INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ORIGINAL ARTICLE

Dual Arc Volumetric-Modulated Arc Therapy for Cervical Cancer: A Dosimetric and Treatment Planning Comparison with 9 Fields Intensity-Modulated Radiotherapy Technique

Rahul Rai[1]*, **Krishna Kumar Singh**[1]

1 Department of Physics, FS University, Shikohabad, Uttar Pradesh, India

OPEN ACCESS

Received: 16/06/2025

Accepted: 16/07/2025

Published: 09/08/2025

Citation: Rai R, Singh KK (2025) Dual Arc Volumetric-Modulated Arc Therapy for Cervical Cancer: A Dosimetric and Treatment Planning Comparison with 9 Fields Intensity-Modulated Radiotherapy Technique. Indian Journal of Science and Technology 18(30): 2407-2417. https://doi.org/10.17485/IJST/v18i30.1123

* **Corresponding author**.

happyrahulrai@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Objectives: Finding the most efficient option for therapy for patients with cervical cancer was the goal of this study, which compared and examined the plan quality of IMRT and VMAT procedures using various kinds of dosimetric indices. **Methods**: The study considered 13 patients retrospectively who were previously treated using sliding window IMRT techniques during September 2023 to July 2024. IMRT and VMAT plans were compared in terms of target coverage, organs at risk (OARs), homogeneity index (HI), conformity index (CI), gradient index (GI), Unified Dosimetry Index (UDI), conformation number (CN), integral dose (ID), the number of monitor units (MUs) and treatment time (s). **Findings**: The target coverage ($p<0.001$), CI ($p=0.001$), HI ($p=0.009$), GI ($p=0.042$) and CN ($p<0.001$) and UDI($p=0.006$) in all parameters VMAT plan was superior to the IMRT plan. The better OARs sparing and significantly reduced MUs ($p<0.001$), treatment time ($p<0.001$) and ID ($p<0.001$) with VMAT was obtained in comparison to fixed field IMRT. **Novelty**: VMAT has the best performance in terms of target coverage, CI, HI, GI, CN and UDI and can better protect the OARs. VMAT plans have fewer MUs and improve treatment efficiency.

Keywords: Cervical cancer; Radiotherapy; Intensity-Modulated Radiation Therapy; Volumetric Modulated Arc Therapy; Integral Dose; Homogeneity Index

1 Introduction

Cervix uteri cancer is the fourth most frequent cancer in women globally, accounting for an anticipated 604,127 new cases and 341,831 fatalities in 2020. With a 57% mortality to incidence ratio, cervical cancer mortality rates are significantly lower than incidence rates worldwide (GLOBOCAN 2020)[(1)]. In India, cervical cancer is the second most common cancer in women and the second most common cancer in women aged 15 to 44[(2)]. The two primary causes of its incidence are inadequate cleanliness and delayed

investigation. Thus, it continues to be a major public health issue that mostly affects middle-aged women, particularly in underdeveloped nations[3].

According to National Comprehensive Cancer Network (NCCN) guidelines, concurrent radiation and cisplatin-based chemotherapy has become the recommended treatment for patients with early-stage cervical cancer who have positive pelvic nodes, positive surgical margins, or positive parametrium[4]. The main objective of radiation therapy is to reduce long-term side effects by delivering a high dose to the tumor while minimizing exposure to surrounding healthy organs as much as possible. While conventional conformal radiotherapy (CRT) can provide effective tumor coverage, it often results in higher doses to organs at risk (OARs). These challenges highlight the need for advanced technologies in treatment that can both spare healthy organs and enhance target coverage. By using intensity modulated radiation therapy (IMRT), an advanced radiation therapy technique that minimizes radiation dosage to vulnerable organs, highly conformal dose distribution can be delivered[5]. Even while IMRT has many advantages, it also has certain drawbacks. This approach often necessitates for several fixed-angle radiation beams, which may prolong the time required to deliver treatment and affect intra-fraction movement, patient comfortability and treatment position reproducibility. In addition, IMRT employs more monitor units (MUs) than traditional CRT, which increases the level of low-dose radiation that the body absorbs overall during the duration of treatment. This brings up the possibility of secondary radiation-induced cancer, which is especially concerning for young patients or those with extended life expectancies. Compared to traditional IMRT, volumetric modulated arc therapy (VMAT) offers comparable target coverage while drastically lowering the dose to OARs, such as the rectum, bladder, colon, and femoral head. Additionally, VMAT expedites delivery time, lowers average monitor units (MUs), and improves conformity and homogeneity criteria to the planned target volume (PTV)[6]. Nonetheless, a common disadvantage of VMAT is the worry about low-dose exposure to healthy tissues[7]. Many studies suggest advantages of VMAT over IMRT techniques in terms of target coverage and better sparing of OARs. According to study of Zhai *et al.* found that IMRT is better than arc therapy when treating cervical cancer. Some studies showed that both IMRT and VMAT may be recommended for use, decisions on patient-specific practicalities[8]. But advantages or disadvantages of both the techniques is still debatable.

In this study to extract the dosimetric advantages and disadvantaged of IMRT and VMAT by using several parameters such as Unified Dosimetry Index (UDI) which was developed by Akpati H. et al., that uses all four dosimetric indices such as coverage index (C), Conformity Index (CI), Homogeneity Index (HI), and Gradient Index (GI) are included in the UDI for determining the scores of treatment plan. UDI score was rated based on the lowest number indicating a better treatment technique strategy for that plan. Integral dose (ID), which is the measure of the entire radiation deposited throughout the body during the course of treatment. This current study employs all of these variables to evaluate dosimetric parameters concerning enhanced conformal target coverage and organ-at-risk (OAR) sparing through the comparison of intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT).

