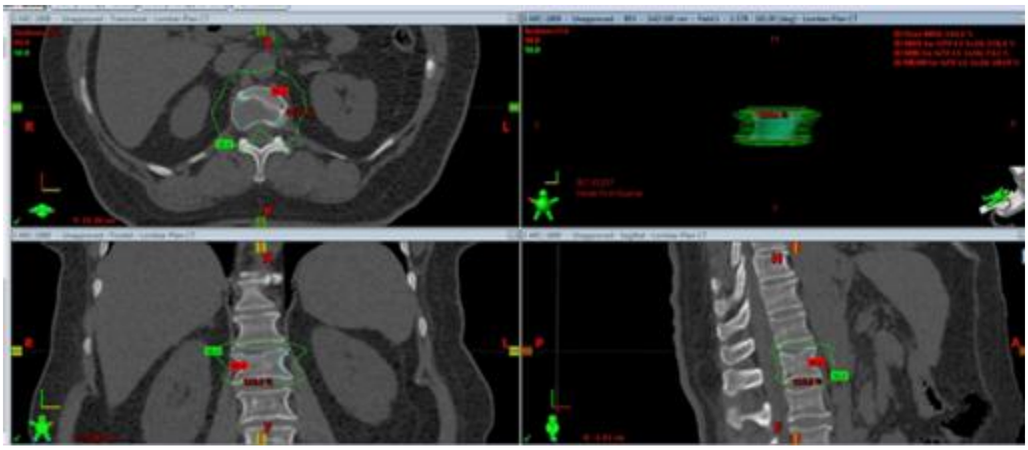


Figure 1c: Typical isodose distribution of the IMRT plan in the transverse, sagital and coronal planes.

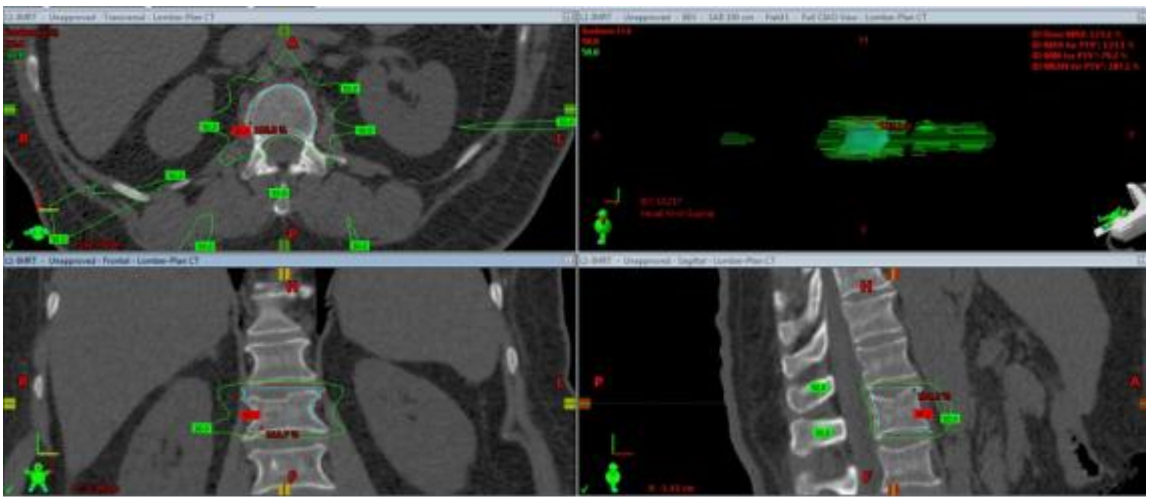


Table 3 shows the summary of dosimetric results of target volume. The average mean doses for target volume were 19.100 ± 0.015, 19.330 ± 0.011 and 18.970 ± 0.016 Gy for IMRT, 1 arc VMAT and 2 arc VMAT plans, respectively. The trend of mean DVH was similar for IMRT, 1 arc VMAT and 2 arc VMAT plans from $V_{17\ Gy}$to $V_{9\ Gy}$. However, 2 arc VMAT plans had a highest minimum dose and lower maximum dose. In RTOG 0631 protocol, dose in homogeneity were allowed in the target volume as long as ≥ 90 % of the target volume receives the prescribed radiosurgery dose. The average min dose of target volumes were 16.200 ± 0.097, 16.300 ± 0.080 and 16.800 ± 0.030 for IMRT, 1 arc VMAT and 2 arc VMAT plans, respectively. The maximum dose in target was kept below 130% of the prescribed dose. The average of max dose in target were 22.800 ± 0.019, 22.560 ± 0.016 and 22.150 ± 0.012 for IMRT, 1 arc VMAT and 2 arc VMAT plans, respectively.

