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Comparison of Volumetric Modulated Arc Therapy and Intensity Modulated Radiotherapy with Brachytherapy for Carcinoma Cervix Boost

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ABSTRACT

Introduction: It is challenging to deliver brachytherapy for patients who refuse minor surgical insertion of applicators. As external beam radiation therapy(EBRT) can be delivered more precisely using advanced radiotherapy techniques, this study compares the dosimetric differences between intensity-modulated radiation therapy(IMRT), volumetric-modulated arc therapy(VMAT), and intracavitary brachytherapy (ICBT) for cervix boost.
Material and Methods: Thirty patients with cervix cancer treated with 3-dimensional conformal radiation therapy (3DCRT) followed by ICBT were considered retrospectively for this study. IMRT and VMAT plans were generated for high-risk clinical target volume (HR-CTV). The dose prescription for VMAT and IMRT plans were the same as the ICBT, between 6 to 7.5 Gy per fraction. Target coverage (TC), organ at risk(OAR) doses, conformity index(CI), homogeneity index(HI), BED(biologically effective dose), and EQD_2(2Gy equivalent dose) were calculated. IMRT and VMAT were compared with ICBT.
Results: The EBRT plans in comparison to ICBT gave exceptional target coverage greater than 95%. Mean dose and D_{2cc} to bladder and rectum in the EBRT plans were higher than ICBT. Dose to bladder, rectum and femur were high in the IMRT plans. Bowel bag dose in ICBT was higher compared to EBRT. Target conformity was superior for ICBT compared EBRT, however homogeneity was better for the EBRT plans. EQD_2 values for bladder and rectum for all three plans were well within accepted tolerances.
Conclusion: The current study dosimetrically suggests that in the absence of a Brachytherapy unit or if patients are unwilling to brachytherapy, EBRT can be opted for, with VMAT being the more suitable choice of treatment.

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Introduction

Cancer is a disease in which the cells proliferate uncontrollably and spread to other body parts[1]. Globally Cervical Cancer is considered the second most common malignant tumour that threatens the female body and is even fatal in most cases. It has been clarified that cancer of cervix is caused by tenacious infection with the high-risk human papillomavirus(HPV)[2]. Statistically, cervical tumors affect around 500,000 women worldwide, among which around 46% succumb to death[3]. Surgery, radiation therapy, hormone therapy, and chemotherapy are the treatment methods employed for cervical cancer. Currently, external beam radiation therapy(EBRT) for the whole pelvis followed by brachytherapy boost is the most common treatment options practiced by many radiation oncologist[4].

Radiation therapy modalities such as 3-dimensional conformal radiation therapy (3DCRT) and intracavitary brachytherapy (ICBT) are most often used in combination. In 3DCRT, four-field box technique is used with a dose of 45 to 50Gy in 1.8 to 2Gy per fraction. The EBRT treatment is followed by high dose rate (HDR) brachytherapy to the high-risk clinical target volume (HR-CTV) with boost dose of 6 to 7.5Gy in 3 to 4 fractions. Brachytherapy is delivered using remote after-loading technique where the radiation dose is administered through Gamma rays from high-activity[5-9]. Brachytherapy is superior in comparison to EBRT when it comes to its unrivalled dose distribution, which is characterised by a low integral dose and sharp dose gradient, allowing for

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optimal normal tissue sparing while delivering large doses to the tumour [7].

HDR has gained popularity in the recent decade as it has a lot of benefits including the ability to get treatment as an outpatient, the avoidance of long-term bed rest, and the prevention of cervical dilatation[8]. However, since in brachytherapy the applicator has to be inserted surgically, it is a quite painful procedure[9]. Furthermore, better sparing of the rectum and bladder by keeping bladder and rectum empty, dose optimization and integration with EBRT to the pelvis are possible. These benefits must be weighed against the higher number of sessions necessary (usually 3-4, that might increase to 5-6 treatments lasting 10-15 minutes each), which prolongs the overall treatment time[8]. Hence the necessity to replace Brachytherapy with EBRT with treatment planning techniques such as intensity-modulated radiation therapy (IMRT) or volumetric-modulated arc therapy (VMAT) arises. It has been found that IMRT has significantly reduced haematological toxicity compared to the 3DCRT plans[10]. Although VMAT has considerable advantages in terms of treatment duration, there are no significant differences in case conformity index(CI) and homogeneity index(HI)[11]. However, there might be a significant improvement in organ at rosk(OAR) and healthy tissue sparing[12]. Studies have been performed wherein either VMAT or IMRT is compared with brachytherapy[13–18]. Hence the focus of this study is to compare the dosimetric parameters between VMAT and IMRT with Brachytherapy for cervical boost.