2 Methodology

2.1 Patient selection

This was the retrospective study done on data of 13 patients treated for cervical cancer at a Raj Scanning Ltd., Lucknow. These patients were previously treated using sliding window IMRT techniques during September 2023 to July 2024. Biopsy proven carcinoma cervix patients with their International Federation of Gynaecology and Obstetrics (FIGO) stage IIB-IVA were selected for this study. Each patient was received concurrent chemotherapy with cisplatin 35 mg/m^2. All patients were more than 50 years of age, with an average age of 62 years. According to FIGO staging, patient's characteristics is shown in Table 1.

2.2 CT simulation

Before the CT positioning was performed, the patients were required to empty their bowels and fill their bladders. All patients underwent CT scans in the supine position with thermoplastic mold with knee rest for immobilization, IV contrast was given with dose calculated at 1 ml/Kg up to a maximum of 60 ml. Scans were taken with a slice thickness of 3 mm from T12 vertebral level to mid-thigh. Three Fiducials were placed at the expected isocenter, approximately midway between the umbilicus and the symphysis pubis in the midplane. After completion of simulation, the CT images were transferred into the Eclipse treatment planning system (V15.6).

Table 1. Patients' characteristics of 13 patients with cervical cancer

Patient no.	Age (y)	FIGO stage	PTV (cc)
1	54	IIIB	1061.06
2	56	IIB	1034
3	70	IVA	846.8
4	72	IIB	917.6
5	55	IIIA	731.4
6	63	IIB	929.1
7	50	IIA	827.2
8	66	IIIB	874.4
9	57	IIB	923.7
10	58	IVA	944.9
11	60	IIB	1120.8
12	67	IIIB	872.5
13	78	IIA	997.6

2.3 Delineation of target volumes and OARs

Contouring was carried out using the principal clinical findings and conventional RTOG recommendations. GTV was contoured by detecting the gross tumor volume using Contrast CT scans. CTV- primary (CTV-P) included whole uterus which contains cervix with gross tumor, vagina and parametrium. CTV nodal consists of bilateral internal & external iliac, presacral, obturator lymph nodes. To generate the final PTV, the primary and nodal CTVs were combined and given an additional uniform margin of 0.7 cm in all directions as shown in Figure 1. The OARs included rectum, bladder, small bowel, bilateral femoral head and bone marrow.

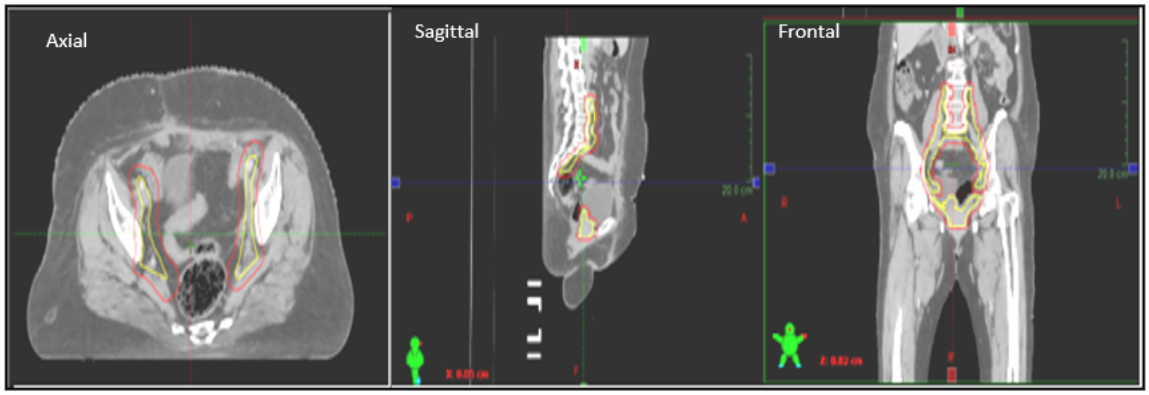

Fig 1. Planning target volume (PTV) and clinical target volume (CTV) of one cervical cancer patient

2.4 IMRT and VMAT planning methodology used for patients

The prescription doses were 50.4 Gy in 28 fractions (with a daily dose of 1.8 Gy) for 9 Field (9F) IMRT plan evenly separate coplanar beam with gantry angles of 40°, 80°, 120°, 160°, 200°, 240°, 280°, 320°, and 0° was used and for VMAT two full rotation arcs (clockwise and anticlockwise) were used. Energy of beam used in IMRT and VMAT plans was 6X-FFF of Varian Halcyon^{TM} linear accelerator with a dose rate of 800MUs/min. The algorithm used for planning purposes was Anisotropic Analytical Algorithm (AAA)[9]. The planning goal was 95% of Prescription Dose (PD) to cover 98% of the PTV and not exceed 107% of maximum dose. OARs dose analyzed according to both QUANTEC and RTOG guidelines.

2.5 Dosimetric evaluation

Dose coverage can be defined as the ratio of the minimal dose (D_{min}) within the target volume to the prescribed dose (PD). The plan is considered acceptable if the target volume accounts for 90% of the recommended isodose. A considerable variation occurs when the target volume covers less than 80% of the prescribed dose [10]. In most clinical circumstances, a $\pm 10\%$ variance is acceptable [11].

$$\text{Coverage} = \text{D}_{\text{min}}/\text{PD}$$

According to ICRU 62 [12] report the Conformity Index (CI) is the ratio of Treated volume (TV) i.e. the volume that is enclosed by 95% isodose to Planning target Volume (PTV).

$$\text{CI} = \text{TV}/\text{PTV}$$

It's ideal value is 1 but if it lies between 1 and 2 it is considered to be acceptable.