Table 3: Summary of dosimetric results of target volume

Parameter	IMRT (Gy)	1 arc VMAT (Gy)	2 arc VMAT (Gy)
PTV Mean	19.100 ± 0.015	19.330 ± 0.011	18.970 ± 0.016
PTV Min	16.200 ± 0.097	16.300 ± 0.080	16.800 ± 0.030
PTV Max	22.800 ± 0.019	22.560 ± 0.016	22.150 ± 0.012

The homogeneity index of each patient was represented in figure 2 for IMRT, 1 arc VMAT and 2 arc VMAT plans. The average HI was nearly the same for all the plans. So, there was no statistically significant difference between the plans in terms of HI (p>0.05).

The gradient index of each patient was given in figure 3 for IMRT, 1 arc VMAT and 2 arc VMAT plans. The average GI was 2.820 ± 0.097, 3.130 ± 0.380 and 3.580 ± 0.450 for IMRT, 1 arc VMAT and 2 arc VMAT plansrespectively. There was no statistically significant difference between the IMRT and 1 arc VMAT plans in terms of GI (p=0.055). However, there was a statistically significant difference between the IMRT and 2 arc VMAT plans (p=0.005) and 1 arc VMAT and 2 arc VMAT plans (p=0.005). The improvement was remarkable when using 2 arcsVMAT compared to 1 arc VMAT. GI decreased significantly when 2 arcVMAT was compared to IMRT.

