

# A comparative study of RapidArc and intensity-modulated radiotherapy plan quality for cervical cancer treatment

Atia Atiq, Maria Atiq, Khalid Iqbal<sup>1</sup>, Manzar A. Sial<sup>2</sup>, Saima Altaf, Quratul Ain Shamsi, Saeed A. BuzdarDepartment of Physics, The Islamia University of Bahawalpur, Bahawalpur, <sup>1</sup>Shaukat Khanum Cancer Hospital and Research Center, Lahore, Pakistan, <sup>2</sup>Department of Bioscience, King Abdullah University of Science and Technology, Thuwal, Kingdom of Saudi Arabia  
Correspondence to: Dr. Atia Atiq, E-mail: [atiaatiq@hotmail.com](mailto:atiaatiq@hotmail.com)

## Abstract

**BACKGROUND:** RapidArc therapy, a complex form of intensity-modulated radiotherapy (IMRT), is now widely used to treat cancer patients. **AIMS:** This study aimed to investigate and compare the plan quality of IMRT and RapidArc techniques using various dosimetric indices to find the better treatment modality for treating patients with cervix cancer. **MATERIALS AND METHODS:** Thirteen cervical cancer patients treated with IMRT were selected for analysis and original plans were subsequently re-optimized using the RapidArc technique. Plans were generated such that dose of 5000 cGy was delivered in 25 equal fractions. Inverse planning was done by Eclipse (Varian Medical Systems, Palo Alto, CA) treatment planning system for 15 MV photon beams from computed tomographic data. Double arcs were used for RapidArc plans. 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. **RESULTS AND CONCLUSION:** RapidArc 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), RapidArc plans exhibit superior organ sparing as is evident from integral dose comparison. Difference between both techniques was determined by statistical analysis. For all cases under study, modest differences between IMRT and RapidArc treatment were observed. RapidArc-based treatment planning is safer with similar planning goals compared to the standard fixed IMRT technique. This study clearly demonstrated that favorable dose distribution in PTV and OARs was achieved using RapidArc technique, and hence, the risk of damage to normal tissues is reduced.

**Key Words:** Integral dose, intensity-modulated radiotherapy, rapidarc, unified dosimetry index

## Introduction

Globally, cervical cancer is the fourth most common type of cancer among women.<sup>[1-3]</sup> High risk of radiation-induced toxicity for cervical cancer has been reported,<sup>[4,5]</sup> leading to relapse following treatment. High dose of radiation to the target volume (TV) will reduce probability of disease relapse while increasing the likelihood of exposure to normal tissues, consequently limiting the delivery of high radiation doses to the tumor. Intensity-modulated radiotherapy (IMRT) involves the basic principle of irradiation of target from various directions with radiation beams that are optimized to provide high dose to tumor site and acceptably low dose to healthy normal tissues. Treatment planning system (TPS) is used to divide each radiation beam into number of beamlets and choose the optimum setting of beam weights or energy fluence.<sup>[6]</sup> Limitations of fixed-field IMRT are: time-consuming and complex quality assurance procedures, high peripheral doses, and the use of large number of monitor units (MUs). Rotational or arc-based therapies are gaining interest to overcome these limitations. Arc therapy is based on its ability to treat patients by continuous rotation of radiation source from complete 360° beam angle. Arc therapy techniques are able to achieve highly conformal radiation dose distribution and are considered as replacement of IMRT. Otto<sup>[7]</sup> developed the concept of planning and delivery of volumetric modulated arc therapy-based technique, called RapidArc (Varian Medical System, Palo Alto, CA). Use of novel treatment technique, RapidArc therapy, initiated in 2007, which permitted simultaneous variation of gantry rotation speed, dose rate, and dynamic

multileaf collimator during treatment delivery.<sup>[8]</sup> Arc therapy can deliver uniform intensity of radiations at constant or variable dose rate. Single or multiple arcs can be delivered by this technique.<sup>[9]</sup> This technique has been investigated for treatment of prostate, esophageal, cervix, and small brain malignancies.<sup>[10,11]</sup> The dosimetric comparison of IMRT and RapidArc techniques had previously been investigated.<sup>[12]</sup> Few studies suggest improved coverage of target and better sparing of organs at risk (OARs) by RapidArc technique over IMRT technique.<sup>[13,14]</sup> However, study of Zhai *et al.*<sup>[15]</sup> proved superiority of IMRT over arc therapy for treatment of cervical cancer. Therefore, dosimetric comparison of both techniques is made in order to understand which technique yields better results in terms of improved conformal target coverage and OAR sparing for cervical cancer patients.