Homogeneity Index (HI) is defined as the ratio of maximum dose (D_{max}) to minimum dose (D_{min}) as per ICRU-62**.**

$$\text{HI} = \text{D}_{\text{max}}/\text{D}_{\text{min}}$$

It's ideal HI value is 1 but it acceptable between values 1 and 1.5.

Dose gradient index (GI) helps to estimate the degree of shallowness or steepness of dose fall-off beyond the tumor volume. A lower value of GI indicates sharper dose fall-off and better is the planning technique [13], [14].

$$\text{GI} = \text{PTVPD}/\text{PTVPD50}\%$$

where, PTVPD50% represents planning target volume coverage at 50% of PD.

Unified Dosimetry Index (UDI) is the product of four parameters which are target volume coverage, conformity index, dose homogeneity index, and dose gradient index. An ideal UDI value is 1. UDI with Lower value considered to an excellent plan, whereas a high value greater than 1 indicates a fewer plan.

$$\text{UDI} = \text{Coverage} \times \text{CI} \times \text{HI} \times \text{GI}.$$

The conformation number (CN) in a treatment plan accounts for the relative measure of target coverage and sparing of OARs. Van't Riet Model [15] used for calculation of CN is as follows.

$$\text{CN} = \text{TV}_{\text{ref}}^2/\text{TV} \times \text{V}_{\text{ref}}$$

where TV_{ref} represents volume of target receiving a dose equal to or greater than the reference dose which is 95% of isodose; TV is the volume of target; and V_{ref} is the volume getting a dose equal to or greater than the reference dose (treated volume). The CN value lies in the range of 0 to 1, where 1 is the considered to be an ideal value.

Integral dose (ID) is calculated as the product of mean dose received by an organ, volume receiving that dose, and the density of that volume as given by the equation.

$$\text{ID (GyL)} = \text{D}_{\text{mean}} \times \text{V} \times \rho$$

where, D_{mean} = organ mean dose, V= Volume of the organ that receives the dose, ρ= Density of the volume of that organ.

To keep things simple, we assumed that the patient's body volume was uniformly dense. Therefore, in our study, we calculated Integral dose of the body by creating a structure set "Body subtracted from PTV" for measurement. Although no optimal threshold value for ID is advised, it is essential to keep it as low as possible without significantly influencing target coverage [16].

2.6 Monitor unit (MU) and treatment time

The treatment times for the two radiotherapy techniques were noted, along with the fired MUs (treatment time taken from the first treatment field to last treatment field).

2.7 Statistical analysis

SPSS 26.0 (IBM Corp, Armonk, NY, USA) was used to perform a t-test analysis of the measurement data between the two groups. Additionally, a difference in statistical significance was defined as a P value <0.05.

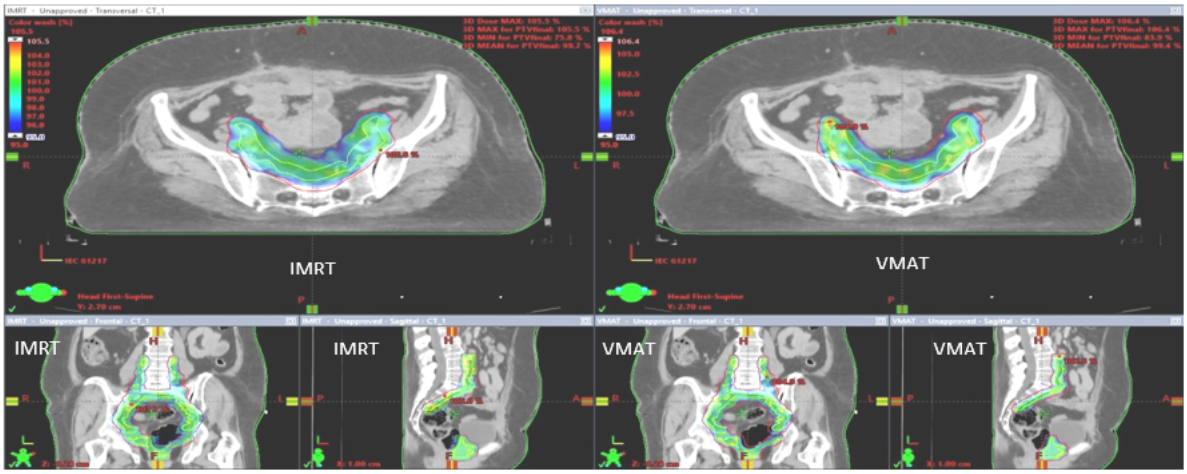

Fig 2. Typical dose distribution of 9Field IMRT and dual arc VMAT for one cervical cancer patient

3 Results and Discussion

Figure 2 showing typical dose distribution of 9Field IMRT and dual arc VMAT for one cervical cancer patient.

3.1 DVH comparison

Figure 3 shows a typical DVH of a single patient for comparison between the IMRT and VMAT plans. The curves of the various OARs show that the mid-proportion of volumes irradiated in the VMAT plan was much at lower doses than the IMRT plan, especially for the bladder, rectum, and small bowel. Although the maximum and minimum dosage values for almost all OARs volumes are on the upper levels for the VMAT plan. But they were within their threshold limits. For the remaining OARs like bilateral femoral head and bone marrow no major differences were observed in the shape of their curves.