Figure 2: Homogeneity index of ten patients for three different plans

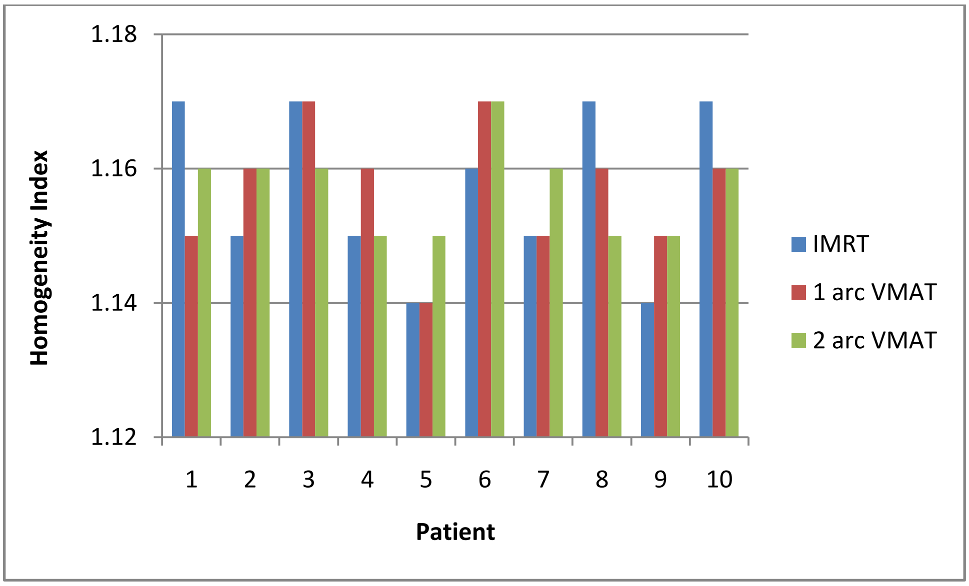
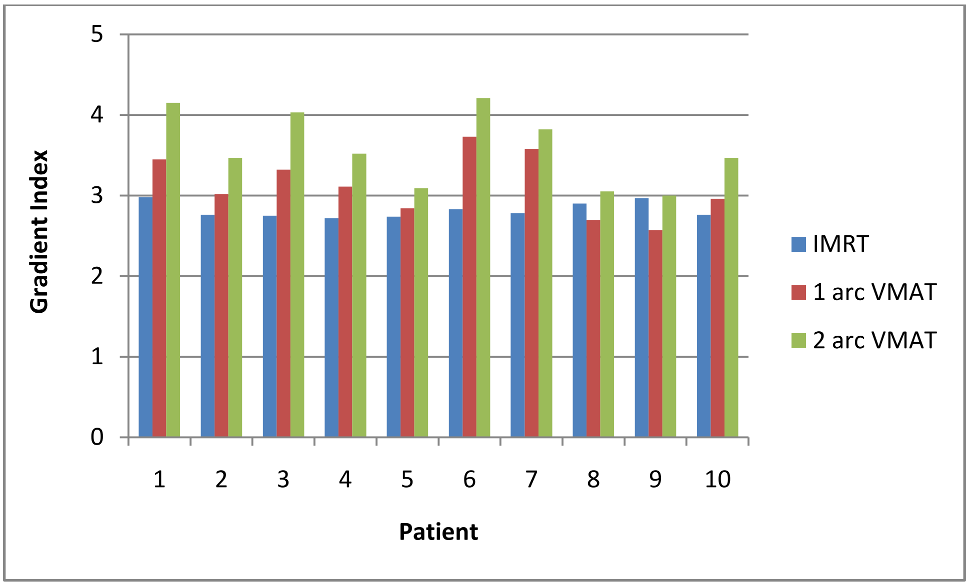
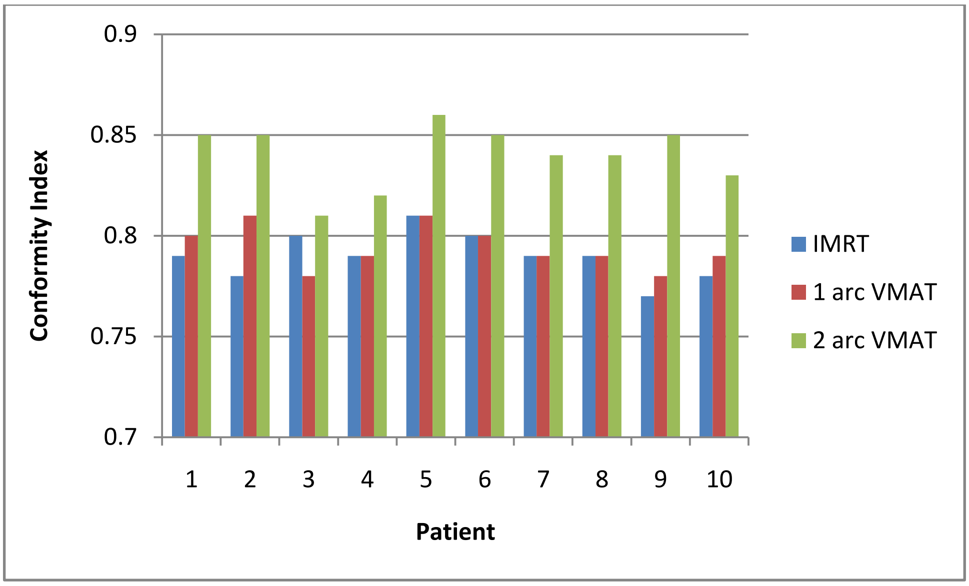


Figure 3: Gradient index of ten patients for three different plans



The conformity index of each patient was shown in figure 4 for IMRT, 1 arc VMAT and 2 arc VMAT plans. The average CI was 0.790 ± 0.011, 0.790 ± 0.011 and 0.840 ± 0.016 for IMRT, 1 arc VMAT and 2 arc VMAT plans respectively. There was no statistically significant difference between the IMRT and 1 arc VMAT plans in terms of CI (p=0.346). However, there was a statistically significant difference between the IMRT and 2 arc VMAT plans (p=0.005) and 1 arc VMAT and 2 arc VMAT plans (p=0.004). This implies 2 arc VMAT plans were better than IMRT and 1 arc VMAT plans and there was no difference among the IMRT and 1 arc VMAT plans in terms of the CI.