Dosimetric treatment planning typically 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.<sup>[16]</sup> Integral dose (ID) is the measure of total dose deposited in the whole body and

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is considered to determine the risk of complications due to radiotherapy.<sup>[17]</sup>

The present study aims to investigate and compare dosimetric indices and ID of fixed IMRT and RapidArc technique for 15 MV photon beams in cervical cancer.

### Materials and Methods

Thirteen cervical cancer patients treated with IMRT were selected for analysis and original plans were subsequently re-optimized using RapidArc technique. Plans were generated such that dose of 5000 cGy was delivered in 25 equal fractions. All cases were planned as well as treated with bladder filling and rectal balloon of 200 cm<sup>3</sup>. Inverse planning was done by Eclipse (Varian Medical Systems, Palo Alto, CA) TPS for 15 MV photon beams from computed tomographic (CT) data. Seven evenly spaced coplanar beams were used for inverse IMRT treatment plans. For treatment planning, CT scans of all the patients were obtained using CT simulator with slice thickness of 2 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 internal organ motion. Patients were immobilized using vacuum bag (MED-TEC, Orange City, IO). Double arcs were used for RapidArc plans. The treatment couch was set to 0° and collimator angle was kept at 30° and 330° in order to avoid tongue and groove effects. Patient characteristics and their stages are given in Table 1.

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.<sup>[18]</sup> 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.<sup>[19]</sup> However, most clinical practices consider ±10% as an acceptable deviation.<sup>[20]</sup>

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

CI was calculated by using formula as reported in RTOG 90-05 protocol.<sup>[21]</sup> 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.

$$CI = \frac{PIV}{TV} \quad (2)$$

The HI used in this study is referred to as the ratio of maximum dose to prescription dose.<sup>[21]</sup> It is defined as the ratio of maximum dose delivered to the target volume to prescribed dose as per RTOG protocol.<sup>[22]</sup>

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

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.<sup>[23]</sup>

**Table 1: Patients characteristics**

Patient no	Age	FIGO stage
1	55	IIB
2	57	IIB
3	31	IVA
4	40	IIA
5	63	IA
6	56	IB2
7	58	IIA
8	32	IIB
9	49	IIIA
10	66	IIIB
11	70	IVA
12	35	IIB
13	54	IVA

GI accounts for the measurement of shallowness or steepness of dose fall-off in tumor volume.<sup>[24]</sup> GI is defined as volume of PD to the 50% isodose volume of PD.<sup>[25,26]</sup> Lower GI ratio indicates greater dose fall-off and better plan conformity.

$$GI = \frac{PTV(PD)}{PTV(PD50\%)} \quad (4)$$

Akapati *et al.*<sup>[16]</sup> 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).<sup>[27]</sup> 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.<sup>[28]</sup> Analysis is simplified by considering equal weightage of all four indices of UDI.

$$UDI = \text{Coverage} \times CI \times HI \times GI \quad (5)$$

In a treatment plan, relative measure of target coverage and sparing of OARs is accounted by conformation number (CN).<sup>[24]</sup> Van't Riet Model<sup>[29]</sup> used for calculation of CN is as follows.

$$CN = \frac{TV_{\text{ref}}^2}{TV \times V_{\text{ref}}} \quad (6)$$

where TV<sub>ref</sub> represents volume of target receiving a dose equal to or greater than the reference dose; TV is the volume of target; and V<sub>ref</sub> 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. V<sub>95</sub>. CN varies from 0 to 1 having ideal value 1.

Aoyama *et al.*<sup>[6]</sup> proposed formula of ID 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 receiving that dose, and the density of that volume as represented by equation.<sup>[30]</sup>

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

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. For fair comparison this supposition was made for both RapidArc and IMRT calculation. 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.<sup>[17]</sup>

## Results

Quality of IMRT and RapidArc 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 two treatment techniques are listed in Table 2. Statistical analysis is used to determine relationship between dosimetric indices. Significance or nonsignificance of treatment plan is described by *P* value by taking significance level  $\leq 0.05$ . No significant difference in values of CI and UDI is observed between two planning techniques. Minimum, mean, and maximum doses were given for PTV and OARs in Table 3

