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Dosimetric influence of photon beam energy and number of arcs on volumetric modulated arc therapy in carcinoma cervix: A planning study

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ABSTRACT

Aim: Aim of the present study was to compare the dosimetric impact of different photon beam energies and number of arcs in the treatment of carcinoma cervix.

Background: Carcinoma cervix is a common cancer in women worldwide with a high morbidity rate. Radiotherapy is used to treat such tumours. Volumetric Modulated Arc Therapy (VMAT) is considered superior to other techniques with multiple arcs and energies.

Materials and methods: Twenty patients with carcinoma cervix underwent radiotherapy in a prospective observation study conducted at our institute. Volumetric modulated arc plans with 6 MV, 10 MV and 15 MV photon energies using single arc (SA) and dual arc (DA) were generated. Several physical indices for planning target volume (PTV) like $V_{95\%}$, $V_{100\%}$, $V_{110\%}$, $D_{98\%}$, $D_{50\%}$, $D_{2\%}$ and total number of MUs were compared. Normal Tissue Integral Dose (NTID) and dose to a shell structure $PHY_{2.5}$ and $PHY_{5.0}$ were analyzed.

Results: Comparable dose coverage to PTV was observed for all the energies and arcs. CI for DA_{6MV} (1.095) was better than SA_{6MV} (1.127), SA_{10MV} (1.116) and SA_{15MV} (1.116). Evaluated parameters showed significant reduction in OAR doses. Mean bladder dose for DA_{6MV} (41.90 Gy) was better than SA_{6MV} (42.48 Gy), SA_{10MV} (42.08 Gy) and SA_{15MV} (41.93 Gy). Similarly, *p*-value for the mean rectal dose calculated was 0.001 ($SA_{6\text{ vs }15}$), 0.013 ($DA_{6\text{ vs }10}$) and 0.003 ($DA_{6\text{ vs }15}$) and subsequently favoured DA_{6MV}. Difference in NTID was very small.

Conclusions: The study showed no greater advantage of higher energy, and DA VMAT plan with 6 MV photon energy was a good choice of treatment for carcinoma cervix as it delivered a highly homogeneous and conformal plan with superior target coverage and better OAR sparing.

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1. Background

Carcinoma cervix is the fourth most common cancer in women worldwide, with an estimated 5,300,000 new cases resulting in 7.5% of all female cancer deaths. Around 85% of the estimated deaths occur in developing countries from cervical cancer every year. The high mortality rate from cervical cancer globally (around 52%) could be reduced by effective screening and treatment programmes.[1] Morbidity rate was very high either due to disease progression or due to complications of the treatment until a few years back. But advancement in technology has helped a lot in curing these patients by delivering adequate dose to tumour and lesser dose to critical surrounding structures, leading to minimal complications during and after treatment.

Historically, a conventional technique using high photon energy with AP/PA fields or box technique was used for treatment of carcinoma of the cervix.[2] It was observed that the conventional technique delivered unnecessary doses to nearby critical organs, thereby leading to treatment related complications which was a big issue considering the high rate of cure and survival of disease. This was a problem we had to accept to cure the disease (Figs. 1–3).

Conventional modalities have given way to Intensity Modulated Radiation Therapy (IMRT) for the past two decades and most recently, we have seen the emergence of Volumetric Modulated Arc Therapy (VMAT) in which the treatment is delivered using partial or full arcs. IMRT uses fluence modulation and provides clinical and dosimetric benefits over the conventional technique. However, there is an increase in total monitor units (TMUs) with IMRT leading to increased risk of secondary cancers[3,4] known as radiation induced malignancies. Due to the movement of different machine parameters, VMAT manages to provide equivalent dose distribution with lesser monitor units and treatment time.[5]

In VMAT, radiation remains 'ON' even as the gantry rotates, MLCs shift and the dose rate varies, which translates into faster treatment. It also claims a higher degree of conformity of the intensity modulation which is proven to spare more of normal tissues.[6,7]

VMAT has received massive interest from the radiation therapy community as it was capable of delivering a highly conformal dose distribution within a short time interval. The clinical applicability of such new treatment techniques should be preceded by detailed dosimetric validation. Each arc creates its own impact on target coverage and sparing of nearby critical structures.[8]

2. Aim

This study was designed to compare the dosimetric effects of different photon beam energies in the treatment of carcinoma cervix. In addition to this, effect of the change in the number of arcs in accordance with beam energies to treat deep-seated tumours were also noted.

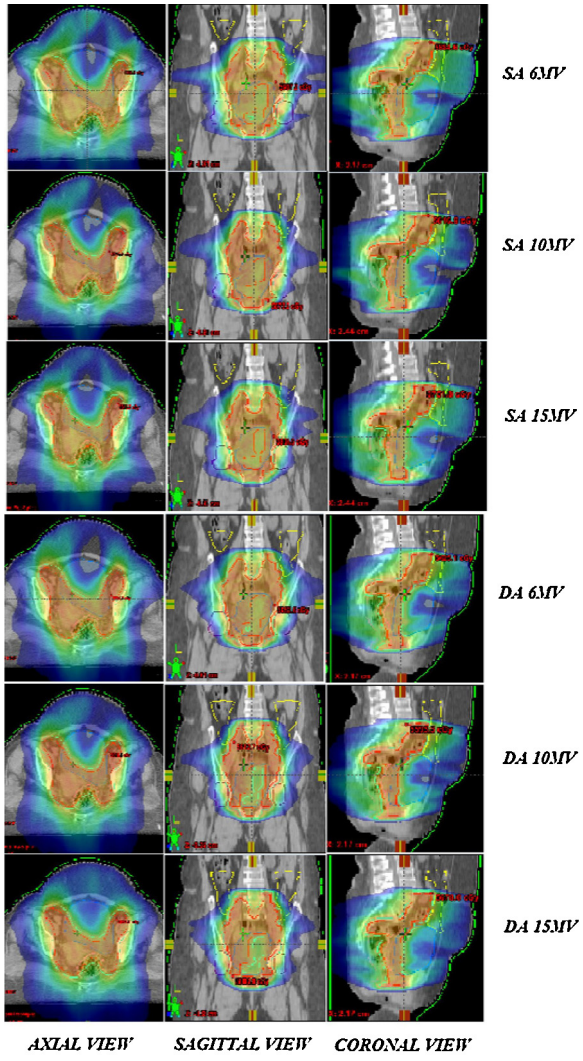

Fig. 1 – Spillage comparison (50% prescription dose) for different energy for SA and DA in different views.