Figure 4: Conformity index of ten patients for three different plans



Dose Constraints

All the planning dose constraints were achieved with the three plans. The dosimetric findings for the OAR and healthy tissue were reported in table 4.

Table 4: Summary of dosimetric results of OAR

Organ	Parameter	IMRT	1 arc VMAT	2 arc VMAT
Spinal Cord (Gy)	$D_{0.35\ cc}$	8.780 ± 0.950	8.800 ± 0.860	8.230 ± 0.110
	$D_{0.03\ cc}$	10.710 ± 0.800	10.990 ± 0.920	9.650 ± 0.900
Partial Spinal (Gy)	$D_{10\ \%}$	8.050 ± 0.750	8.440 ± 0.850	7.180 ± 0.690
Healty Tissue (cm^3)	$V_{2\ Gy}$	4.320 ± 2.060	4.500 ± 2.070	5.000 ± 2.080
	$V_{5\ Gy}$	1.006 ± 0.390	1.182 ± 0.390	1.391 ± 0.400
	$V_{10\ Gy}$	0.199 ± 0.060	0.181 ± 0.060	0.170 ± 0.056
	$V_{18\ Gy}$	0	0	0

The dose constraint suggested by RTOG 0631 for the 0.35 volume of spinal cord is below 10 Gy. In our study, all of the plans were met this criteria and doses were even below 9 Gy. The average dose for 0.35 cm^3volume of spinal cord 8.780 ± 0.950, 8.800 ± 0.860 and 8.230 ± 0.110 Gy for IMRT, 1 arc VMAT and 2 arc VMAT plans, respectively. There was no statistically significant difference between the IMRT and 1 arc VMAT plans (p=0.688). However, there was a statistically significant difference between the IMRT and 2 arc VMAT plans (p=0.002) and 1 arc VMAT and 2 arc VMAT plans (p=0.002). The average dose for 0.35 cm^3 volume of spinal cord was the lowest when 2 arc VMAT techniques was used. On the other hand,it was the highest for 1 arc VMAT plans.

RTOG 0631 recommended 0.03 cm^3 for the max critical volume above treshold of 14 Gy for the spinal cord in a single fraction. In this study, max dose to 0.03 cm^3 volume of spinal cord was below 11 Gy for all of the plans. The average dose for 0.03 cm^3 volume of spinal cord 10.710 ± 0.800, 10.990 ± 0.900 and 9.650 ± 0.920 Gy for IMRT, 1 arc VMAT and 2 arc VMAT plans respectively. There was a statistically significant difference between the IMRT and 1 arc VMAT plans (p=0.023). Besides, there was also statistically significant difference between the IMRT and 2 arc VMAT plans (p=0.001) and 1 arc VMAT and 2 arc VMAT plans (p=0.001). This implies 2 arc VMAT plans were better than IMRT and 1 arc VMAT plans also IMRTplans were better than 1 arc VMAT plans in terms of 0.03 cm^3spine doses.

RTOG 0631 suggested constraints dose of below the 10% with partial spinal cord receiving more than 10 Gy. The dose to the partial volume of spinal cord for all of the plans were satisfying the constraint and even below 8.5 Gy. The average dose for $V_{10\%}$ partial spinal cord 8.050 ± 0.750, 8.440 ± 0.850 and 7.180 ± 0.690 Gy for IMRT, 1 arc VMAT and 2 arc VMAT plans respectively. There was a statistically significant difference between the IMRT and 1 arc VMAT plans (p=0.016). Besides, there was also statistically significant difference between the IMRT and 2 arc VMAT plans (p=0.004) and 1 arc VMAT and 2 arc VMAT plans (p=0.002). This implies 2 arc VMAT plans were better than IMRT and 1 arc VMAT plans also IMRT plans were better than 1 arc VMAT plans in terms of 10% with partial spinal cord doses. 2 arc VMAT plans were highly efficient in reducing $V_{10\%}$ of the partial volume tolerance.

