Original

Comparison between Three-Dimensional Conformal Radiation Therapy (3DCRT) and Intensity-Modulated Radiation Therapy (IMRT) for Radiotherapy of Cervical Carcinoma: A Heterogeneous Phantom Study

Payal Raina[1]*, Sudha Singh[1]

[1]PhD, Department of Physics, Ranchi University, Ranchi- 834008, Jharkhand, India

ABSTRACT

Background: Radiotherapy plays a major role in the treatment of the cervical cancer.

Objective: Dosimetric comparison of intensity-modulated radiation therapy (IMRT) with three-dimensional conformal radiation therapy (3DCRT) in cervical cancer treatment was performed by modifying the beams arrangements to achieve better organ at risk (OAR) sparing.

Material and Methods: The analytical evaluation study was made by modifying the IMRT plan, subtracting the rectal volume from planning target volume (PTV), and applying the field-in-field technique in 3DCRT. Eight patients in various cervical cancer stages, from I–III, were inducted for this investigation. The prescribed dose was 5000 cGy in 25 fractions. For all cases, both IMRT and 3DCRT plans were generated. For PTV and OARs, dose volume histogram (DVH) comparative analysis was carried out. For safety checks and quality control, pre-treatment verification of all the plans was performed using an indigenously developed pelvic phantom (for IMRT and 3DCRT) and gamma analysis with Delta4 phantom (for IMRT).

Results: This study indicated that IMRT can treat cervical cancer more efficiently with less damage to OARs as compare to 3DCRT.

Conclusion: In this study, we observe that the IMRT plans with subtracting rectal volume achieve better OAR sparing.

Citation: Raina P, Singh S. Comparison between Three-Dimensional Conformal Radiation Therapy (3DCRT) and Intensity-Modulated Radiation Therapy (IMRT) for Radiotherapy of Cervical Carcinoma: A Heterogeneous Phantom Study. *J Biomed Phys Eng*. 2022;12(5):465-476. doi: 10.31661/jbpe.v0i0.2101-1257.

Keywords

Radiotherapy; Intensity-Modulated; Radiotherapy; Conformal; Phantoms; Imaging; Homogeneity Index; Conformity Index

Introduction

Cervical carcinoma is one of the most common diseases of women in India. According to the Global Cancer Observatory 2018 database, cervical cancer is the fourth most recurrent cancer in ranking after breast cancer, colorectal cancer, and lung cancer. Radiotherapy plays a critical role to treat cervical cancer. Presently several treatment techniques are available due to the advancement of imaging system such as three-dimensional conformal radiotherapy (3D-CRT), intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT). In the beginning, treatment modality was two-dimensional

*Corresponding author: Payal Raina
Department of Physics, Ranchi University, Ranchi- 834008, Jharkhand, India
E-mail: payalraina2008@gmail.com

Received: 4 January 2021
Accepted: 13 March 2021

radiotherapy (2D) [1]. IMRT is an improved treatment strategy [2]. 3DCRT technique can deliver uniform intensity to target, whereas IMRT delivers non uniform intensity. In IMRT technique, the non-uniform energy fluence in the complex target is achieved by multiple beams with sub fields directed from different direction [3, 4]. The advantages of this technique reduced toxicities because of improved conformal dose, particularly in complex target shapes [5]. IMRT leads to generate non uniform dose distribution within the target volume by simultaneous delivery of different doses per fraction [6]. IMRT uses large number of monitor units in comparison to 3DCRT because multiple beams are involved [7]. Two modes of treatment, i.e. dynamic and step-and-shoot are possible to deliver IMRT [8]. In the step & shoot technique, the multileaf collimator (MLC) takes the shape of allocated segment positions and delivers radiation only when the leaves are at stationary position [9]. In the dynamic technique, MLC takes the desired shape with continuous delivery of radiation with required intensity modulation [10]. VMAT is a more advanced technique than IMRT, in which the gantry angle, dose rate, and MLC leaf position varies continuously during treatment delivery [11].

In comparison to conventional radiotherapy techniques, IMRT has become one of the standard treatment techniques due to the clinical advantage of decreased radiation toxicity to OARs and advantage of dose conformity to the target volume [12]. The most prevalent late toxicity of pelvic radiation is rectal bleeding. Late toxicity consists of radiation proctitis, ulceration, stricture, and fistula to the rectum. The aim of the present study is to reduce the rectal dose by a field-in-field technique for 3DCRT and IMRT plan optimization after subtracting the rectal volume from the planning target volume (PTV).

The present paper is divided into two parts. In part A, we have compared the 3DCRT and IMRT plans in terms of plan quality and delivery efficiencies to reduce the OAR dose. Part B deals with pretreatment verification conducted with an indigenously developed pelvic phantom.

Material and Methods

Patient selection

A total of 8 cervical cancer patients were selected for this analytical investigation. Four patients were in stage III, three patients were in stage II, and one patient was in stage I. The stages mentioned were based on the American Joint Committee (AJCC) on Cancer 2010 Guidelines. Details are shown in Table 1. Patients were aged between 42 and 64 years with an average age of 52.6 years. Existence of distant metastasis was used to rule out by computed tomography, and weekly concurrent chemotherapy was received by patients.