3. Materials and methods

3.1. *Patient selection*

A cohort of 20 patients, diagnosed with carcinoma cervix were enrolled in this prospective observational study. Volumetric modulated arc plans with 6 MV, 10 MV and 15 MV photon energies using single arc (SA) and dual arc (DA) were generated.

3.2. *CT simulation*

CT scan was done for all the patients on CT-simulator unit (Somatom Sensation Open, Siemens, Germany). Patients were instructed to follow a bladder protocol, in which each patient was asked to void the bladder and then drink approximately 1 l of water to fill the bladder. They were asked to wait for around 45 min before planning scan to ensure bladder filling. Fiducial markers were kept at the level of pubic symphysis. Orfit immobilizing casts were made for the patient and scans of 5 mm thickness were acquired in supine position and were

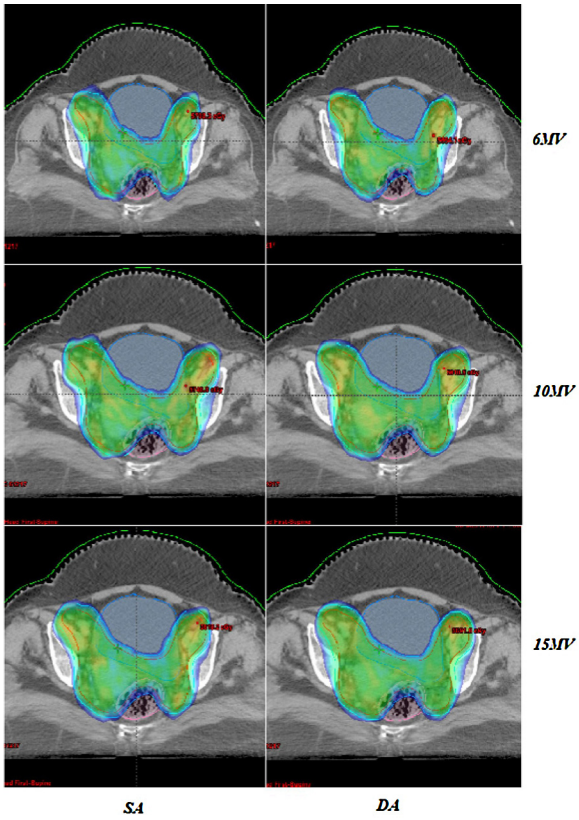

Fig. 2 – Axial view of prescription dose.

taken from the L1–L2 Vertebral level to 5 cm below the ischial tuberosity.

3.3. *Target and OAR delineation*

Target volumes (TV) and OARs were delineated for all the patients using Somavision workstation (Varian Medical Systems). Clinical Target Volume (CTV) included lymphonodal regions (common iliac, external iliac, internal iliac, presacral, osturator), uterus, adnexa and vagina. A margin of 0.5 cm was given to CTV to generate planning target volume (PTV). The OARs viz. bladder, rectum, bowel and femoral heads were contoured. Contour of the bladder from apex to dome was drawn while the rectum was contoured from the anus (at inferior level of ischial tuberosity) to recto-sigmoid junction. Contours of the bilateral femoral heads were drawn up to the level of ischial tuberosity.[9]

3.4. *Planning objectives*

Prescribed dose to PTV was 50.4 Gy in 28 Fractions at 1.8 Gy per fraction. It was stipulated that not less than 98% volume of PTV should receive a dose less than the prescribed dose and that not more than 2% volume of PTV should receive a dose more than 110% of the prescription dose. QUANTEC Protocol[10] was used for all the OARs. The hot spot was considered as a 2% volume receiving more than 110% of the prescription dose.

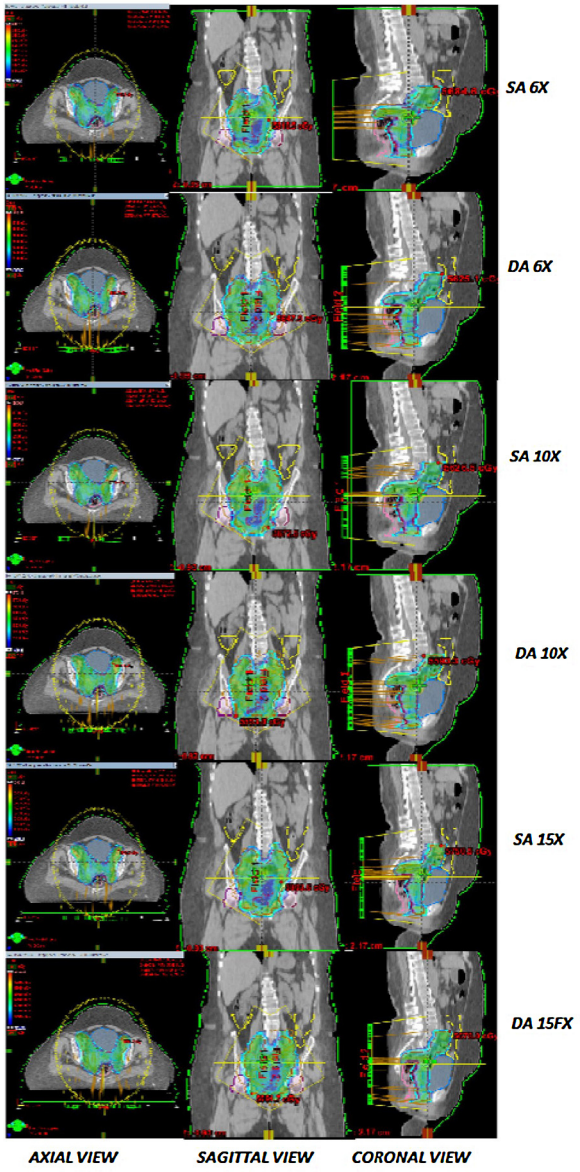

Fig. 3 – Comparison of 50.4 Gy dose coverage for SA vs DA for 6, 10 and 15 MV.