For healthy tissue, the planning objective consisted in minimizing the dose. 2 arc VMAT plans were the highest low doses to the healthy tissue. However, IMRT plans reached the lowest values for the low doses to the healty tissue compared to VMAT and 1 arc VMAT plans. The average $V_{2\ Gy}$of healthy tissue were 4.302 ± 2.060, 4.500 ± 2.070 and 5.000 ± 2.080 for IMRT, 1 arc VMAT and 2 arc VMAT plans respectively. There was no statistically difference between the plans in terms of $V_{2\ Gy}$ of healty tissue (p>0.05).

The average $V_{5\ Gy}$ of healthy tissue was 1.006 ± 0.390, 1.182 ±0.390 and 1.391 ±0.400 for IMRT, 1 arc VMAT and 2 arc VMAT plans respectively. There was a statistically significant difference between the IMRT and 1 arc VMAT plans (p=0.007). Besides, there was also statistically significant difference between the IMRT and 2 arc VMAT plans (p=0.005) and 1 arc VMAT and 2 arc VMAT plans (p=0.028). This implies IMRT plans were better than 1 arc VMAT and 2 arc VMAT plans also 1 arc VMAT plans were better than 2 arc VMAT plans in terms of V5Gy of healty tissue.

The average V10 Gy of healthy tissue was0.199 ± 0.060, 0.181 ±0.060 and 0.170 ±0.061 for IMRT, 1 arc VMAT and 2 arc VMAT plans respectively. There was no statistically significant difference between the IMRT and 1 arc VMAT plans (p=0.112) and 1 arc VMAT and 2 arc VMAT plans (p=0.066). Besides, there was statistically significant difference between the IMRT and 2 arc VMAT plans (p=0.015). This implies 2 arc VMAT plans were better than 1 arc VMAT and IMRT plans in terms of V10Gy of healty tissue.

In this study, none of the plans had high dose spillage region, that is V18 Gy of the healthy tissue were 0 for all the plans.

2. Plan Efficiency

The box plot of MU and BOT of the plans were given in figure 5 and 6 respectively. The average MU was 10060, 6331 and 6151 for IMRT, 1 arc VMAT and 2 arc VMAT plans respectively. The range (and SD) was 8756–10260 (727), 5412–7009 (531), and 5190–6812 (494) respectively. There was a statistically significant difference between the IMRT and 1 arc VMAT plans (p=0.001). Besides, there was also statistically significant difference between the IMRT and 2 arc VMAT plans (p=0.001) and 1 arc VMAT and 2 arc VMAT plans (p=0.038). The MU decreased significantly when 1 arc VMAT was used instead of IMRT. However lowest number was achieved with2 arc VMAT.

Figure5: The box plot of MU for three different plans

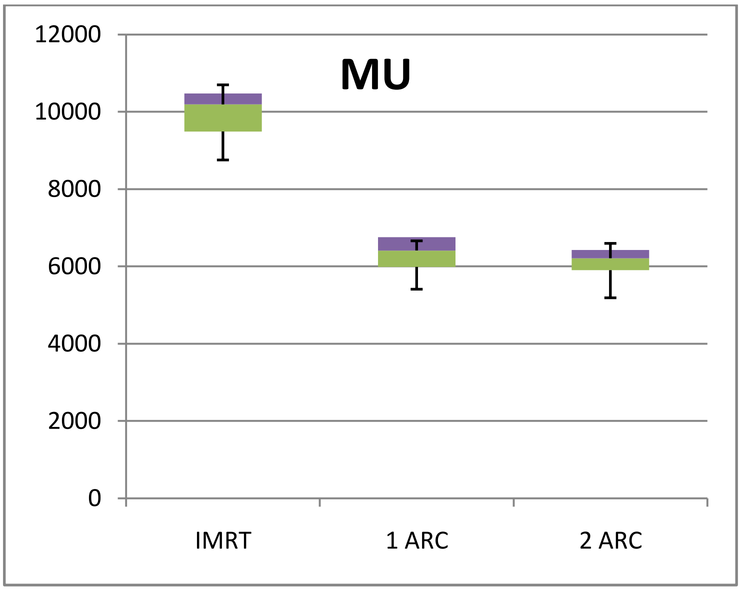
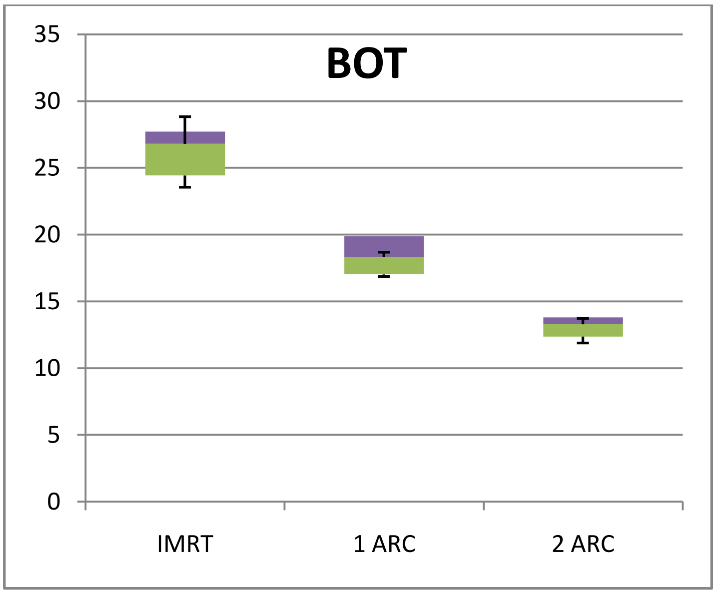