**Table 2: Average and *p*-value of dosimetric indices of IMRT and RapidArc plans for cervix cancer patients**

	IMRT	RapidArc	<i>P</i>
CI	1.02	1.59	3.66523E-06
HI	1.13	1.12	0.735780992
Coverage	0.76	0.76	0.969624717
GI	0.98	0.94	0.166589875
UDI	1.48	1.26	0.023726186
CN	0.45	0.46	0.836870527

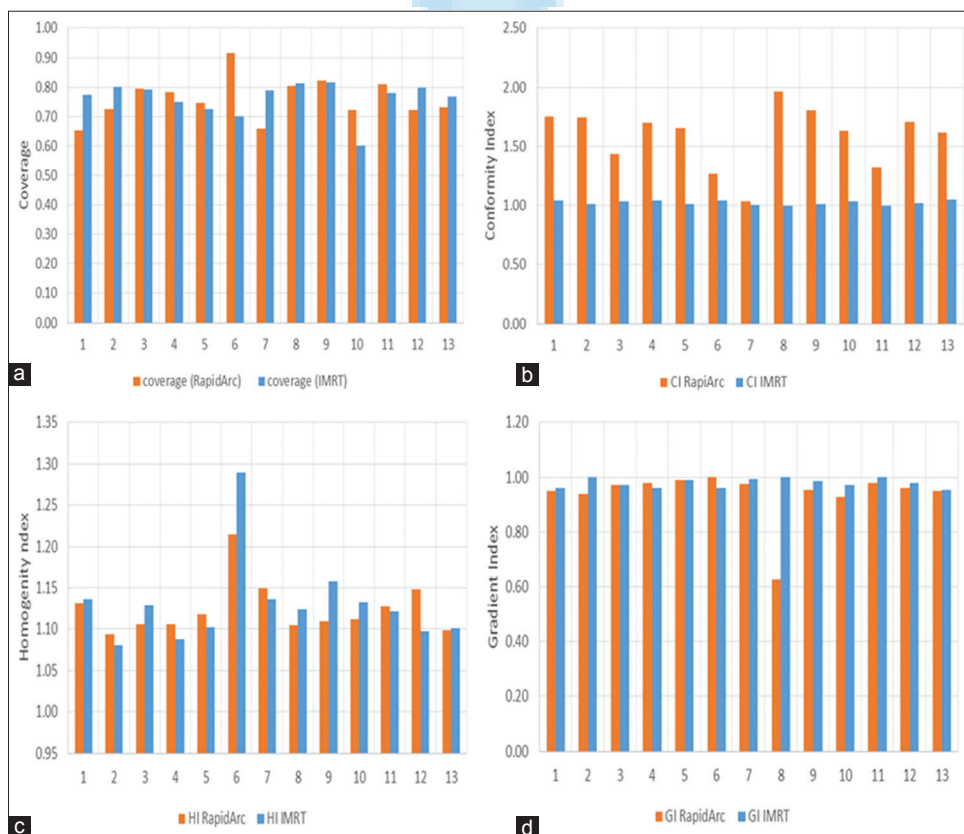
for 13 patients. In all the treatment plans, doses to rectum and bladder were well below the tolerances as recommended by RTOG guideline P0126.<sup>[31]</sup>

Results presented in Figure 1 shows that values of dosimetric indices of both techniques lies in acceptable range. Thus, requirement of conformal and homogeneous dose to tumor is achieved in our case, with no overdosage or underdosage. So, quality of treatment plans is assured. Study revealed that no general increasing or decreasing trend is found in both techniques for four dosimetric indices, however, results of RapidArc techniques score better than IMRT technique.

In this study rival plans (IMRT vs. RapidArc) are ranked by UDI, which combines all four above-mentioned components into a single score. Figure 2 represents radar graph of UDI values for RapidArc and IMRT plans. Our results show low values of UDI for RapidArc plans as compared to IMRT plans.

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.