3.5. *Planning techniques*

Plans were generated using External Beam planning system Eclipse (Eclipse Treatment Planning Software version 10.0.28, Varian Medical System, Palo Alto, CA). Rapid arc optimization using Progressive Resolution Optimizer (PRO) algorithm and Anisotropic Analytical Algorithm (AAA) for final calculation of optimized plan was done.[11,12]

A brief summary for the VMAT algorithm has been discussed in several reports.[13–15] The initial arc parameters such as arc length, delivery time, number of arcs are set by the user. The aim of using a dual arc is to increase the modulation factor during optimization. Plans were made using single-arc (clockwise; Gantry rotation 179*–181* with collimator 30*) and dual-arc (a clockwise; Gantry rotation 179*–181* with collimator 30* and an anti-clockwise, Gantry rotation 181*–179* with

Table 1 – Optimization parameters used for PTV and OARs.

Structure	Objective	Volume (%)	Dose (cGy)	Priority
Bladder	Upper	0	5250	95
	Upper	40	3600	90
	Upper	20	4500	80
	Upper	10	4900	70
	Mean		4000	95
Bowel	Upper	0	4500	65
	Mean		1250	95
CTV	Upper	0	5300	125
	Lower	100	5250	145
Femur (L)	Upper	0	4800	65
	Mean		2050	95
Femur (R)	Upper	0	4800	65
	Mean		2050	95
PTV	Upper	0	5250	125
	Lower	100	5200	145
Rectum	Upper	0	5250	65
	Upper	30	4100	95
	Upper	15	4650	85
	Mean		4000	75

collimator 330*) with 6 MV photon energy. The collimator was rotated in order to reduce the effect of inter-leaf leakage. Both plans were then optimized again for 10 MV and 15 MV photon energies.

The purpose behind this was that dual arc plan was expected to achieve better TV coverage than a single arc plan as two different arcs create a completely unrelated sequence of MLC shapes, dose rates and gantry speed combinations. All the plans were delivered by Varian TRUE BEAM linear accelerator using the beam energy of 6 MV, 10 MV and 15 MV. Machine is equipped with HD MLC with 120 leaves having spatial resolution of 2.5 mm at isocentre for central 32 leaves and 5.0 mm in the outer 14 leaves on both sides, with a maximum leaf speed of 4.8 cm/s and a leaf transmission of 1.4%. Rapid arc plans were delivered with a dose rate of 600 MU/min.

3.5.1. *Optimization strategy*

All the plans were made with the same optimization parameters. Priorities were given in such a manner that the optimized plan will deliver desired dose to PTV and minimal dose to nearby critical organs. Optimization parameters used are mentioned in Table 1.

3.6. *Data collection and plan evaluation tools*

3.6.1. *Target volume (TV)*

Quantitative and qualitative methods were used for evaluation of PTV. The references were taken from the recommendations of International Commission for Radiation Units (ICRU) Report No. 83.[16] Plans were analyzed using CT slice-by-slice isodose coverage and dose volume histograms (DVH). TV coverage and the conformity of the PTV was evaluated with isodose distribution in the transverse, sagittal and coronal planes. The criteria for dose minimum and maximum was considered as $D_{98\%}$ and $D_{2\%}$, respectively. $D_{98\%}$ and $D_{2\%}$ were referred to as a dose received by 98% and 2% volume of PTV, respectively. For evaluating the degree of conformity, the Conformity Index (CI_{98}) was used which is given by the ratio of volume of PTV covered with 98% isodose line to the total volume of PTV i.e.

$$CI_{98} = \frac{\text{Volume of PTV receiving } 98\% \text{ dose}}{\text{Total volume of PTV}}$$

As per ICRU83, Homogeneity Index (HI) was defined by the ratio of difference of $D_{2\%}$ and $D_{98\%}$ and dose received by 50% of PTV ($D_{50\%}$). A value of HI close to zero considered as homogeneous plan. Hence

$$HI = \frac{(D_{2\%} - D_{98\%})}{D_{50\%}}$$

3.7. *Organs at risk*

Total six dosimetric plans were generated for each patient and their specific DVHs were compared for organ-sparing. Different parameters, like $D_{2\%}$, Mean dose, V_{50Gy}, V_{40Gy}, V_{30Gy}, V_{20Gy} and V_{10Gy}, were compared for critical structures like the bladder, rectum, bowel and femoral heads.

3.8. *Non-cancerous tissues*

To compare the plans for dose-spillage inside healthy tissues, two structures were delineated viz. $PHY_{2.5}$ and $PHY_{5.0}$. The structure $PHY_{2.5}$ and $PHY_{5.0}$ were referred to as a shell of radius 2.5 cm and 5.0 cm around the TV, respectively. $PHY_{2.5}$ was contoured to evaluate the dose-fall off in near target region. $PHY_{5.0}$ was delineated to compare the dose fall far from the target tissues.

3.8.1. *Normal tissue integral dose (NTID)*

NTID is the dose deposited to the normal tissues outside the PTV in a patient. It is also the area under the curve of a differential absolute dose, absolute volume histogram. It was calculated to assess the plan quality based on the following formula considering uniform tissue density: Normal tissue integral dose (NTID) = mean dose × volume of normal tissue outside PTV.

3.9. *Treatment efficiency*

Beam-on time (BOT) and TMUs were compared for all the plans to assess the efficiency of the treatment. TPS was used to calculate MU and its average was obtained to calculate the BOT. All the plans were delivered at dose rate of 600 MU/min to minimize the treatment time.

3.9.1. *Data and statistical analysis:*

DVH was plotted by the TPS for TV, OARs and other healthy tissues. The qualitative analysis of target coverage was done using the axial, sagittal and coronal slices. For statistical analysis, the two-tailed paired *t-test* was performed to compare the results between SA and DA plans. Data analysis was performed by a Statistical Package of Social Sciences software (SPSS version 20.0), with the statistical significance level set at $p < 0.05$, designed in Chicago, USA.