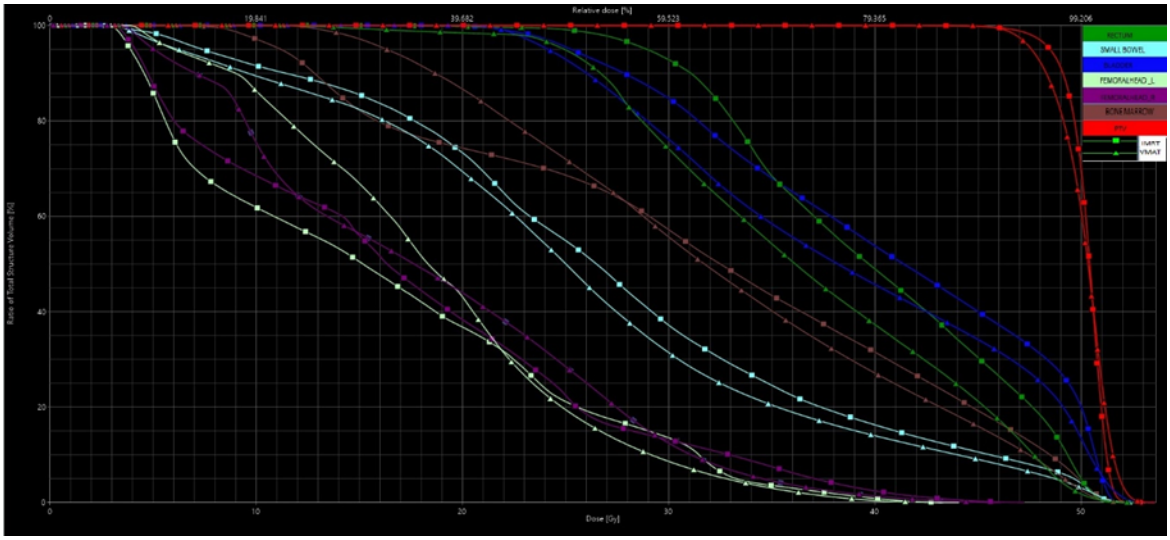

Fig 3. Comparison of DVH between 9Field IMRT and dual arc VMAT for one cervical cancer patient

3.2 Dosimetric comparison

Table 2 and Figure 4 show the overall quality of IMRT and VMAT plans in terms of coverage, CI, HI, GI, UDI and ID was evaluated and compared in this study. Significant difference in values of Coverage (p<0.001), CI (p=0.001), HI (p=0.009), GI (p=0.042) and CN (p<0.001) was in favor of VMAT. Our study showed UDI (p=0.006) was better for VMAT plan compared to IMRT plan. For ID (p<0.001) comparison between IMRT (238.22 ± 39.23) and VMAT (231.03 ± 36.67), significant difference was found in favor of VMAT.

Table 2. Dosimetric parameters comparison between 9Field IMRT and dual arc VMAT

Parameters	IMRT (Mean±SD)	VMAT (Mean±SD)	p value (Paired t-test)
Coverage	0.85 ± 0.09	0.928 ± 0.03	<0.001
Conformity Index (CI)	1.17 ± 0.04	1.05 ± 0.05	0.001
Homogeneity Index (HI)	1.39 ± 0.18	1.27 ± 0.04	0.009
Gradient Index (GI)	0.98 ± 0.012	0.97 ± 0.020	0.042
Unified Dose Index (UDI)	1.28 ± 0.05	1.20 ± 0.08	0.006
Conformation No. (CN)	0.86 ± 0.02	0.89 ± 0.02	<0.001
Integral Dose (ID) (GyL)	238.22 ± 39.23	231.03 ± 36.67	<0.001

3.3 Comparison of OARs irradiation doses

Table 3 and Figure 5 show dose parameter comparisons for OARs. For bladder, on comparing doses in volumes of V10, V20, V35, V40 no significant differences were observed for IMRT and VMAT technique. On comparing maximum dose (D_{max}) value between IMRT (52.54 ± 11.95) and VMAT (52.71 ± 14.74) a significance level of p=0.005 was observed, which was in favor of IMRT. Similarly higher values of mean dose (D_{mean}) and minimum dose (D_{min}) was obtained in VMAT plan but not at significant levels.

For rectum, on comparing doses in volumes of V10, V20, V35, V40 and values of D_{max}, D_{min} and D_{mean} were having no significant differences were observed but gone in favor of VMAT.

For small bowel, V25, V35, D195cc and D_{mean} showed no significant difference between IMRT and VMAT plans. However, for D_{max} and D_{min} having significant difference were observed between IMRT and VMAT, which was in favor of IMRT with p=0.004 and p<0.001 respectively.

For bilateral femoral head, V30 and V40 showed significant differences between IMRT and VMAT, which was in favor of VMAT with p=0.001 and p=0.017 respectively. Although, D_{max} ,D_{min} and D_{mean} showed no significant differences.

For bone marrow having V10, V20, D_{min} and D_{mean} values with having no significant differences for IMRT and VMAT, but D_{max} was having significant difference which was in favor of IMRT with p=0.013.

Vx, volume receiving at least X Gy dose; D195cc is dose received by 195cc of volume; D_{max}, D_{min} and D_{mean} are the maximum, minimum and mean dose.