Materials and Methods

The study included 30 patients with cervical cancer, treated at the Department of Radiotherapy and Oncology, Kasturba Hospital, Manipal, between 2020 to 2021. The selected cases were in the stages of IB to IIIC with median age 54.5 years (Table 1,2). Each of these patients had undergone 3DCRT with a dose prescription of 45Gy in 25 fractions delivered in 5 weeks followed by ICBT for cervical boost with a prescribed dose of 6-7.5Gy in 3-4 fractions.

Table1. Patient Characteristics

Sample size	30
IB_3	6
IIA	10
IIB	9
$IIIC_1$	5
Age	38-72yrs

The nature of this investigation is retrospective. A thermoplastic mould (ORFIT) for the pelvic area was used to immobilize the patient. The Philips Brilliance Big Bore CT was used to obtain computed tomography (CT) scans with a 3mm slice thickness. The scanned images were then exported to the MONACO 5.11.03 treatment planning system (TPS). The physicians defined OARs like the bladder, rectum, bowel, femurs and targets like gross tumor volume (GTV), clinical target volume (CTV), and planning target volume (PTV).

Table 2. Dose Distribution of patients

Dose Prescribed (Gy)	No. of Patients
6Gy per fraction	12
6.5Gy per fraction	2
7Gy per fraction	15
7.5Gy per fraction	1

Treatment Planning

Monaco (5.11.03) TPS

The Monaco planning system was developed to counter the challenges associated with simulating the actual delivered dose to the patient while ensuring high quality treatment plans, that can be delivered fast and effectively[19]. With these constructed and advanced optimization tools having better calculation accuracy of the Collapsed Cone and Monte Carlo dose calculation algorithms, Monaco can deliver 3DCRT, VMAT, IMRT, stereotactic radiosurgery(SRS), and stereotactic body radiation therapy(SBRT) plans seamlessly while ensuring consistency and efficiency in their plans. 3DCRT planning technique uses forward planning, while IMRT and VMAT techniques use inverse planning[20].

Three-Dimensional Conformal Radiotherapy

The 3DCRT treatment planning was performed using Monaco(5.11.03) TPS and the treatment was delivered with a prescription dose of 45Gy in 25 fractions over 5 weeks using Elekta High Definition(HD) Versa Linear Accelerator(LINAC). The treatment plan was made using a box technique where anterior-posterior(0°), left lateral(90°), posterior-anterior(180°) and right lateral(270°) beams were used. The beam energies were selected between 6MV, 10MV, and 15MV based on the patient separation, improvement of dose coverage, and reduction of hotspots. Collapsed Cone algorithm was employed to compute the dose distribution.

Treatment planning and delivery in intracavitary brachytherapy

The ICBT was planned using BrachyVision treatment planning software and the treatment was executed with Varian HDR GammaMed plus iX brachytherapy unit with a prescription dose of 6 to 7.5Gy per fraction. For the purpose of the study, a treatment plan with a single fraction was considered to evaluate the dose. Gamma rays produced by Iridium-192 were used for the effective treatment delivery. The applicators (central tandem and 2 ovoids) were selected based on the anatomy such as type of applicator (Flexible geometry/Fixed geometry), angulation of central tandem (15^0, 30^0, 45^0) and the type of ovoid's(half, small, medium, large) and surgically placed in the patient with a minor procedure by the physician.

CT images of the patients were acquired using Brilliance Bigbore 16 slice CT scanner with 3mm slice thickness, and the images were exported to the BrachyVision TPS. Delineation of HR-CTV, bladder, rectum, sigmoid, bowel, and femurs(Right and Left) were performed by the physicians based on the embrace II protocol[21]. The treatment plan was performed on the basis of point A dose prescription. Length of treatment in the central tandem was between 4 to 6 cm and ovoid were up to 1.5cm[22].