4. Results

4.1. *Planning target volume (PTV)*

Plan evaluation showed a comparable dose coverage to PTV for all the energies and arcs. To study the impact of energy among different plans, same optimization parameters were considered for VMAT plans having SA and DA using 6 MV, 10 MV and 15 MV photon beam energies. The average volume of PTV in the present study was $1479.29 \pm 242.91\ cm^3$. There was a significant difference ($p < 0.05$) observed between the plans for dose maximum. $D_{2\%}$ (Gy) was lesser for all the DA plans. The differences in the mean dose, modal dose and median dose were also significant for all the plans made and there was a subsequent advantage of using 6 MV over 10 MV and 15 MV for SA and DA ($p < 0.05$) (Table 2).

Similarly, the CI has shown a significant difference ($p < 0.05$) for the data and was close to unity for 6 MV. HI results also followed a similar pattern ($p < 0.05$) for SA_{6MV}, SA_{10MV}, SA_{15MV}, DA_{6MV}, DA_{10MV} and DA_{15MV} plans and favoured DA with 6 MV photon energy.

4.2. OAR

4.2.1. *Bladder*

The doses evaluated for the bladder in each plan were within tolerance. Percentage volume of the bladder receiving 50 Gy (V_{50Gy}) and 40 Gy (V_{40Gy}) was significantly lesser ($p < 0.05$) in the case of DA as compared to SA. The mean dose was significantly different for both the treatment techniques and lesser for DA plans (Table 3).

4.2.2. *Rectum*

The plans were evaluated for rectal doses for different photon energies and found a significant difference ($p < 0.05$) at higher doses. It was observed that the percentage volume of the rectum receiving 50 Gy (V_{50Gy}) was significantly lesser ($p < 0.05$) in the case of DA in comparison to SA.

4.2.3. *Bowel*

Evaluated doses for contoured bowel showed significant difference for lower doses like V_{40Gy}, V_{30Gy} and V_{20Gy}. Similarly, the dose received by 195 cc volume of the bowel was significantly lesser in the case of DA. Also, the maximum dose in different plans was compared and was found to be significantly lesser with DA plans.

4.2.4. *Femoral heads*

Mean doses for the right femur as well as the left femur were evaluated and a lesser dose in dual-arc plan was seen in comparison to single-arc plans (Table 4).

4.2.5. *Healthy tissues*

To evaluate the dose to non-cancerous healthy tissues, the contoured body tissues were divided into two structures viz. $PHY_{2.5}$ and $PHY_{5.0}$. Mean doses received by $PHY_{2.5}$ and $PHY_{5.0}$ remain significantly unchanged in both modalities ($p > 0.05$).

Table 2 – Dosimetric parameters of planning target volume.

PTV	Energy									p-value					
	6 MV			10 MV			15 MV			SA			DA		
Parameter	SA	DA	*p-value*	SA	DA	*p-value*	SA	DA	*p-value*	6 vs 10	10 vs 15	6 vs 15	6 vs 10	10 vs 15	6 vs 15
$V_{95\%}$ (%)	99.93 ± 0.27	100.0 ± 0.00	NS	99.95 ± 0.22	100.0 ± 0.00	NS	99.95 ± 0.22	100.0 ± 0.00	NS	NS	NS	NS	NS	NS	NS
$V_{98\%}$ (%)	97.78 ± 1.15	97.49 ± 1.02	NS	97.77 ± 0.81	97.97 ± 0.91	NS	98.11 ± 0.94	98.30 ± 0.68	NS	NS	NS	NS	NS	NS	0
$V_{100\%}$ (%)	93.97 ± 2.79	93.07 ± 2.38	NS	94.15 ± 1.64	94.02 ± 1.77	NS	94.93 ± 1.80	94.68 ± 1.31	NS	NS	NS	NS	NS	NS	0.002
$V_{105\%}$ (%)	65.39 ± 12.22	44.09 ± 18.05	0	64.92 ± 10.41	47.84 ± 15.73	0	68.78 ± 6.14	48.44 ± 17.05	0	NS	NS	NS	NS	NS	NS
$V_{107\%}$ (%)	43.18 ± 13.08	16.48 ± 10.85	0	40.46 ± 11.34	16.15 ± 9.86	0	44.51 ± 7.11	17.91 ± 12.57	0	NS	NS	NS	NS	NS	NS
$V_{110\%}$ (%)	13.72 ± 6.87	1.31 ± 1.59	0	9.94 ± 5.53	0.70 ± 1.11	0	11.88 ± 4.32	1.37 ± 2.30	0	0.002	NS	0.03	NS	NS	0.046
$D_{98\%}$ (Gy)	49.28 ± 0.43	49.20 ± 0.39	NS	49.31 ± 0.35	49.41 ± 0.43	NS	49.48 ± 0.41	49.52 ± 0.31	NS	NS	NS	0.035	0.034	NS	0
$D_{50\%}$ (Gy)	53.66 ± 0.54	52.77 ± 0.52	0	53.57 ± 0.42	52.89 ± 0.41	0	53.72 ± 0.26	52.93 ± 0.46	0	NS	NS	NS	NS	NS	0.046
$D_{2\%}$ (Gy)	56.65 ± 0.82	54.93 ± 0.72	0	56.29 ± 0.63	54.84 ± 0.49	0	56.51 ± 0.42	54.97 ± 0.68	0	0.002	NS	NS	NS	NS	NS
D_{min} (Gy)	42.74 ± 2.51	43.39 ± 2.51	NS	42.63 ± 2.30	43.66 ± 2.35	0.013	43.31 ± 2.29	44.27 ± 2.35	0.029	NS	0.002	0.043	0.033	0.002	0
D_{max} (Gy)	59.76 ± 1.15	57.56 ± 1.11	0	58.81 ± 0.83	56.81 ± 0.84	0	59.17 ± 0.82	57.35 ± 1.07	0	0.001	NS	0.021	0	0	NS
D_{mean} (Gy)	53.50 ± 0.52	52.62 ± 0.48	0	53.39 ± 0.39	52.71 ± 0.36	0	53.56 ± 0.26	52.78 ± 0.43	0	NS	NS	NS	NS	NS	0.04
D_{modal} (Gy)	53.91 ± 0.52	52.93 ± 0.55	0	53.79 ± 0.50	53.08 ± 0.46	0	53.97 ± 0.31	53.08 ± 0.49	0	NS	NS	NS	NS	NS	NS
D_{median} (Gy)	53.67 ± 0.53	52.77 ± 0.51	0	53.58 ± 0.42	52.89 ± 0.40	0	53.73 ± 0.27	52.94 ± 0.46	0	NS	NS	NS	NS	NS	0.044
GM	4.05 ± 0.31	3.97 ± 0.318	0.05	3.83 ± 0.285	3.77 ± 0.288	NS	3.75 ± 0.26	3.69 ± 0.275	0.037	0	0.001	0	0	0	0
HI	0.137 ± 0.015	0.109 ± 0.014	0	0.130 ± 0.013	0.103 ± 0.012	0	0.131 ± 0.011	0.103 ± 0.014	0	0	NS	0.001	0	NS	0
CI	1.127 ± 0.119	1.095 ± 0.089	0.002	1.116 ± 0.118	1.087 ± 0.083	0.006	1.116 ± 0.118	1.086 ± .088	0.002	0	NS	0	0.004	NS	0