3.4 Comparison of MUs and treatment time

The MU and treatment time were compared between the two plans and given in Table 4 and Figure 4 to assess the performance of the dual arc VMAT and 9Field IMRT plans. The dual arc VMAT plans lowered the average number of MUs (678.37 ± 50.53 vs. 1377.39 ± 112.38) for the 13 patients by 49% as compared to 9 Field IMRT. The VMAT plans shortened the mean delivery time by 30% (34.93 ± 2.60 vs. 114.78 ± 9.36 s) when compared to 9Field IMRT. As a result, the dual arc VMAT plans had improved treatment efficiency as they reduced MU and treatment duration.

The VMAT practice involves many control points (178) for dynamic dose delivery during gantry rotation which offers a high degree of freedom. Dosage delivery is restricted to already defined beam angles with IMRT planning, in contrast to VMAT. The best available beam angles for dosage delivery may therefore be skipped in IMRT planning. VMAT provides a simple solution for this kind of issue[17]. According to investigations by Oliver M et al. and Nicolini G et al., VMAT can provide a plan with greater homogeneity and conformity at the same level PTV coverage[18],[19].

According to Huang et al., evaluation of the dose distribution between VMAT and 7F-IMRT in 13 patients with cervical cancer, the VMAT regimen significantly surpassed the 7-IMRT approach in terms of target region dosage uniformity and

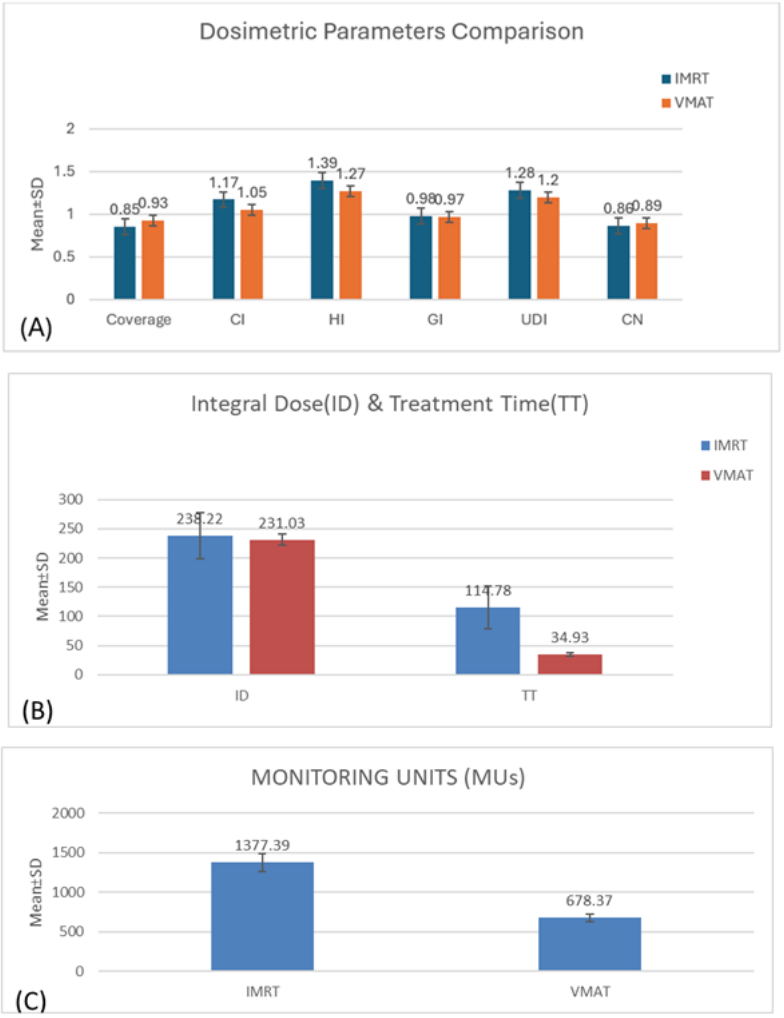

Fig 4. A) Dosimetric comparison; B) Integral Dose and Treatment Time; C) monitoring units for IMRT and VMAT

organ sparing[20]. Nguyen et al. discovered that, in contrast to a traditional IMRT regimen, VMAT might accomplish a highly conformal target region dose distribution and more effectively protect normal tissues[21].

According to Atiq et al., comparison of VMAT with IMRT for cervical cancer pelvic radiation therapy, VMAT performed better with respect to homogeneity, conformity, coverage, high gradient index, and improved sparing of normal tissue at a comparable integral dose[16].

In our study on comparing IMRT plan with VMAT plan for 13 patients for OARs sparing, VMAT showed lower mean doses to all the critical organs except for bladder. However, maximum doses to OARs were higher in case of VMAT plans but, with an exception for rectum dose. However, doses for all OARs remained within their tolerance limits. From our study we had understood that, in order to achieve better conformity of VMAT resulted in producing higher maximum dosages to PTV and OARs. But overall VMAT is capable to provide better sparing to OARs across all volume of doses in comparison to IMRT.

In terms of the target coverage, HI, GI and CI, and UDI and CN score in all parameters VMAT plan was superior to the IMRT plan, and the calculated MUs and treatment time of the IMRT was longer than that of the VMAT plan. With VMAT, patients can have less discomfort from holding their posture for a longer period of time, experience fewer errors in therapy due to body positioning, and receive more accurate treatment. Moreover, the integral dose is significantly reducing in VMAT plans for remaining body parts this can reduce chances for secondary malignancies.

The superior target coverage, significantly reduced MU and treatment time, with better OARs sparing to the greater extent with VMAT can be obtained in comparison to fixed field IMRT in pelvic RT for cervical cancer.