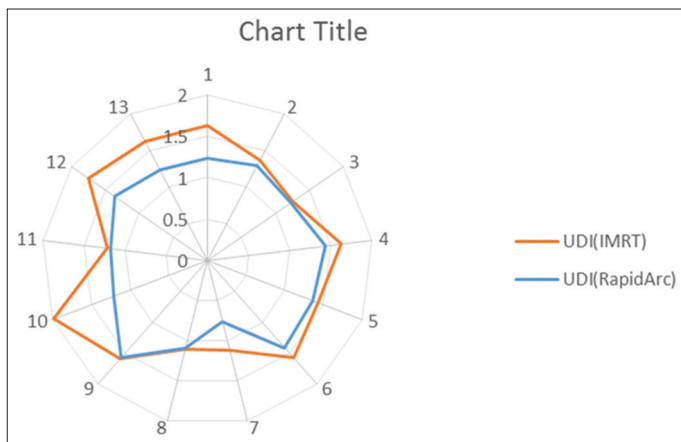
A graph of ranking system figure IMRT and RapidArc plans is illustrated in Figures 3 and 4, respectively. Of the 13 cases evaluated, 3 treatment plans are excellent, 3 are good, 5 are average, and 2 are poor for IMRT cases and for RapidArc cases 1 treatment plan is excellent, 6 are good, 5 are average, and 1 is poor. Lower UDI scores represent



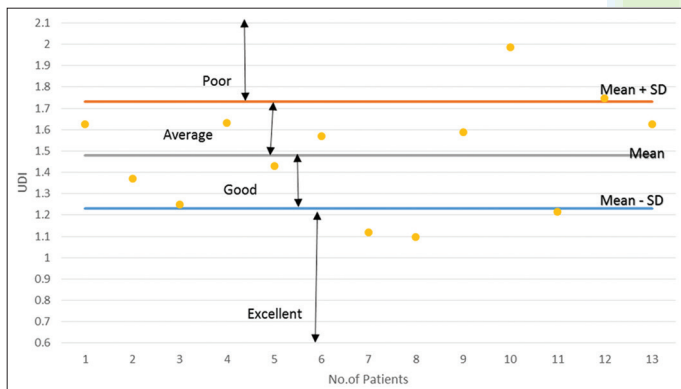
**Figure 1: Summary of average values of (a) coverage, (b) conformity index (CI), (c) homogeneity index (HI), and (d) gradient index (GI) for 13 clinical cases**

**Table 3: Minimum, mean, and maximum doses of IMRT and RapidArc plans**

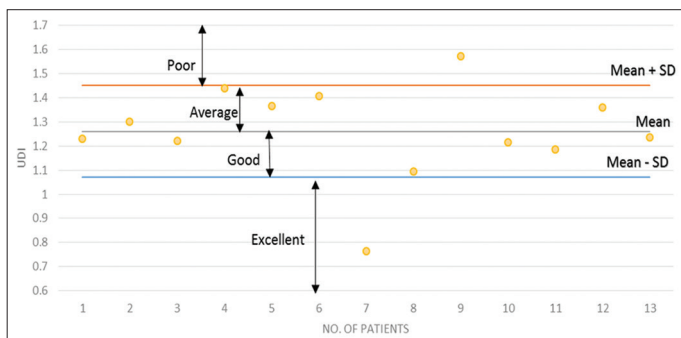
Dosimetric (cGy)	IMRT		RapidArc	
	Average of 13 plans	Range (min-max)	Average of 13 plans	Range (min-max)
<b>PTV</b>				
Dmin	3770.44	3000.6-4141.8	3800.7	3265.5-4110.7
Dmean	5028.656	5000-5144.1	5112.13	5000-5183.4
Dmax	5558.544	5421.1-5787.2	5622.68	5471.3-6070
<b>Rectum</b>				
Dmin	367.84	88.6-1530.9	370.62	90.4-1151.7
Dmean	3717.53	2456.7-5324.1	3095.75	2129.6-3823.5
Dmax	5436.86	5283.8-5700	5376.18	5289.4-5669.2
<b>Bladder</b>				
Dmin	969.96	638-1689.5	698.36	461.9-1088.2
Dmean	3817.12	3610.4-4341.5	3357.36	2910.8-3810.1
Dmax	5542.95	5379-5914.4	5439.33	5298.3-5762.8



**Figure 2: The UDI score of each patient's RapidArc and IMRT plans of cervical cancer**



**Figure 3: A plot of UDI for 13 IMRT cases**



**Figure 4: A plot of UDI for 13 RapidArc cases**

minimum deviation from ideal plans whereas higher scores represent maximum deviation from ideal plans.

The mean integral doses of PTV, rectum, and bladder are depicted in Figure 5.