Table 3 – Dosimetric parameters for bladder and rectum.

Parameter	Energy								p-value					
	6 MV			10 MV			15 MV		SA			DA		
	SA	DA	p	SA	DA	p	SA	DA	6 vs 10	10 vs 15	6 vs 15	6 vs 10	10 vs 15	6 vs 15
Bladder														
V_{50} (%)	35.36 ± 4.85	32.17 ± 6.12	0.017	35.24 ± 4.78	33.35 ± 4.54	0.023	34.45 ± 4.54	32.45 ± 5.10	0.009	NS	0.04	NS	0.032	NS
V_{40} (%)	60.14 ± 8.23	58.01 ± 8.55	0.003	59.14 ± 8.59	57.48 ± 8.39	0.003	58.72 ± 8.84	56.97 ± 8.54	0	0.001	NS	0	0.005	0.003
V_{30} (%)	84.92 ± 6.52	84.76 ± 6.34	NS	82.85 ± 7.18	83.54 ± 5.59	NS	82.70 ± 7.30	82.05 ± 6.66	NS	0.006	NS	0.008	0.012	0.001
V_{20} (%)	98.13 ± 3.16	98.58 ± 2.39	NS	98.26 ± 2.82	98.69 ± 2.89	NS	97.54 ± 3.85	98.29 ± 3.07	0.049	NS	NS	NS	NS	NS
$D_{2\%}$ (Gy)	55.37 ± 0.99	53.93 ± 0.86	0	55.08 ± 0.76	53.79 ± 0.68	0	55.09 ± 0.62	53.75 ± 0.83	0	0.035	NS	NS	NS	0.048
D_{max} (Gy)	58.37 ± 1.28	56.07 ± 1.16	0	57.56 ± 0.95	55.71 ± 0.74	0	57.48 ± 0.72	55.83 ± 1.11	0	0.001	NS	0.001	NS	NS
D_{mean} (Gy)	42.48 ± 1.81	41.90 ± 1.65	0.01	42.08 ± 1.92	41.77 ± 1.53	NS	41.93 ± 2.04	41.46 ± 1.77	0.003	0.003	NS	0.001	0.003	0.01
Rectum														
V_{50} (%)	28.48 ± 8.86	21.80 ± 7.18	0	28.38 ± 8.96	24.43 ± 7.16	0	31.11 ± 9.26	25.69 ± 8.11	0	NS	0.011	0.004	0.026	NS	0
V_{40} (%)	78.16 ± 10.57	75.98 ± 10.68	NS	78.12 ± 10.60	77.1 ± 10.69	NS	79.68 ± 10.85	77.21 ± 10.75	0.004	NS	0.003	0.005	NS	NS	0.03
V_{30} (%)	93.57 ± 4.98	93.15 ± 4.84	NS	93.28 ± 5.20	93.32 ± 5.02	NS	93.59 ± 4.87	93.12 ± 5.15	0.21	NS	NS	NS	NS	NS	NS
V_{20} (%)	95.89 ± 4.30	96.09 ± 4.44	NS	96.06 ± 4.32	96.02 ± 4.21	NS	96.13 ± 4.23	96.18 ± 4.25	NS	0.041	NS	0.004	NS	0.008	NS
$D_{2\%}$ (Gy)	53.69 ± 0.95	52.60 ± 0.73	0	53.73 ± 0.94	52.68 ± 0.67	0	53.80 ± 0.75	52.70 ± 0.66	0	NS	NS	NS	NS	NS	NS
D_{max} (Gy)	56.56 ± 1.22	54.76 ± 1.17	0	56.03 ± 0.95	54.49 ± 0.73	0	56.19 ± 0.86	54.66 ± 0.89	0	NS	NS	NS	NS	NS	NS
D_{mean} (Gy)	44.16 ± 2.43	43.49 ± 2.42	0.001	44.19 ± 2.48	43.76 ± 2.39	0.012	44.55 ± 2.50	43.87 ± 2.49	0	NS	0.003	0.001	0.013	NS	0.003

4.2.6. *Normal tissue integral dose (NTID)*

Integral dose to normal tissue (NTID) was also evaluated. It was observed that the integral dose was 295.35 ± 49.83, 284.72 ± 47.42, 283.19 ± 46.90, 289.02 ± 47.30, 280.08 ± 45.25 and 278.43 ± 45.24 for SA_{6MV}, SA_{10MV}, SA_{15MV}, DA_{6MV}, DA_{10MV} and DA_{15MV}, respectively.

4.2.7. *Total monitor units (TMU) and treatment efficiency*

Treatment time for the single-arc plan was lesser than for the dual-arc plan irrespective of photon beam energy. But the reduction in total monitor units increased with increasing photon energy.

5. Discussion

As per the observations of our study, higher beam energy should be used for deep-seated tumours. Das et al.[17] noted that there is no significant improvement in dose distribution and integral dose above 15 MV photon energy. Hence, the manufacturers of linear accelerators have kept 15 MV as an upper photon beam energy level in most treatment units installed in different radiotherapy departments. Varian TRUEBEAM is equipped with 6 MV, 10 MV and 15 MV photon energies to deliver the optimum dose at any depth. VMAT allows for better conformity of the high dose volume to the PTV compared with three dimensional conformal therapy. This may help in reducing the risk of secondary cancers, developing inside the in-field high dose regions. Alvarez Moret et al.[18] established the same fact for prostate cancers.