Treatment planning with VMAT and IMRT

Treatment plan with VMAT was performed with Monaco(5.11.03) TPS using Monte Carlo algorithm based on the embrace protocol II[21]. Additional delineation of the boost-CTV and boost PTV on the same CT image was done by the help of physicians. The plan was performed for single fraction and the dose kept same as brachytherapy. Two Partial posterior arcs were used to perform treatment plan with first arc starting from 30°-40° ending at 180° and the second arc starting from 180° ending at 290°-310° with an intention to reduce the bowel and bladder dose. The 6MV beam energy was used for the planning purpose. Iterative optimization of the treatment plan was carried out based on the constraints given as the input parameters, and the best final plan was considered for the comparison purpose. Treatment plan with IMRT was performed using the same Monaco TPS and algorithm. The plan was performed for single fraction and the dose was kept same as brachytherapy. Seven beams were selected with gantry angles 0°, 51°, 102°, 153°, 204°, 255° and 306° to plan IMRT. Beam energy of 6MV was selected, and Iterative optimization of the treatment plan was carried out based on constrains given as the input parameters and the best final plan was considered for the comparison purpose.

Treatment Plan evaluation

For plan evaluation and quantitative analysis of the VMAT and IMRT plans, data of target volume receiving 95%(V95%) and 100%(V100%) of the prescribed dose and dose received by 95%(D95%) and 100%(D100%) of the target volume was collected. The D2cc (dose received by 2cc volume) of the bladder, rectum, and bowel bag and maximum dose to the femurs were noted down. Standard Dose Volume Histogram (DVH) analysis was performed for target, bowel bag, bladder, rectum and femurs. Radiobiological parameters biologically effective dose (BED) and equivalents dose in 2Gy (EQD_2) were also used to assess the plans. BED is the measure of true biological dose received through a particular combination of dose per fraction and total dose by a particular OAR or the target which is characterised by its α/β[23].

The BED formula is given by

$$\text{BED} = nd\left[1 + \frac{\text{d}}{\alpha/\beta}\right]$$

Where α and β are the coefficients of cell survival [24], n is the number of fractions, d is the dose per fractions and α/β is the ratio of the linear quadratic(LQ) parameters of the tissue under investigation. Table 3 lists the α/β values for the different organs [25].

Table 3. Alpha/Beta values for tumor and healthy tissues

Tissue	Alpha/Beta(Gy)
Body and core	3
Tumor	10
Rectum	3.9
Bladder	6
Femoral heads	0.9
Spinal cord	3.3
Arbitrary/muscle-vascular	3.1

The same formula for EBRT and brachytherapy has been applied since there was not much difference in the dose for both the techniques.

EQD2 evaluates biological equivalent dose in 2Gy equivalent. It can be calculated using:

$$EQD_2 = \frac{BED}{1 + \frac{2}{\alpha/\beta}}$$

where BED is obtained from calculation and α/β values are the same used in BED calculation[26].

Conformity index was calculated using the formula, $CI = V_{RI} / TV$, where V_{RI} is reference isodose volume and TV is target volume. The radiation therapy oncology group(RTOG) definition defined radiation conformity index as a ratio between the volume covered by the reference isodose, which according to international commission on radiation units and measurements(ICRU) is a 95% isodose, and the target volume designated as Planning target volume(PTV) and represented by the equation[27].

Here we took the reference isodose volume as the 100% isodose, i.e. target volume covered by prescribed dose was taken.

Homogeneity Index has also been used for plan analysis.

For EBRT plans:

$HI = I_{max} / RI$, where I_{max} is maximum isodose and RI is reference isodose[27].

For Brachytherapy plans:

$HI = D_5 – D_{95} / D_P$, where D_5 is the dose received by 5% of the target volume, D_{95} is the dose received by 95% of the target volume and D_P is the prescribed dose[17].

Results

In the two boost plans generated through VMAT and IMRT technique, using the same prescribed dose as delivered in brachytherapy, it was seen that the target coverage for the tumor is excellent and very much comparable to brachytherapy (Figure1,2,3,4). Among the three planning techniques for cervical boost, VMAT and IMRT had the maximum coverage for $V_{95}\%$ with 99.24 ± 0.84 and 99.156 ± 0.99 respectively. Brachytherapy provided the least coverage (94.15 ± 6.35) in comparison with the EBRT plans (p = 0.002). However, $V_{100}\%$ for brachytherapy was significantly higher than the EBRT plans with $p<0.0001$. On the other hand, there was no statistically significant difference in $D_{95}\%$ for tumors among the three planning techniques (p=0.242). Overall specifically for the target, the dose distribution and coverage provided by the EBRT plans were better.

