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STUDY OF DOSIMETRIC INDICES OF RAPID-ARC RADIOTHERAPY PLANS FOR INTRACRANIAL TUMOR SITES

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ABSTRACT

BACKGROUND: Rapid-Arc therapy, a complex form of intensity modulated radiotherapy (IMRT) which is called volumetric arc therapy (VMAT), is now widely used for cancer treatment management. This study aimed to investigate plan quality of Rapid -Arc techniques using various dosimetric indices to find out the better treatment plan for intracranial sites.

METHODS: Ten different diagnosing intracranial cancer patients treated with Rapid- Arc were selected for analysis. Plans were generated and inverse planning was done by Eclipse 15.6 (Varian Medical Systems, Palo Alto, CA) treatment planning system with 06 MV photon beams of true beam linear accelerator from computed tomographic data. Double arcs (179^0-181^0 and 181^0-179^0) were used for Rapid-Arc plans. Quality of Rapid Arc treatment plans was evaluated by calculating conformity index (CI), homogeneity index (HI), gradient index (GI), coverage, and unified dosimetry index (UDI) for each plan.

RESULTS: Rapid-Arc resulted in better planning target volume (PTV) coverage as is evident from its superior conformation number, coverage, CI, HI, GI, and UDI. Regarding organs at risk (OARs), Rapid Arc plans exhibit superior organ sparing as is evident from integral dose comparison. Rapid Arc-based treatment planning is safer with similar planning goals.

CONCLUSION: This study clearly demonstrated that favorable dose distribution in PTV and OARs was achieved using Rapid Arc technique, and hence, the risk of damage to normal tissues is reduced.

KEYWORDS : IMRT, VMAT, SBRT, SRS, treatment planning software

INTRODUCTION:

Rapid-Arc is a radiation technique that delivers highly conformal dose distributions through the complete rotation (360°) and speed variation of the linear accelerator gantry. This technique, called volumetric modulated arc therapy (VMAT), compared with conventional radiotherapy techniques, can achieve high-target volume coverage and sparing damage to normal tissues. Rapid Arc delivers precise dose distribution and conformity similar to or greater than intensity-modulated radiation therapy in a short time. Rapid arc plan is widely used now for intracranial treatment sites as it deliver very less dose to other part of brain than target volume (TV) . Rapid-Arc treatment is delivered rapidly, which has the advantage of decreasing the risk of intra-fractional positional shifts of the patient [1]. Otto [2] developed the concept of planning and delivery of volumetric modulated arc therapy-based technique, called Rapid-Arc (Varian Medical System, Palo Alto, CA). Use of novel treatment technique, Rapid-Arc therapy, initiated in 2007, which permitted simultaneous variation of gantry rotation speed, dose rate, and dynamic multileaf collimator during treatment delivery [3]. Arc therapy can deliver uniform intensity of radiations at constant or variable dose rate. Single or multiple arcs can be delivered by this technique [4]. This technique has been investigated for treatment of prostate, esophageal, cervix, and brain malignancies [5,6].

Dosimetric treatment planning basically aims to fulfill the following objectives: (a) Covering 100% of the tumor site with prescribed dose (PD), i.e., attaining uniform coverage to the target. (b) Achieving high dose conformity to the target. (c) Achieving homogenous dose distribution to the target. (d) Minimizing the dose to normal tissues Below their tolerance level.

First three objectives are easy to achieve, while it becomes quite complex to score the last objective. If sharp fall-off of dose beyond the TV is observed, then the dose to OARs may also be minimized. Therefore, the fourth objective can be indirectly achieved by quantifying the dose gradient [7]. Integral dose (ID) is the measure of total dose deposited in the whole body and is considered to determine the risk of complications due to radiotherapy [8]. The present study aims to investigate and compare dosimetric indices and ID Rapid Arc technique for 06 MV photon beams in intracranial tumors.