Target volume conformity and homogeneity are closely related to the complexity of TV and optimization parameters. Single arc VMAT has been shown to successfully meet the clinical requirements of IMRT for a simple target volume. Most previous studies have indicated that, for complex target volumes in head and neck cancer, single-arc VMAT may be less favourable dosimetrically than a fixed-field IMRT.[19–21]

Another aspect for discussion is the energy of photon beam, on which rapid arc is performed. Sternick et al.[22] noted that for treating prostate carcinoma with fixed field IMRT, there was no significant difference in dose distribution for photon energies ranging from 4 MV to 18 MV. Soderstrom et al.[23] also concluded that the need of beam energy selection reduces significantly with optimized intensity-modulated plans.

Although the high energy photon beam should be used due to their greater penetration property for treating deeper targets, Kry et al. and Schneider et al.[24] have supported the fact that a higher photon energy could lead to increased risk of secondary malignancies. Literature also proved that higher photon energy (*E*) >8 MV contains the presence of neutrons generated from different parts of the linac head. Therefore, we compared 6 MV photon beam energy with 10 MV and 15 MV for both the treatment arcs.

Our statistical analysis showed an edge of the dual-arc plan with 6 MV photon beam energy over other photon energies for target conformity as well as homogeneity.[25,20] This may be explained by the degree of freedom attained by dual rotation of the gantry and multileaf collimator motion with variable dose rate in DA plans. Pirzkall et al.[26] supported this notion

Table 4 – Dosimetric parameters for bowel and femoral heads.

Bowel	Energy									p-value					
	6 MV			10 MV			15 MV			SA			DA		
	SA	DA	*p*	SA	DA	*p*	SA	DA	*p*	6 vs 10	10 vs 15	6 vs 15	6 vs 10	10 vs 15	6 vs 15
Parameter															
V_{40} (%)	7.24 ± 4.73	5.27 ± 3.58	0	6.60 ± 4.32	5.15 ± 3.66	0	6.80 ± 4.38	5.13 ± 3.62	0	0.045	NS	NS	NS	NS	NS
V_{30} (%)	26.62 ± 9.13	23.53 ± 8.72	0.001	24.80 ± 8.89	22.54 ± 8.67	0.004	24.68 ± 9.12	22.0 ± 8.48	0	0.002	NS	0.001	0.02	0.01	0
V_{20} (%)	49.17 ± 9.22	47.99 ± 8.92	0.032	48.08 ± 9.27	46.85 ± 8.87	0.018	47.84 ± 9.32	46.74 ± 8.76	0.047	0.018	NS	0.004	0.024	NS	0.024
V_{10} (%)	62.80 ± 11.22	62.07 ± 10.81	NS	62.75 ± 10.89	62.44 ± 10.88	0.036	63.31 ± 10.81	63.15 ± 10.81	NS	NS	0	NS	0.001	0	0
D_{max} (Gy)	53.38 ± 3.32	51.96 ± 3.30	0.006	53.22 ± 3.44	51.58 ± 3.22	0.001	52.89 ± 3.44	51.74 ± 3.36	0.005	NS	NS	NS	NS	NS	NS
D_{mean} (Gy)	19.18 ± 3.47	18.43 ± 3.17	0	18.69 ± 3.45	18.32 ± 3.01	NS	18.69 ± 3.48	18.12 ± 3.19	0	0	NS	0	NS	NS	0.001
V_{195cc} (Gy)	36.35 ± 3.89	34.85 ± 3.49	0	35.82 ± 3.90	34.55 ± 3.53	0	35.82 ± 3.99	34.39 ± 3.64	0	0.013	NS	0.003	0.035	0.047	0.003
RT femur															
V_{50} (%)	0.0 ± 0.0	0.0 ± 0.0	NS	0.0 ± 0.0	0.0 ± 0.0	NS	0.1 ± 0.246	0.0 ± 0.0	NS	NS	NS	NS	NS	NS	NS
V_{40} (%)	7.24 ± 4.73	5.27 ± 3.58	0	6.6 ± 4.32	5.15 ± 3.66	0	6.8 ± 4.38	5.12 ± 3.62	0	0.045	NS	NS	NS	NS	NS
V_{30} (%)	27.64 ± 8.15	20.82 ± 4.67	0	26.87 ± 7.96	21.52 ± 3.88	0.001	26.22 ± 8.28	21.48 ± 3.92	0.009	NS	NS	NS	NS	NS	NS
V_{20} (%)	47.69 ± 9.65	39.47 ± 5.85	0	46.91 ± 9.34	39.8 ± 5.17	0.002	47.41 ± 9.68	40.57 ± 5.38	0.001	NS	NS	NS	NS	NS	NS
V_{10} (%)	83.92 ± 10.03	85.79 ± 11.83	NS	82.45 ± 10.01	85.42 ± 12.52	0.031	82.65 ± 9.8	83.9 ± 8.66	NS	NS	NS	NS	NS	NS	NS
D_{max} (Gy)	52.72 ± 2.95	51.99 ± 2.61	NS	51.98 ± 3.19	51.72 ± 2.34	NS	52.24 ± 3.39	52.13 ± 2.28	NS	NS	NS	NS	NS	0.032	NS
D_{mean} (Gy)	21.86 ± 2.32	20.42 ± 2.03	0	21.61 ± 2.32	20.37 ± 1.74	0	21.64 ± 2.47	20.49 ± 1.85	0	NS	NS	NS	NS	NS	NS
LT femur															
V_{50} (%)	0.96 ± 1.56	0.68 ± 1.24	0.049	1.02 ± 1.73	0.73 ± 1.31	NS	0.93 ± 1.63	0.58 ± 0.95	NS	NS	NS	NS	NS	NS	NS
V_{40} (%)	8.91 ± 3.49	8.29 ± 3.28	NS	9.82 ± 3.49	8.5 ± 3.52	NS	9.42 ± 3.41	8.54 ± 3.26	NS	NS	NS	0.023	NS	NS	NS
V_{30} (%)	21.76 ± 5.06	21.02 ± 4.55	NS	22.28 ± 5.30	21.04 ± 4.23	NS	23.02 ± 5.10	21.22 ± 4.4	0.028	NS	NS	0.01	NS	NS	NS
V_{20} (%)	44.17 ± 6.66	40.6 ± 5.67	0.008	43.72 ± 6.84	39.54 ± 6.09	0.018	45.50 ± 7.43	41.02 ± 7.09	0.001	NS	NS	NS	NS	NS	NS
V_{10} (%)	84.92 ± 11.74	83.96 ± 11.68	NS	83.46 ± 12.24	85.52 ± 12.59	NS	85.09 ± 11.59	85.51 ± 12.21	NS	NS	0.048	NS	NS	NS	NS
D_{max} (Gy)	52.37 ± 3.02	51.50 ± 2.31	0.028	52.26 ± 3.11	51.45 ± 2.06	0.04	52.51 ± 2.72	51.72 ± 2.22	NS	NS	NS	NS	NS	NS	NS
D_{mean} (Gy)	21.12 ± 1.98	20.43 ± 1.79	0.003	20.93 ± 1.95	20.26 ± 1.92	0.015	21.37 ± 1.98	20.51 ± 1.99	0	NS	0.001	NS	NS	NS	NS
$PHY_{2.5}$															
D_{mean} (Gy)	27.31 ± 2.45	26.44 ± 3.97	NS	26.92 ± 2.56	26.19 ± 3.99	NS	26.79 ± 2.53	26.04 ± 4.02	NS	0	0	0	0	0	0
$PHY_{5.0}$															
D_{mean} (Gy)	16.72 ± 1.46	16.46 ± 1.44	0.009	16.06 ± 1.45	15.89 ± 1.41	NS	15.86 ± 1.35	15.69 ± 1.41	NS	0	0	0	0	0	0
TMU															
TMU Mean	515.47 ± 28.06	522.11 ± 33.58	NS	454.59 ± 33.63	456.64 ± 25.31	NS	425.18 ± 28.20	430.94 ± 22.63	NS	0	0	0	0	0	0