### Discussion

According to the study conducted by Oliver *et al.*<sup>[32]</sup> and Nicolini *et al.*,<sup>[33]</sup> RapidArc plans are capable of producing better conformation in PTV than IMRT plans. RapidArc 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). Fixed-field IMRT provides limited number of radiation beams which result in some optimal beam angles being missed. On the contrary, RapidArc utilizes all possible beam angles during optimization and hence it can produce optimal dose distribution resulting in better plans than IMRT.<sup>[34]</sup> More number of arcs are necessary for larger TVs such as gynecological malignancies. Double arcs associated with RapidArc are more beneficial at conforming radiation to target than static multiple beams. Findings of this study are in accordance with the results of Poon *et al.*<sup>[35]</sup> and Coozi *et al.*<sup>[13]</sup> For RapidArc 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 RapidArc as compared to IMRT plans. Limiting dose to adjacent neighboring healthy tissues is important as well as difficult to achieve. So, by the use of multiple concentric arcs in RapidArc technique stringent dose objectives fulfill the requirement of steeper dose gradient around the TV.<sup>[17]</sup> Spikes in the 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. Various studies suggest improved homogeneity and conformity using arc therapy compared to IMRT.<sup>[12,36-38]</sup>

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.

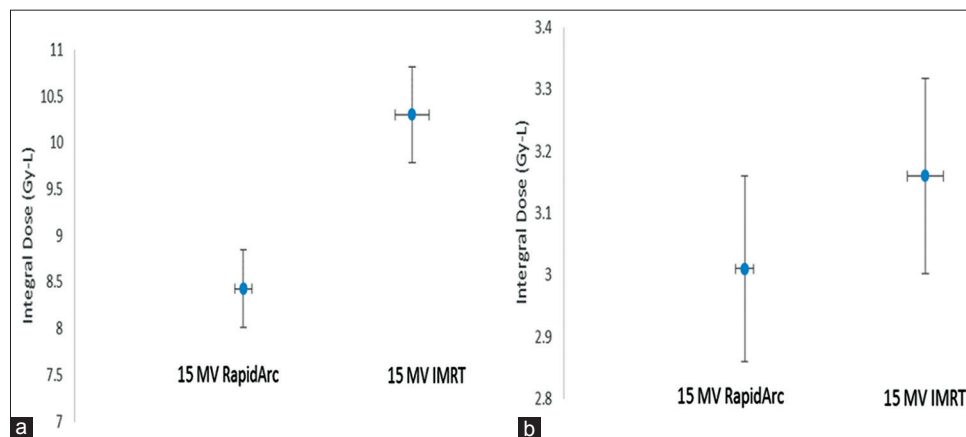


Figure 5: Mean value and standard error of the integral dose of (a) bladder (b) rectum

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.<sup>[16]</sup> 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. Better results of all dosimetric parameters are observed for RapidArc plans as compared to IMRT plans. However, plans using both techniques were clinically acceptable according to dosimetric criteria. There are two poor plans for IMRT, while only one poor plan is observed for RapidArc. Also, excellent + good plans for RapidArc are more than for IMRT plans. Average UDI value for RapidArc is 1.26 and for IMRT is 1.48, so RapidArc is slightly better technique.

The ID received by rectum and bladder is calculated from dose volume histogram. Compared to IMRT, RapidArc reduced IDs to rectum and bladder by 4.7% and 18.1%, respectively. Literature suggests that large number of MUs and beamlets used in IMRT results in increase in the value of ID.<sup>[39,40]</sup> It is often stated that ID to normal tissues decreases as the size of tumor increases for the same anatomical regions. In case, if tumors are of same size, then ID increases with increasing anatomical sizes.<sup>[6]</sup>

### Conclusion

Dosimetric comparison of RapidArc and IMRT treatment plans for cervical cancer in 13 patients indicates better conformity, coverage, and homogeneity of PTV, together with high dose gradient in favor of RapidArc technique. For surrounding normal tissues such as rectum and bladder, ID gives satisfactory result for both the techniques, however, better critical tissue sparing was achieved by using RapidArc technique. RapidArc appears to improve dosimetry and treatment efficiency when compared to IMRT. This could result in improvement in patient's quality of life. Although this study employed Varian DHX linear accelerator and Varian Eclipse TPS, treatment principles and techniques outlined in this study are also applicable to other treatment planning and delivery systems.

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### Conflicts of interest

There are no conflicts of interest.

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