Figure6:The box plot of BOT for three different plans



The average BOT for IMRT, 1 arc VMAT and 2 arc VMAT plans were 26.29, 18.14, and 11.89 minutes, respectively. The range (and SD) was 29.75– 23.55 (2.75), 20.25–16.86 (1.71), and 14.23–12.21 (1.27) respectively. There was a statistically significant difference between the IMRT and 1 arc VMAT plans (p=0.001). Besides, there was also statistically significant difference between the IMRT and 2 arc VMAT plans (p=0.001) and 1 arc VMAT and 2 arc VMAT plans (p=0.033). This implies 1 arc VMAT plans were better than IMRT but2arc VMAT plans were better than 1 arc VMAT plans in terms of BOT.

Discussion

SBRT refers to the precise and focused delivery of a single, high dose of radiation in a single session and has been used to treat various tumors. The dosimetric characteristics of SBRT, namely a highly conformal isodose distribution and a very steep dose gradient of dose fall-off beyond the prescribed isodose line, lend themselves well to the delivery of an ablative dose of radiation to tumor volume. Because of these characterictics of SBRT, it is very crucial to find the techniques which satisfy these requirements. In this study we compared the dosimetric outcomes of commonly used techniques in treatment planning of spine sterotactic radiosurgery. To best of our knowledge there is no study in the literature comparing treatment planning techniques for spine radiosurgery using RTOG 0631 criteria.

Plan Quality

The results show different benefits with IMRT and 1 arc/2 arc VMAT plans. 2 arcsVMAT plans were the best in terms of dose distribution. Since gradient and conformity indexes of 2 arc VMAT plans were better than IMRT and 1 arc VMAT plans, one can use 2 arc VMAT techniques as a first choice to get more conformal and highly gradient plans.

When the dose constraints of spinal cord imposed by RTOG 0631 are taken into account, 2 arc VMAT hadalsothe best result. Whereas 1 arc VMAT plans had the worst result.

However, 2 arc VMAT plans were the highest low doses to the healthy tissue. Whereas IMRT plans reached the lowest values for the low doses to the healty tissue compared to VMAT and 1 arc VMAT plans. In this study, IMRT was shown to spare more healthy tissue, particularly in the low dose region at V2Gy and V5Gy when compared with VMAT. Radiation was delivered around the patient's body with the use of VMAT and thus all body tissues in the rotation path would receive some radiation dose whereas IMRT only delivered radiation at seven fixed angles. On the contrary, VMAT had a statistically significant reduction in the volume of healthy tissue irradiated in the medium to high dose regioni.e V10 Gy. This is characteristic of rotational beam delivery which is the case with VMAT [10].