The Homogeneity Index for the brachytherapy plans were quite high with a value of 3.789 ± 1.6204, while VMAT and IMRT plans had much similar values for HI, stating that the EBRT plans had better homogenous dose distribution than brachytherapy plans.

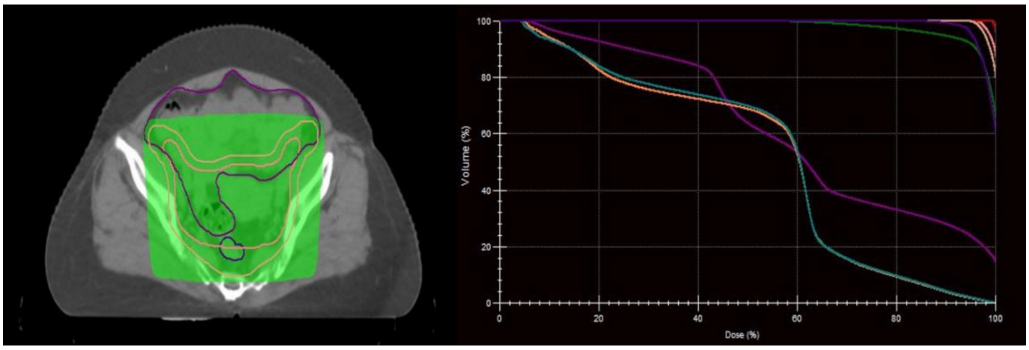

Figure 1. 95% dose distribution and dose volume histogram (DVH) in Monaco treatment planning system (TPS) for 3-dimensional conformal radiation therapy(3DCRT) plan

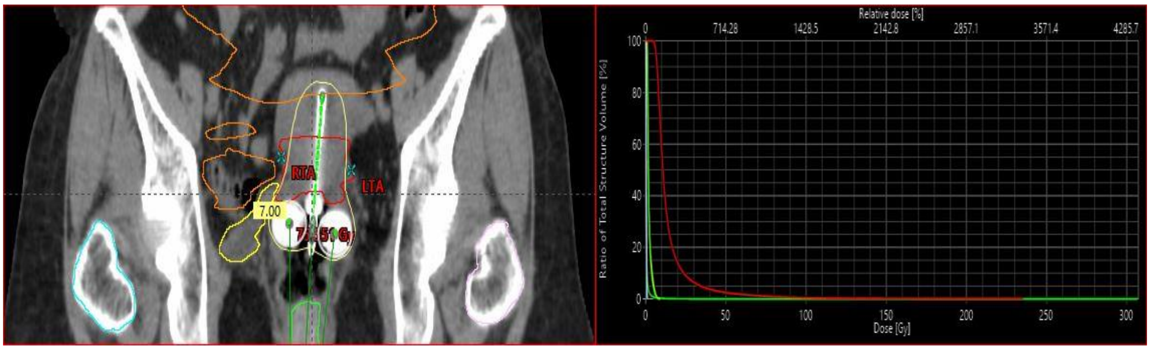

Figure 2. Pear shaped isodose distribution around target in BrachyVision treatment planning system (TPS) and dose volume histogram (DVH) for Brachytherapy plan

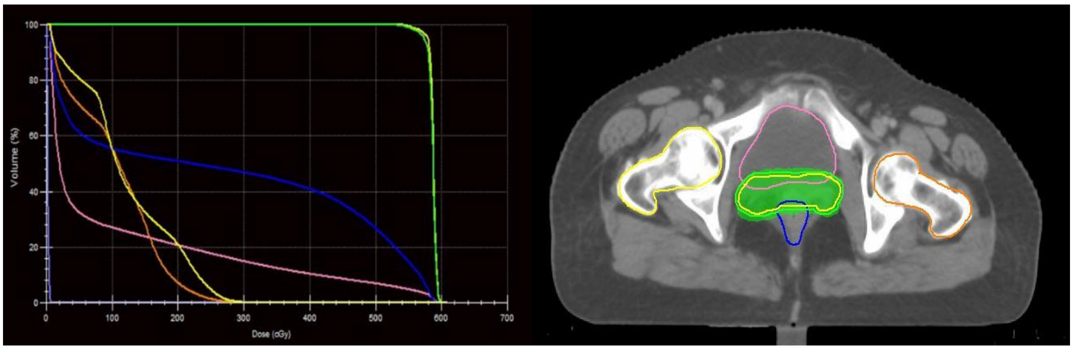

Figure 3. 95% dose distribution and dose volume histogram (DVH) in Monaco treatment planning system (TPS) for volumetric-modulated arc therapy (VMAT) boost plan