and found that even energies as low as 6 MV can produce clinically equivalent dose distribution as long as the number of fields used were sufficient (>9 fields) for the treatment of pelvic tumours with fixed-field IMRT.

DA was found to be superior to SA for mean bladder doses ($p < 0.05$) for the change in photon energies for both treatment arcs, except for 6 MV over 10 MV ($p > 0.05$). For rectal mean dose, *p-value* was significant ($p < 0.05$) and in favour of DA in comparison to SA and was significant ($p < 0.05$) for the change in photon energies for both treatment modalities. This may be explained by smaller apertures created during optimization for dual-arc plans. Mattes et al.[27] also found that 10 MV energy provides additional sparing of the bladder in a low-dose region, at the cost of high dose to the rectum. Gulliford et al.[28] noted that the volume of the rectum receiving as low as 30 Gy reduced the late rectal toxicities by 10–18%.

Mean dose to the femoral heads were significantly different for DA in comparison to SA plans. The increased conformity reduces the doses to the femoral head in dual-arc plans. Laughlin et al.[29] observed that for conformal radiation therapy using non-modulated beams, 6 MV produces tighter dose distribution around the target due to a tighter penumbra. This reduces the dose to nearby OARs while depositing higher dose near the surface region at the beam entry area. Higher photon energies are therefore required to treat deeper targets due to their greater penetration power, but the same benefit decreases with increased number of beams.

Integral dose to normal tissues were lesser for dual arc plans as the second arc also contributes in PTV coverage and limits dose spillage. Limited dose seepage inside normal tissues offers lesser integral dose. Similarly, a significant reduction in entrance dose is observed when photon beam energy increases. One can raise the issue of exit dose but that exit dose will not increase in the same ratio as the reduction in entrance dose. Plans with 15 MV photon beam offer significant reduction in NTID in comparison to 6 MV. But there will be neutron production in case of 15 MV, and inclusion of neutron will eventually increase the risk of secondary malignancies.[30]

Thangavelu et al.[31] and Kumar et al.[32] reported that 15 MV provides slightly better target coverage and better OARs sparing, but it cannot be considered as a better choice as there is a risk of secondary malignancies due to neutron production.

The total monitor units were lesser for SA plans. The lesser monitor units lead to lesser beam-on time and, hence, increases the patient comfort and treatment accuracy. However, the plan should be finalized on the basis of parameters achieved after optimization and not just on the basis of the patient comfort.

6. Conclusions

In the present study, SA and DA were investigated for Carcinoma Cervix patients. DA plans show significant improvement in all aspects of plan parameters except total monitor units. DA with 6 MV photon beam provides uncompromised tumour coverage with better conformity. Considering photo-neutron production in $E > 10$ MV, we conclude that DA with 6 MV photon beam energy should be the choice of treatment for cervical cancer cases.

Conflict of interest

None declared.

Financial disclosure

None declared.