MATERIALS AND METHODS:

Ten intracranial cancer patients of different diagnosis treated with Rapid-Arc were selected for analysis. Plans were generated by Inverse planning was done by Eclipse 15.5 (Varian Medical Systems, Palo Alto, CA) TPS for 6 MV photon beams from computed tomographic (CT) data. Double arcs (1790-181^0 and 181^0-179^0) were used for Rapid Arc plans. For treatment planning, CT scans of all the patients were obtained using CT simulator with slice thickness of 3 mm. TPS contours all OARs, clinical target volume (CTV), and planning target volume (PTV). All macroscopic as well as potential microscopic disease was covered by CTV. To determine PTV, 2 mm margin was added to CTV to compensate for possible errors in treatment delivery. Patients were immobilized using fixation device orfit (Macromedias). The treatment couch was set to 0° and collimator angle was kept at 10° and 350° in order to avoid tongue and groove effects.

Quality of treatment plans was evaluated by calculating conformity index (CI), homogeneity index (HI), gradient index (GI), coverage, and unified dosimetry index (UDI) for each plan. The dose coverage calculated in the present study is defined as the ratio of Dmin to PD.[9] The plan is considered acceptable if TV completely covers 90% of prescription isodose. There will be a minor deviation if 80% of PD encompass TV. A major deviation is considered below the coverage of 80% of TV.[10] However, most clinical practices consider ±10% as an acceptable deviation.[11]

$$\text{Coverage} = D_{min}/PD \quad (1)$$

CI was calculated by using formula as reported in RTOG 90-05 protocol [12]. It is defined as prescription isodose volume (PIV) that completely envelops the tumor volume. Observing RTOG guidelines, if values of PIV lie between 1 and 2, treatment plan is acceptable.

$$CI = PIV/TV \quad (2)$$

The HI used in this study is referred to as the ratio of maximum dose to prescription dose.[21] It is defined as the ratio of maximum dose delivered to the target volume to Prescribed dose as per RTOG protocol [13].

$$HI = D_{max}/PD \quad (3)$$

If value of HI A is closer to 1, it indicates better homogeneity. Homogeneity of treatment plans, calculated using this formula, have acceptable values between 1 and 1.5[14].

GI accounts for the measurement of shallowness or steepness of dose fall-off in tumor volume [15]. GI is defined as volume of PD to the

50% isodose volume of PD[16,17]. Lower GI ratio indicates greater dose fall-off and better plan conformity.

GI = PTV (PD)/ PTV (PD50%) (4)

Akapati *et al*.[7] proposed UDI integrating contribution from all four above-mentioned dosimetric components. It is considered as an efficient tool to define ideal plan. Ideal plan is the one with perfect coverage, homogeneity, conformity, and dose gradient (stepwise fall-off of dose to zero) [18]. For ideal treatment plan its value is one. For actual dosimetry plan, UDI value is always >1 and worsening of any of the four dosimetric components results in an increase in value of UDI. Low UDI value corresponds to good plan, whereas a high value indicates poor plan [28]. Analysis is simplified by considering equal weightage of all four indices of UDI.

UDI = Coverage × CI × HI × GI (5)

In a treatment plan, relative measure of target coverage and sparing of OARs is accounted by conformation number (CN) [15] Van't Riet Model [19] used for calculation of CN is as follows.

$CN = TVref^2 / TV \times Vref$ (6)

Where TVref represents volume of target receiving a dose equal to or greater than the reference dose; TV is the volume of target; and Vref is the volume receiving a dose equal to or greater than the reference dose (treated volume).

TV is defined as the volume for target enclosed by 95% of isodose lines, i.e. V95. CN varies from 0 to 1 having ideal value 1.

Aoyama *et al*.[20] proposed formula of ID (Integral Radiation Dose) in normal tissues and employed to compute and compare dose in PTV and patient body for different irradiation techniques. ID is equal to the product of mean dose received by organ, volume (V) receiving that dose, and the density (ρ) of that volume as represented by equation.[21]

$ID (GyL) = D_{mean} \times V \times \rho$ (7)

Complex calculation is required for determination of ID with variable tissue densities. Calculations are made simpler by considering uniform density of the patient's body volume.

No ideal threshold value for ID is suggested, however, it is recommended to maintain it as low as possible without compromising target coverage so that risk of relapse of malignancies is reduced[8].