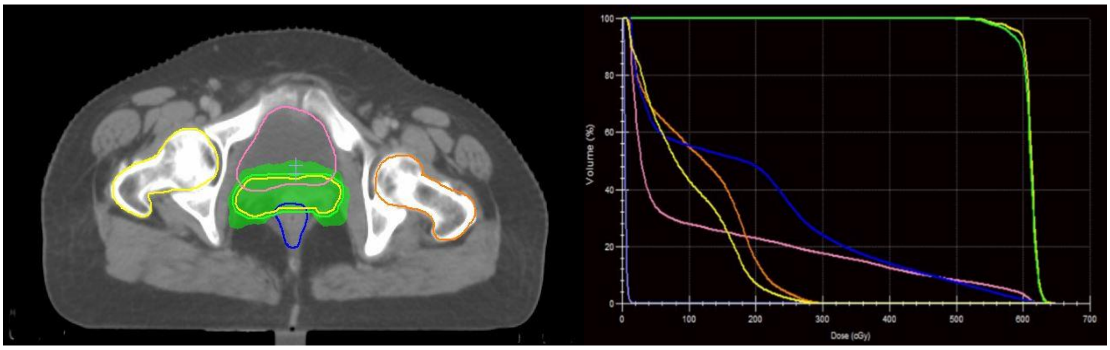

Figure 4. Axial view of dose distribution and dose volume histogram (DVH) in intensity modulated radiation therapy (IMRT) plan

Table 4. Summary of Comparison data between the Brachytherapy, volumetric-modulated arc therapy (VMAT) and intensity modulated radiation therapy (IMRT) plans

Parameters	Plans Generated			
	Brachytherapy	VMAT	IMRT	P-value (<0.05 is significant)
V95%(%)	94.15 ± 6.35	99.24 ± 0.84	99.156 ± 0.99	0.002
V100%(%)	91.72 ± 7.63	75.88 ± 0.85	72.196 ± 24.25	0.0001
D95%(cGy)	652.76 ± 170.82	651.01 ± 50.04	650.803 ± 49.38	0.242
D100%(cGy)	473.3 ± 152.41	573.126 ± 55.2	573.227 ± 58.03	0.001
HI	3.789 ± 1.6204	1.0619 ± 0.0163	1.062 ± 0.0149	0.0001
CI	0.935 ± 0.07	0.735 ± 0.266	0.719 ± 0.242	0.0001

Note: Values here are written as mean of 30 cases and the standard deviation. V95% , V100% are the percentage of volume receiving 95% and 100% of the prescribed dose respectively , D95%, D100% are the dose received by the 95% and 100% of the volume , homogeneity index(HI), conformity index(CI)

Table 5. Statistical comparison of dosimetric parameters for organ at risk (OAR)

Oar	Parameters	Plans Generated			P-value (<0.05is significant)
		Brachytherapy	VMAT	IMRT	
Bladder	Mean Dose(cGy)	245.02 ± 55.05	258.36 ± 94.78	294.99 ± 105.11	0.004
	D2cc (cGy)	505.94 ± 129.745	652.44 ± 50.71	653.41 ± 50.13	0.0001
Rectum	Mean Dose(cGy)	186.73 ± 43.44	259.73 ± 56.69	261.16 ± 55.96	0.0001
	D2cc (cGy)	381.99 ± 109.22	572.77 ± 91.45	554.88 ± 138.71	0.0001
Bowel Bag	Mean Dose(cGy)	116.303 ± 74.55	12.69 ± 12.06	15.51 ± 14.07	0.0001
	D2cc (cGy)	1330.12 ± 1075.58	234.32 ± 233.36	247.55 ± 236.37	0.0001
Right Femurs	Max Dose(cGy)	101.05 ± 26.11	301.69 ± 60.77	322.11 ± 65.28	0.0001
Left Femurs		112.4 ± 23.03	329.29 ± 63.82	319.93 ± 68.63	0.0001

Note: Values here are written as mean of 30 cases and the standard deviation. D2cc refers to the dose received by the 2cc of the volume

The Conformity Index values for VMAT and IMRT were 0.735 ± 0.266 and 0.719 ± 0.242 respectively, whereas the brachytherapy plans provided better conformity in tumor coverage with a CI value of 0.935 ± 0.07 (Table 4).