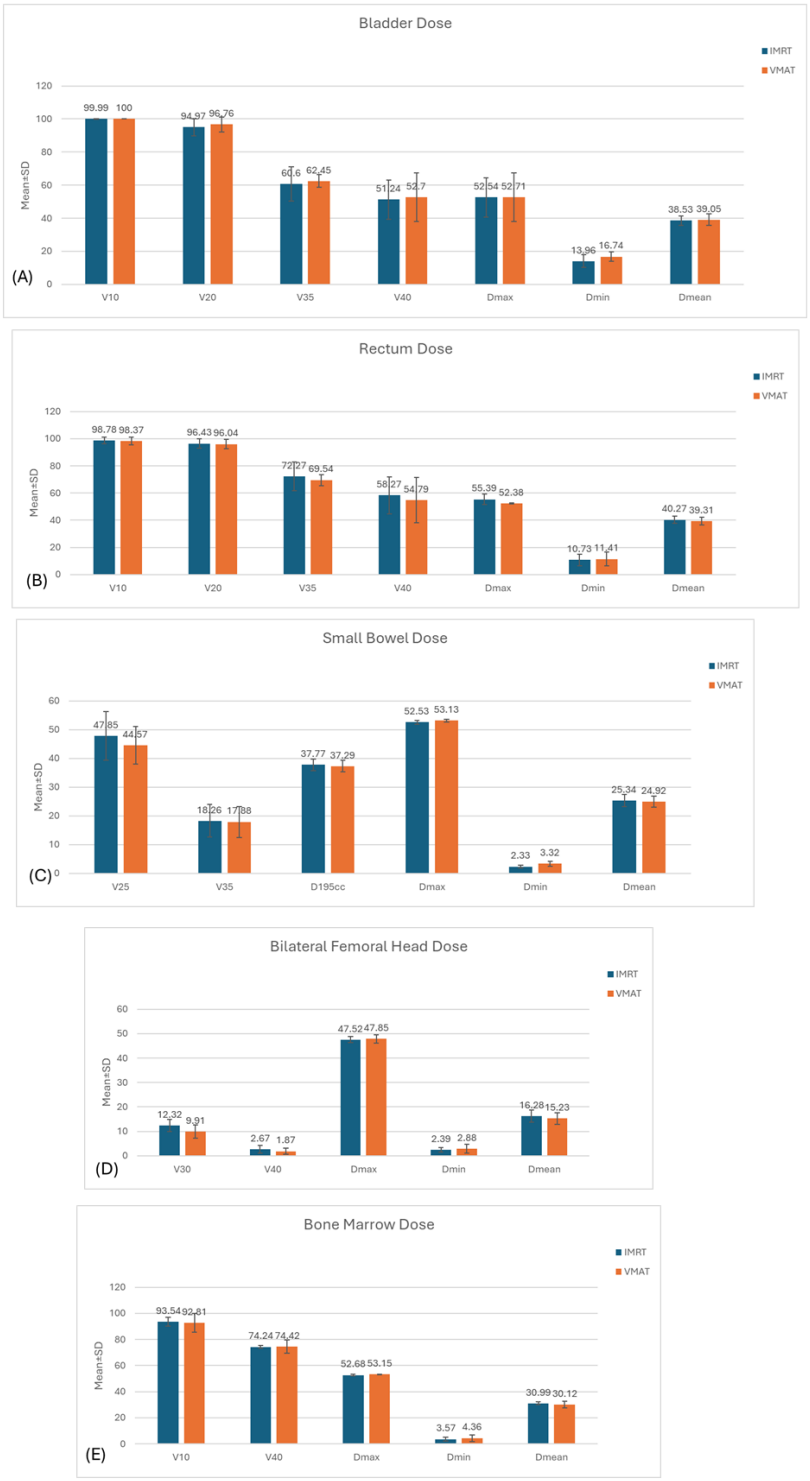

Fig 5. Comparison of OARs irradiation doses: A) Bladder dose; B) Rectum dose; C) Small bowel dose; D) Bilateral Femoral Head dose; E) Bone Marrow dose

Table 3. Comparison of dose parameters for OARs between 9Field IMRT and dual arc VMAT

OAR	Parameters	IMRT (Mean±SD)	VMAT (Mean±SD)	p value (Paired t-test)
Bladder	V10 (%)	99.99 ± 0.01	100 ± 0.00	0.341
	V20 (%)	94.97 ± 5.18	96.76 ± 4.53	0.352
	V35 (%)	60.60 ± 10.37	62.45 ± 3.79	0.372
	V40 (%)	51.24 ± 11.95	52.71 ± 14.74	0.472
	D_{max} (Gy)	52.54 ± 11.95	52.71 ± 14.74	0.005
	D_{min} (Gy)	13.96 ± 3.86	16.74 ± 2.96	0.055
	D_{mean} (Gy)	38.53 ± 2.903	39.049 ± 3.564	0.334
Rectum	V10 (%)	98.78 ± 2.39	98.37 ± 2.91	0.332
	V20 (%)	96.43 ± 3.37	96.04 ± 3.61	0.533
	V35 (%)	72.27 ± 10.48	69.54 ± 4.14	0.315
	V40 (%)	58.27 ± 13.53	54.79 ± 16.78	0.171
	D_{max} (Gy)	55.39 ± 3.88	52.38 ± 0.40	0.464
	D_{min} (Gy)	10.73 ± 4.27	11.41 ± 5.15	0.604
	D_{mean} (Gy)	40.272 ± 2.664	39.315 ± 2.958	0.096
Small Bowel	V25 (%)	47.846 ± 8.5	44.571 ± 6.598	0.098
	V35 (%)	18.262 ± 5.627	17.881 ± 5.358	0.597
	D195cc (Gy)	37.766 ± 1.990	37.293 ± 2	0.255
	D_{max} (Gy)	52.526 ± 0.590	53.135 ± 0.430	0.004
	D_{min} (Gy)	2.335 ± 0.446	3.316 ± 0.842	<0.001
	D_{mean} (Gy)	25.375 ± 2.164	24.925 ± 1.965	0.174
Bilateral Femoral Head	V30 (%)	12.322 ± 2.464	9.913 ± 2.659	0.001
	V40 (%)	2.667 ± 1.650	1.867 ± 1.172	0.017
	D_{max} (Gy)	47.524 ± 1.295	47.848 ± 1.644	0.214
	D_{min} (Gy)	2.385 ± 0.942	2.880 ± 1.893	0.19
	D_{mean} (Gy)	16.283 ± 2.555	15.233 ± 2.338	0.168
Bone Marrow	V10 (%)	93.542 ± 3.551	92.816 ± 7.113	0.604
	V20 (%)	74.237 ± 0.922	74.428 ± 5.181	0.901
	D_{max} (Gy)	52.679 ± 0.570	53.153 ± 0.407	0.013
	D_{min} (Gy)	3.573 ± 1.502	4.358 ± 2.495	0.178
	D_{mean} (Gy)	30.998 ± 1.00	30.117 ± 2.631	0.244