REFERENCES

1. World Health Organization (WHO) Reports on Cervical Cancers. *HPV and Cervical Cancer in the World 2007*, vol. 25(Suppl. 1). 2007. p. 35–40. Available on: www.who.int/mediacentre/factsheets/fs380/en/ ISSN 0264-410X.
2. Gupta D, Shukla P, Bisht SS, et al. Comparitive study of efficacy, tolerability of four field box technique vs. two field anterior posterior technique in locally advanced carcinoma cervix – a prospective analysis. *Cancer Biol Ther* 2009;**8**(9):759–64.
3. Kry SF, Salehpour M, Followill DS, et al. The calculated risk of fatal secondary malignancies from intensity-modulated radiation therapy. *Int J Radiat Oncol Biol Phys* 2005;**62**(4):1195–203.
4. Kry, Kry SF, Followill D, White RA, Stovall M, Kuban DA, Salehpour M. Uncertainty of calculated risk estimates for secondary malignancies after radiotherapy. *Int J Radiat Oncol Biol Phys* 2007;**68**(4):1265–71.
5. Cozzi L, Dinshaw KA, Shrivastava SK, et al. A treatment planning study comparing volumetric arc modulation with RapidArc and fixed field IMRT for cervix uteri radiotherapy. *Radiother Oncol* 2008;**89**(2):180–91.
6. Mazeron R, Dumas I, Khouri EIC, et al. Intensity-modulated radiotherapy in cervical cancer: towards a new standard? *Cancer Radiother* 2014;**18**(2):154–60.
7. Lv Y, Wang F, Yang L, et al. Intensity-modulated whole pelvic radiotherapy provides effective dosimetric outcomes for cervical cancer treatment with lower toxicities. *Cancer Radiother* 2014;**18**(8):745–52.
8. Bertelsen A, Hansen CR, Johansen J, et al. Single arc volumetric modulated arc therapy of head and neck cancer. *Radiother Oncol* 2010;**95**(2):142–8.
9. William SJ, Mundt AJ. Consensus guidelines for the delineation of the intensity modulated pelvic radiotherapy CTV in the postoperative treatment of endometrial and cervical cancer. *Int J Radiat Oncol Biol Phys* 2008. Available from: https://www.rtog.org/CoreLab/ContouringAtlases/GYN.aspx.
10. Quantitative analysis of normal tissue effects in the clinic, guidelines. *Int J Radiat Oncol Biol Phys* 2010;**76**(3):S15–8. Supp.
11. Gagne IM, Zavgorodni S. Evaluation of the analytical anisotropic algorithm (AAA) in an extreme water-lung interface phantom using Monte Carlo dose calculations. *J Appl Clin Med Phys* 2007;**8**(1).
12. Vanetti E, Nicolini G, Nord J, et al. On the role of the optimization algorithm of RapidArc volumetric modulated arc therapy on plan quality and efficiency. *Med Phys* 2011;**38**(11):5844–56.
13. Otto K. Volumetric modulated arc therapy: IMRT in a single gantry arc. *Med Phys* 2008;**35**:310–7.
14. Bedford JL, Warrington AP. Commissioning of volumetric modulated arc therapy (VMAT). *Int J Radiat Oncol Biol Phys* 2009;**73**(2):537–45.
15. Bortfeld T, Webb S. Single-arc IMRT? *Phys Med Biol* 2009;**54**:N9.

16. *ICRU Report 83, Journal of the ICRU, Vol. 10, No. 1*. Oxford University Press; 2010.
17. Das IJ, Kase KR. Higher energy: is it necessary, is it worth the cost for radiation oncology? *Med Phys* 1992;**19**:917–25.
18. Alvarez Moret J, Koelbl O, Bogner L. Quasi-IMAT technique and secondary cancer risk in prostate cancer. *Strahlenther Onkol* 2009;**185**:248–53.
19. Lee TF, Ting HM, Chao PJ, et al. Dual arc volumetric-modulated arc radiotherapy (VMAT) of nasopharyngeal carcinoma: a simultaneous integrated boost treatment plan comparison with intensity-modulated radiotherapies and single arc VMAT. *Clin Oncol (R Coll Radiol)* 2012;**24**:196–207.
20. Guckenberger M, Richter A, Krieger T, et al. Is a single arc sufficient in volumetric modulated arc therapy (VMAT) for complex shaped target volumes? *Radiother Oncol* 2009;**93**:259–65.
21. Zhang DD, Huang SM, Deng XW, et al. Comparison and evaluation of VMAT and IMRT for the treatment of initial treated nasopharyngeal carcinoma. *Chin J Radiat Oncol* 2012;**21**:364–8.
22. Sternick ES, Bleier AR, Carol MP, et al. Intensity modulated radiation therapy: what photon energy is best? (Abstr.). In: *Proceedings of the international conference on the use of computers in radiation therapy (ICCR), XIIth annual meeting, Salt Lake City, UT*. Madison, WI: Medical Physics Publishing; 1997. p. 418–9.
23. Soderstrom S, Eklof A, Brahme A. Aspects on the optimal photon beam energy for radiation therapy. *Acta Oncol* 1999;**38**(2):179–87.
24. Schneider U, Lomax A, Pemler P, et al. The impact of IMRT and proton radiotherapy on secondary cancer incidence. *Strahlenther Onkol* 2006;**182**:647–52.
25. Sharma MK, Mitra S, Saxena U, et al. Is volumetric modulated arc therapy (RapidArc) better than intensity modulated radiotherapy for gynecological malignancies? A dosimetric comparison. *J Can Res Ther* 2014;**10**:883–8.
26. Pirzkall, et al. The effect of beam energy and number of fields on photon based IMRT for deep-seated targets. *Int J Radiat Oncol Biol Phys* 2002;**53**(2):434–42.
27. Mattes MD, Tai C, Lee A, Ashamalla H, Ikoro NC. The dosimetric effects of photon energy on the quality of prostate volumetric modulated arc therapy. *Pract Radiat Oncol* 2014;**4**:e39–44.
28. Gulliford SL, Foo K, Morgan RC, et al. Dose-volume constraints to reduce rectal side effects from prostate radiotherapy: evidence from MRC RT01 Trial ISRCTN 47772397. *Int J Radiat Oncol Biol Phys* 2010;**76**:747–54.
29. Laughlin JS, Mohan R, Kutcher GJ. Choice of optimum megavoltage for accelerators for photon beam treatment. *Int J Radiat Oncol Biol Phys* 1986;**12**:1551–7.
30. Kry SF, Salehpour M, Followill DS, et al. Out-of-field photon and neutron dose equivalents from step-and-shoot intensity-modulated radiation therapy. *Int J Radiat Oncol Biol Phys* 2005;**62**:1204–16.
31. Thangavelu S, Jayakumar S, Govindarajan KN, Supe SS, Nagarajan V, Nagarajan M. Influence of photon energy on the quality of prostate intensity modulated radiation therapy plans based on analysis of physical indices. *J Med Phys* 2011;**36**:29–34.
32. Kumar L, Yadav G, Raman K, Bhushan M, Pal M. The dosimetric impact of different photon beam energy on RapidArc radiotherapy planning for cervix carcinoma. *J Med Phys* 2015;**40**:207–13.