D_{2cc} to bladder in the EBRT plans were remarkably higher than Brachytherapy (*p*=0.004 for VMAT and *p*=0.0001 for IMRT). The same trend was seen for rectum. For bowel bag we see that dose received in brachytherapy is crucially higher than in VMAT and IMRT. The femurs received notably more radiation dose in the EBRT plans than brachytherapy plan (Table 5).

Among the VMAT and IMRT plans dose to OARs were higher in the IMRT plans. In pair-wise comparison of the EBRT plans it was seen that there was not much difference with regards to the target coverage parameters for VMAT and IMRT plans (V_{95} % had p=1, V_{100}% had p = 0.07, D_{95}% had p=0.469, D_{100}% had p=0.699). Comparing brachytherapy with VMAT and IMRT individually the tumour target parameters had significant difference for V_{95} %, V_{100}% and D_{100}% except for D_{95}% (p=0.813 for brachytherapy VS VMAT and p=0.845 for Brachytherapy VS IMRT). Mean dose to bladder for Brachytherapy and VMAT plans were similar with less difference while D_{2cc} of bladder had very less significant difference for HDR VS IMRT. For rectum mean and D_{2cc} the null hypothesis is retained, i.e. there is no difference in dose received by the rectum for VMAT and IMRT plans. On the other hand, the bowel bag D_{2cc} had significant difference for all the three individual comparisons. Femur doses were quite less for Brachytherapy, it remained quite comparably similar for the EBRT plans (p =0.439 for right femur and p=0.606 for left femur for VMAT VS IMRT comparison) (Table 6).

The Biological Effective dose and EQD_2 for the tumour was same for Brachytherapy and the EBRT plans as the dose delivered to the tumour was same. However, for the OARs the BED and EQD_2 show statistically significant differences (Table 7). Figures 5 and 6 represent the sum plan dose of EBRT and brachytherapy.

Table 6. Pair-wise comparison of *p-value* of dosimetric parameters for organ at risk (OAR)

	Parameters	BT VS VMAT p-value	BT VS IMRT p-value	VMAT VS IMRT p-value
Target	$V_{95\%}$(%)	0.002	0.002	1
	$V_{100\%}$(%)	0.003	0.0001	0.071
	$D_{95\%}$(cGy)	0.813	0.845	0.469
	$D_{100\%}$(cGy)	0.0001	0.002	0.699
Bladder	D_{2cc} (cGy)	0.00001	0.0001	0.606
Rectum	D_{2cc} (cGy)	0.0001	0.00001	1
Bowel Bag	D_{2cc} (cGy)	0.0001	0.002	0.007
Right Femurs	Max Dose(cGy)	0.00001	0.00001	0.439
Left Femurs		0.0001	0.0001	0.606

V95% , V100% are the percentage of volume receiving 95% and 100% of the prescribed dose respectively , D95%, D100% are the dose received by the 95% and 100% of the volume, D2cc refers to the dose received by the 2cc of the volume

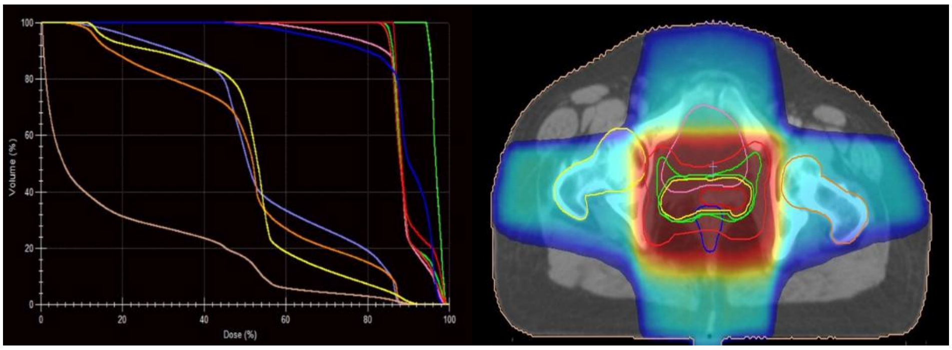

Figure 5. Dose distribution and dose volume histogram (DVH) of 3-dimensional conformal radiation therapy (3DCRT) + volumetric-modulated arc therapy(VMAT) sum plans from 30% to 95% dose