RESULTS AND DISCUSSION:

Quality of Rapid-Arc plans in terms of coverage, HI, CI, GI, UDI, and ID is analyzed and compared in this study.

Mean values of all dosimetric evaluation indices of this treatment technique are listed in Table 1.

Table 1: Average dosimetric indices of Rapid-Arc plans for intra cranial cancer patients

	Rapid Arc
CI	0.763
HI	1.075
Coverage	0.857
GI	1.80
UDI	1.309
CN	0.480

The mean value of UDI, HI and GI are good agreement of rapid Arc plans on the basis of table no.1 data. The mean CN value shows the sparing of OARs are excellent which is possible due to Rapid Arc planning technique.

In this study, the plans (Rapid-Arc) are ranked by UDI, which combines all four above-mentioned components into a single score. We classified our UDI score into four groups based on mean value and standard deviation. Plans with UDI values greater than (mean + SD) are considered as poor. For plans with UDI values ranging from (mean) to (mean + SD) are considered as average. (Mean) to (mean − SD) values are classified as good and UDI values less than (mean – SD) are considered excellent.

Table 2 : Mean UDI , Standard Deviation , Mean+ SD and Mean- SD values of all ten patients

Patient Number	UDI	Mean	Standard Deviation (SD)	Mean+ SD	Mean - SD
1	1.22891	1.30991	0.19324	1.50315	1.11667
2	1.19688				
3	1.17008				
4	1.46868				
5	1.38932				
6	1.12016				
7	1.56687				
8	1.56133				
9	1.34946				
10	1.04750				

Rapid-Arc plans are capable of producing better conformation in PTV than other planning techniques. Rapid-Arc plans yielded better dosimetric indices because of inherent arc therapy nature of these plans, as is evident from this study. Arc trajectory provides large number of radiation beam directions and dynamic dose delivery during gantry rotation (single or double). More number of arcs are necessary for larger TVs such as pelvis and head and neck site. Double arcs associated with Rapid-Arc are more beneficial at conforming radiation to target than static multiple beams. For Rapid-Arc plans the radiation dose conforms to a cylindrically shaped planning TV, while minimizing dose to OARs. GI, measure of dose fall-off, revealed improved results with Rapid-Arc. Limiting dose to adjacent neighboring healthy tissues is important as well as difficult to achieve. So, by the use of multiple concentric arcs in Rapid-Arc technique stringent dose objectives fulfill the requirement of steeper dose gradient around the TV. High values of UDI were noted for few plans. This was due to large tumor size of some patients. These cases yield lower values of CI due to high spillage of dose outside the tumor volume.

Out of four dosimetric indices undertaken in this study, CI has highest score and wider range of values, so it is the most dominant component of UDI. GI and HI are second and third most dominant components of UDI, respectively. The dose coverage has less contribution to the UDI score.

GI and CI are interpreted such that high values of these indices are translated as high-dose gradient, i.e., rapid dose fall-off and good conformity. On the contrary, high HI values depict poor plans, i.e., hotspots in and around PTV. By comparing the dosimetric components, it is observed that HI score good plans in opposite sense as CI and GI. UDI scoring is essential method for determining which plan is better in cases where multiple dosimetry plans are generated. Good dosimetry plan is indicated by low UDI score. Treatment plans of present study were ranked as excellent, good, average, or poor.

CONCLUSION:

Dosimetric comparison of Rapid Arc plan for intracranial sites of 10 patients indicates better conformity, coverage, and homogeneity of PTV, together with high dose gradient in favor of Rapid-Arc technique. Rapid-Arc appears to improve dosimetry and treatment efficiency. This study clearly demonstrated that favorable dose distribution in PTV and OARs was achieved using Rapid Arc technique, and hence, the risk of damage to normal tissues is reduced. This could result in improvement in patient's quality of life. Although this study employed Varian True beam linear accelerator and Varian Eclipse (15.5V) TPS, treatment principles and techniques used in this study are also applicable to other treatment planning and delivery systems as well.

Conflict of interest: The authors declare that they have no conflicts of interest.

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