Table 4. Comparison of MU and treatment time between 9Field IMRT and dual arc VMAT

Parameters	IMRT (Mean±SD)	VMAT (Mean±SD)	p value (Paired t-test)
Monitoring Units (MUs)	1377.39 ± 112.38	678.37 ± 50.53	<0.001
Treatment Time(sec)	114.78 ± 9.36	34.93 ± 2.60	<0.001

4 Conclusion

In conclusion, it can be firmly established that both of the proposed treatment plans under consideration exhibit the inherent capability to adequately meet the established criteria necessary for the protection of organs-at-risk (OAR) in patients who have been diagnosed with cervical cancer, thereby ensuring patient safety and treatment efficacy. When a detailed comparison is conducted between the volumetric modulated arc therapy (VMAT) plan and the intensity-modulated radiation therapy (IMRT) plan, it becomes increasingly evident that the VMAT plan is significantly more advantageous, particularly with respect to the conformity of the target region and its superior effectiveness in preserving the integrity of OARs during treatment. In addition to these benefits, the implementation of VMAT serves a crucial function in reducing the duration of radiation exposure, which, in turn, contributes to a marked decrease in the likelihood of errors that may arise due to positional shifts and the movements

of surrounding organs during the radiation delivery process. As a result of these compelling advantages, the VMAT plan is widely regarded within the medical community as a distinctly superior radiotherapeutic modality in comparison to the IMRT plan, particularly when evaluated within the specific context of providing effective radiotherapy treatment for patients afflicted with cervical cancer. Thus, healthcare professionals may consider the adoption of the VMAT approach as a more reliable and efficient option in the ongoing effort to enhance treatment outcomes and minimize potential complications associated with cervical cancer radiotherapy. Ultimately, the choice between these two treatment plans should be guided by a comprehensive understanding of their respective benefits and limitations, ensuring that patient care remains at the forefront of clinical decision-making.

5 Acknowledgements

Authors are thankful to Raj Scanning Ltd., Lucknow, Uttar Pradesh, India for carry out the validation of work on Halcyon V.2.0, a single-energy (6 MV-FFF), Bore-enclosed linear accelerator (Varian Oncology System).