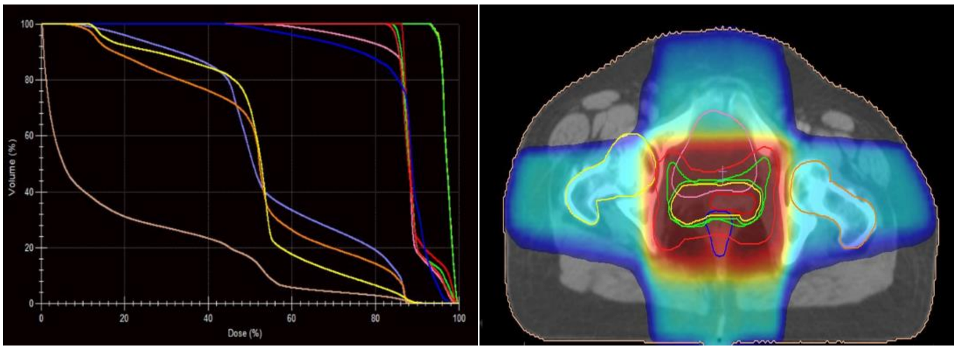

Figure 6. Dose distribution and dose volume histogram (DVH) of 3-dimensional conformal radiation therapy (3DCRT) + intensity-modulated radiation therapy (IMRT) sum plans from 30% to 95% dose

Table 7. Summarizing the biologically effective dose (BED) and equivalent dose in 2Gy (EQD_2) for the bladder, rectum and bowel bag (α/β = 3Gy)

Plans Generated In	Bladder		Rectum		Bowel Bag	
	D_{2cc} (Gy)		D_{2cc} (Gy)		D_{2cc} (Gy)	
	BED	EQD_2	BED	EQD_2	BED	EQD_2
3DCRT + BT	86.137± 5.74	51.69± 3.445	81.067 ± 3.55	48.64± 2.134	181.5± 151.7	108.92± 1.048
3DCRT + VMAT	92.8 ± 2.702	55.67 ± 1.626	88.91 ± 4.37	53.35 ± 2.609	77.94 ± 7.132	46.76 ± 4.27
3DCRT + IMRT	92.86 ± 2.695	55.707 ± 1.62	88.43 ± 5.31	53.15 ± 3.282	78.32 ± 7.34	46.99 ± 4.42
p= value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Note: Values here are written as mean of 30 cases and the standard deviation, D2cc refers to the dose received by the 2cc of the volume

Discussion

In the current study comparison of VMAT and IMRT with brachytherapy was performed to check if brachytherapy can be replaced by EBRT as an alternative option when brachytherapy is not available. In this retrospective study, the first phase of EBRT has been treated with the 3DCRT box technique followed by ICBT for the HR-CTV. HR-CTV drawn on the EBRT CT image was replanned with VMAT and IMRT. As explained in the methodology, VMAT was planned with posterior partial arcs to maximally avoid the bowel and bladder organs, whereas the IMRT was planned with seven circular beams maintaining an equal distance between the beams. The EBRT plans were performed using MONACO 5.11.03 treatment planning software. ICBT plans were made on the basis of point A prescription of the 100% isodose volume[28]. The aim of this study was to improve the target coverage with the reduction of the dose to the organs nearby in EBRT.