Many studies [11-21] comparing VMAT and IMRT treatment planning techniques for various tumor regions VMAT technique was found better than IMRT for OAR sparing and better conformity and target volume coverage like our study. However, different results had been reported by Wu Jackie Q, et al. [22]. They compared IMRT and VMAT techniques for spine body radiotherapy. They found that IMRT plans were the best and 1 arc VMAT plans were the worst in terms of OAR sparing and normal tissue integral dose. On the other hand, they reported that 2 arc VMAT plans had conformity index better than 1 arc VMAT and IMRT plans like our study. The controversies could be due to the variations in tumour shape and their subsequent anatomical relationship with the neighbouring OARs and the different planning strategies used. The average target volumewaslarger than our'sbecause they included patients who were two vertebra metastasis while in our study patients who have just one vertebra metastasis were included. The prescription dose was 16 Gy and RTOG criterias were not used in their study. The MLC thickness could have an impact on sparing normal tissues. HD MLCwith64 inner leaves with 2.5 mm and 56 outer leaves with 5 mm were used in their treatment plans while Millennium MLC with 80 inner leaves with 0.5 mm and 40 outer leaves 1 cm were used in our treatment plans.

Oh AS, et al. [23] compared IMRT and VMAT techniques in spine stereotactic radiosurgery with International Spine Radiosurgery Consortium (ISRC) contoured consensus guidelines for target volume definition. Like our study, they found that VMAT with 2 arcs was the most advantageous for conformity and homogeneity. They concluded that both IMRT and VMAT techniques delivered high conformal dose distributions in spine stereotactic radiosurgery. However, if the target volume includes the vertebral body, pedicle, and transverse process, IMRT planning resulted in insufficient conformity index, compared to VMAT planning. Unlike our study, they found that IMRT technique was more effective in reducing the maximum spinal cord dose compared to VMAT with 1 arc and VMAT with 2 arc techniques at most sites. The differences may have resulted from the different version of the treatment planning system used. In this study, all the plans were generated by the Eclipse 10.1 planning system while Eclipse 8.6 was used in their study. Like Wu's study, they used HD MLC in their plans. In our study, we used RTOG 0631 criteria unlike their study. Our average target volume volumes were 36.31 cc while theirs were 12.6 cc. We normalized our plans such that target volume covers 90% of the prescribed dose while the prescription to target was normalized to 95% coverage of the target volume in their study.

Plan Efficiency

In our study, we found that MU decreased significantly with the VMAT plans compared to IMRT. The mean delivery time of IMRT was much longer owing to the larger number of beams, the dead time in the gantry rotation from field to field and the larger number of MUs delivered. The shorter treatment time of VMAT is beneficial to the patients as it would help reduce the time the patients who usually have a substantial pain required to stay on couch. Also, a shorter treatment time not only reduces the chance of the intra-fractional motion of patients, but also decreases the internal organ motion so that a more accurate treatment is possible. Furthermore, with the smaller number of MUs of VMAT, the hypothesised risk of secondary malignancies by IMRT due to scatter and leakage may be reduced [24].

Wu Jackie Q. et al. also analyzed the differences in treatment delivery and found that treatment time with 2 arcs VMAT decreased substantially like our study.

The challenge for spine SBRT is the need to deliver a highly conformal dose to a concave-shaped target volume. The adjacent spinal cord requires fast dose fall off to avoid cord injury. Gradient index plays an important role when evaluating the SBRT plans because the steep dose gradient outside the radiosurgical target is one of the factors that make radiosurgery possible. Therefore, as Paddick I, et al.[8] suggested in their study a dose GI can be used to compare treatment plans of equal conformity and explore optimal prescription isodoses. But neither Wu Jackie Q, et al. nor Oh AS, et al. the gradient index of treatment plans were calculated in their studies. In our study, we found that 2 arc VMAT plans were the best whereas IMRT plans were the worst in terms of GI.

Conclusion

This study indicates that a 2 arc VMAT plans provide better target volume coverage, favorable dose gradient and conformity and better OAR sparing when compared to 1 arc VMAT and IMRT plans. 2 arc VMAT plans are also the best in terms of treatment efficiency since they require a much smaller number of MUs and thus a shorter treatment time than IMRT plans. On the other hand, with fixed field IMRT, a smaller volume of healthy tissue can be irradiated in the low dose region.

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