References

1) Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A. Global Cancer Statistics 2020: GLOBOCAN Estimates of Incidence and Mortality Worldwide for 36 Cancers in 185 Countries. *A Cancer Journal for Clinicians*. 2021 May;71(3):209–249. https://acsjournals.onlinelibrary.wiley.com/doi/10.3322/caac.21660.
2) Bruni L, Albero G, Serrano B, Mena M, Collado JJ, Gómez D, et al. Human Papillomavirus and Related Diseases in the World. . Available from: https://hpvcentre.net/statistics/reports/XWX.pdf.
3) Arbyn M, Weiderpass E, Bruni L, de Sanjosé S, Saraiya M, Ferlay J. Estimates of incidence and mortality of cervical cancer in 2018: a worldwide analysis. *Lancet Global Health*. 2020 Feb;8(2):e191–e203. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2214109X19304826.
4) Abu-Rustum NR, Yashar CM, Arend R, Barber E, Bradley K, Brooks R. NCCN Guidelines Insights: Cervical Cancer, Version 1.2024. *Journal of the National Comprehensive Cancer Network*. 2023 Dec;21(12):1224–1233. Available from: https://jnccn.org/view/journals/jnccn/21/12/article-p1224.xml.
5) Faye MD, Alfieri J. Advances in Radiation Oncology for the Treatment of Cervical Cancer. *Current Oncology*. 2022 Feb;29(2):928–944. Available from: https://www.mdpi.com/1718-7729/29/2/79.
6) Jindakan S, Tharavichitkul E, Watcharawipha A, Nobnop W. Improvement of treatment plan quality with modified fixed field volumetric modulated arc therapy in cervical cancer. *Journal of Applied Clinical Medical Physics*. 2024 Oct;25(10). Available from: https://aapm.onlinelibrary.wiley.com/doi/10.1002/acm2.14479.
7) Yu PC, Wu CJ, Nien HH, Lui LT, Shaw S, Tsai YL. Tangent-based volumetric modulated arc therapy for advanced left breast cancer. *Radiation Oncology*. 2018 Dec;13(1):236. Available from: https://ro-journal.biomedcentral.com/articles/10.1186/s13014-018-1167-y.
8) S P, K R, R A. Dosimetric Comparison of 3-Dimensional Conformal Radiotherapy (3DCRT), Intensity Modulated Radiotherapy (IMRT) and Volumetric-Arc Radiotherapy (VMAT) in Cervical Cancer Treatment. *Annals of Radiation Therapy and Oncology*. 2023 Feb;4(1):1–3. Available from: https://www.remedypublications.com/open-access/dosimetric-comparison-of-3-dimensional-conformal-radiotherapy-3dcrt-intensity-modulated-radiotherapy--9708.pdf.
9) Knöös T, Wieslander E, Cozzi L, Brink C, Fogliata A, Albers D. Comparison of dose calculation algorithms for treatment planning in external photon beam therapy for clinical situations. *Physics of Medical Biology*. 2006 Nov;51(22):5785–5807. Available from: https://iopscience.iop.org/article/10.1088/0031-9155/51/22/005.
10) Murphy MJ, Chang S, Gibbs I, Le QT, Martin D, Kim D. Image-guided radiosurgery in the treatment of spinal metastases. *Neurosurgeon Focus*. 2001 Dec;11(6):1–7. Available from: https://thejns.org/view/journals/neurosurg-focus/11/6/foc.2001.11.6.7.xml.
11) Das IJ, Cheng CW, Chopra KL, Mitra RK, Srivastava SP, Glatstein E. Intensity-Modulated Radiation Therapy Dose Prescription, Recording, and Delivery: Patterns of Variability Among Institutions and Treatment Planning Systems. *JNCI Journal of the National Cancer Institute*. 2008 Mar;100(5):300–307. Available from: https://academic.oup.com/jnci/article-lookup/doi/10.1093/jnci/djn020.
12) Newhauser W. International Commission on Radiation Units and Measurements Report 78: Prescribing, Recording and Reporting Proton-beam Therapy. *Radiation Protection Dosimetry*. 2009 Jan;133(1):60–62. Available from: https://academic.oup.com/rpd/article-lookup/doi/10.1093/rpd/ncp005.
13) Krishnan J, Shetty J, Rao S, Hegde S, Shambhavi C. Comparison of rapid arc and intensity-modulated radiotherapy plans using unified dosimetry index and the impact of conformity index on unified dosimetry index evaluation. *Journal of Medical Physics*. 2017;42(1):14. Available from: https://journals.lww.com/10.4103/jmp.JMP_112_16.
14) Paddick I, Lippitz B. A simple dose gradient measurement tool to complement the conformity index. *Journal of Neurosurgery*. 2006 Dec;105(Supplement):194–201. Available from: https://thejns.org/view/journals/j-neurosurg/105/Supplement/article-p194.xml.
15) van't Riet A, Mak ACA, Moerland MA, Elders LH, van der Zee W. A conformation number to quantify the degree of conformality in brachytherapy and external beam irradiation: Application to the prostate. *International Journal of Radiation Oncology*. 1997 Feb;37(3):731–736. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0360301696006013.
16) Atiq A, Atiq M, Iqbal K, Sial M, Altaf S, Shamsi Q. A comparative study of RapidArc and intensity-modulated radiotherapy plan quality for cervical cancer treatment. *Indian Journal of Cancer*. 2018;55(1):74. Available from: https://journals.lww.com/10.4103/ijc.IJC_609_17.
17) Michalski JM, Yan Y, Watkins-Bruner D, Bosch WR, Winter K, Galvin JM. Preliminary Toxicity Analysis of 3-Dimensional Conformal Radiation Therapy Versus Intensity Modulated Radiation Therapy on the High-Dose Arm of the Radiation Therapy Oncology Group 0126 Prostate Cancer Trial. *International Journal of Radiation Oncology*. 2013 Dec;87(5):932–938. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0360301613029532.
18) Oliver M, Ansbacher W, Beckham WA. Comparing planning time, delivery time and plan quality for IMRT, RapidArc and tomotherapy. *Journal of Applied Clinical Medical Physics*. 2009 Sep;10(4):117–131. Available from: https://aapm.onlinelibrary.wiley.com/doi/10.1120/jacmp.v10i4.3068.
19) Nicolini G, Clivio A, Fogliata A, Vanetti E, Cozzi L. Simultaneous integrated boost radiotherapy for bilateral breast: a treatment planning and dosimetric comparison for volumetric modulated arc and fixed field intensity modulated therapy. *Radiation Oncology*. 2009 Dec;4(1):27. Available from: https://ro-journal.biomedcentral.com/articles/10.1186/1748-717X-4-27.

20) Huang B, Fang Z, Huang Y, Lin P, Chen Z. A dosimetric analysis of volumetric-modulated arc radiotherapy with jaw width restriction vs 7 field intensity-modulated radiotherapy for definitive treatment of cervical cancer. *British Journal of Radiology*. 2014 Jul;87(1039):20140183. Available from: https://academic.oup.com/bjr/article/7445543.
21) Jeong Y, wook Lee S, Kwak J, Cho I, Yoon SM, Kim JH. A dosimetric comparison of volumetric modulated arc therapy (VMAT) and non-coplanar intensity modulated radiotherapy (IMRT) for nasal cavity and paranasal sinus cancer. *Radiation Oncology*. 2014 Dec;9(1):193. Available from: https://ro-journal.biomedcentral.com/articles/10.1186/1748-717X-9-193.