We found that target coverage in IMRT and VMAT were superior when compared to brachytherapy plans with VMAT providing highest coverage to the tumor. Brachytherapy also gave sufficient coverage to the HR-CTV except for some regions as the 100% dose distribution was prescribed to the point A. Several studies have commented on the same findings wherein EBRT plans were superior with respect to the target coverage[6,10,24,26,27]. In a study by Rajni A. Sethi et al., the brachytherapy plans also have provided 100% coverage with the prescription dose. In this the VMAT, IMRT and also the tomotherapy plans were compared with brachytherapy wherein all the treatment techniques provided better tumor coverage. But with respect to the organ at risk doses, bowel and bladder doses were low, and femoral head doses were high in EBRT[18]. In the current study, the VMAT technique provided lower mean, maximum and D_{2cc} dose to the bladder, rectum, bowel and femurs compared to the IMRT technique. One of the reasons for the bowel and bladder dose reduction could be the use of posterior partial arcs in VMAT technique which helped in the reduction of the lower dose spills in the bowel and bladder region. However the organ dose was superior in both EBRT techniques except for the bowel which was showed to be on the lower side in brachytherapy. *Lila Mahmoud Wali et al.* performed similar study in which VMAT plans were performed with 10MV photon energy using Eclipse treatment planning software achieved less dose to the rectum[7]. *Harish K Malhotra et al.* compared the IMRT with brachytherapy and stated that the coverage provided IMRT plans were comparable with brachytherapy plans[15]. A CI value that equals to 1 is taken as optimum for a treatment plan. The calculated CI for brachytherapy was 0.935 ± 0.07 which provided a statistically significant difference of $p = 0.0001$ among the three planning techniques although the volume of tumour covered by 95% of the prescribed dose both VMAT and IMRT were considerably superior. However, the HI of brachytherapy is high as within the tumour volume the dose gradient is quite steep. Hence the VMAT and IMRT plans had better homogeneity of dose within the target. This finding is in agreement with *B. Swetha et al.* who also concluded that brachytherapy provided better conformity of dose and poor homogeneity compared to EBRT plans[17].

The average value of D_{2cc} of bladder for brachytherapy, VMAT and IMRT were 505.94 ± 129.745 cGy, 652.44 ± 50.71 cGy and 653.41 ± 50.13 cGy respectively, which drove the average EQD_2 values of 51.69± 3.445 cGy, 55.67 ± 1.626 cGy and 55.707 ± 1.62 cGy which is well within the acceptable tolerance of 90Gy. The average value of D_{2cc} of rectum for brachytherapy, VMAT and IMRT were 381.99 ± 109.22 cGy, 572.77 ± 91.45 cGy and 554.88 ± 138.71 cGy each which gave the calculated EQD_2 values of 48.64± 2.134, 53.35 ± 2.609 and 53.15 ± 3.282 which is also within the recommended tolerance of 75Gy. EQD_2 of Bowel bag D_{2cc} for brachytherapy, VMAT and IMRT were 108.92 ± 91.048, 46.76 ± 4.27 and 46.99 ± 4.42. Here only the VMAT and IMRT values were within the acceptable tolerance of 70Gy. Brachytherapy plans had very high doses to the bowel bag and hence the equivalent dose to the bowel bag also increased[29,17].

This current study took patients who had already been treated with the EBRT + Brachytherapy combined treatment method. While planning for the first phase of EBRT, bladder protocol was followed (considering the bladder is full). Hence, the dose to the bladder achieved is high. In the second phase, the brachytherapy was planned following the bladder protocol that the bladder is empty and, therefore, the dose received by the bladder in brachytherapy is low. This creates an inaccuracy in the dose comparison for the study which is one of the limits of this study. Furthermore, the patients had received 3DCRT treatment in the first phase (box-field technique) by assuming the bladder had already received the maximum dose. Thereby, the second phase, which has been planned with VMAT and IMRT techniques for the research purpose, was not able to achieve a reduction in bladder dose. Further extensive research can be carried out on this study by replacing the first phase EBRT with VMAT instead of 3DCRT and followed by second phase EBRT VMAT boost to the target in order to achieve low bladder, rectum, and bowel bag doses.

Conclusion

VMAT and IMRT plans provide dose coverage of greater than 95% to the tumor; however, they lack good conformity but have good homogeneity in target coverage. Moreover, the dose to the bladder, rectum, and femur is high in the EBRT plans, with IMRT plans achieving the highest dose. Bowel bag in Brachytherapy gets a substantially high amount of dose, which can be significantly reduced in VMAT and IMRT plans. It can be concluded that VMAT is superior to IMRT when compared with brachytherapy for cervix boost. However, the intention of this study is not to replace brachytherapy with VMAT but to opt as an alternate option if brachytherapy is unavailable or the patient is unwilling to use brachytherapy. Further research has to be carried out to check for the clinical and radiobiological implications of EBRT in cervix boost.

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