All the patients were positioned on the pelvic base plate in supine position. Thermoplastic sheet was attached to the pelvic region for immobilization after which the patient went to compute tomography (CT) room. Alignment was set using LASER before CT. The patients were positioned on the CT tabletop keeping both arms toward the head and contrast CT images of 3 mm slice thickness was taken using a Brivo CT 325 2-slice CT (Wipro GE Healthcare). The images were imported into the Monaco planning system version 3.1 (Elekta Ltd, Crawley, UK).

Gross Tumor Volume (GTV), Clinical Target Volume (CTV), Planning Target Volume (PTV), and Organ at Risk (OAR) were delineated as per the guidelines of the International Commission on Radiation Units and Measurements report No. 83 (ICRU 83) on the CT images [13]. For PTV, a margin of 1.5 cm was taken around the CTV in all the cases.

Part A

Treatment planning and evaluation criteria

A total prescribed dose was 50 Gy in 25 frac-

Table 1: Patients characteristics

Patient	Age	Sex	Stage	Grade	GTV (cm³)	PTV (cm³)
1	50	F	II B	Grade I	37.03	711.37
2	42	F	IV A	Grade II	136.342	1111.494
3	61	F	II B	Grade II	57.826	683.703
4	44	F	III B	Grade II	100.928	712.774
5	60	F	III A	Grade I	106.204	825.109
6	55	F	III A	Grade I	91.678	845.104
7	64	F	II B	Grade III	58.624	679.379
8	45	F	II B	Grade II	86.368	752.584

GTV: Gross tumor volume, PTV: Planning target volume

tions. After 50 Gy of external radiotherapy, all patients went for 7 Gy of brachytherapy. The IMRT plans were produced for comparisons on the Monaco Planning System (Elekta Ltd, Crawley, UK) for Elekta Synergy Linac. For all IMRT plans, nine non-coplanar field beam arrangement was used. Beam angles were taken from 0° to 320° with interval of 40°. Plans were optimized in such a way to ensure that at least 95% of prescribed dose is delivered to 95% of PTV volume, keeping critical organ dose as low as possible as given in Table 2.

IMRT planning

The plan was created using an Elekta Synergy linear accelerator, producing a 6-MV photon. A 40-pair of MLC system with 1 cm thickness were used for beam shaping. All IMRT plans were optimized for nine beams. Beam angles ranged from 0° to 320° with an internal spacing of 40° between beams. The collimator and couch angle was kept at 0°. Calculation parameters comprising grid spacing, fluence smoothing, and statistical uncertainty were 0.3 cm, medium, and 1% per plan, respectively. Plans were generated in the step & shoot mode. A Monte Carlo algorithm was used for plan optimization. To reduce the rectal dose, IMRT plans were optimized after subtracting the rectum volume from the PTV. The parallel constraint was applied and adjusted during plan optimization.

Table 2: Planning objectives for critical structures

Normal Structure	Radiation Thresholds (Gy)
Rectum	$D_{60\%}$<40
Bladder	$D_{35\%}$<45
Right Femur	$D_{15\%}$<35
Left Femur	$D_{15\%}$<35

3DCRT planning

The 3D-CRT plan was set up using the XiO Planning System. The plan consisted of a four-field box technique (one anterior at 0º, one posterior at 180º, and two lateral beams at 90º and 270º). To reduce the rectal dose, a field-in-field technique was used. The plan was arranged by angles of 0°, 90°, 180º, 270º, 135º, and 240° with energy of 6 MV. The Field-in-field technique was used at angles of 90º and 270º to reduce the rectal dose. At angles 135º and 240º, the rectum was blocked to reduce the rectal dose and achieve the conformal dose distribution.

Plan evaluation parameters

Plan evaluation was performed using the homogeneity index, conformity index, OAR sparing, and target dose. The evaluation parameters are described as follows.

Homogeneity Index (HI)

$(D_{2\%}-D_{98\%})/D_{50\%}$. The HI is used for assessment of the dose homogeneity in the PTV and for choosing the best plan among the available ones. $D_{2\%}$ and $D_{98\%}$ are the doses delivered to 2% and 98% of the PTV, respectively. Zero value of HI indicates that dose distribution is homogeneous throughout the PTV [14].

Conformity Index (CI)

(TV/PTV). TV is defined as the volume of the reference isodose (98% of the specified dose) and PTV is the volume of the target. The CI defines how well the prescription dose conforms to the PTV, and evaluates a plan's ability to spare normal tissue from the high dose delivered to the treatment volume [15].

Target volume

The dose delivered to 98% and 2% of the volume of PTV, viz. $D_{98\%}$ and $D_{2\%}$, respectively, were analyzed.

OARs dose

The analysis was performed using the dose-volume histogram (DVH).

Part B

Pre-treatment plan verification

For pre-treatment verification, all plans were verified using an indigenously developed pelvic phantom and Delta4 phantom.

Indigenous pelvic phantom

An indigenously developed pelvic phantom was used for the plan verification. This phantom was designed by using wax for fat, artificial pelvic bone, water for the bladder, and borax powder with glue for the rectum.

A cylindrical container was taken for the outer shape and the pelvic bone was placed inside it. To represent the bladder aspherical plastic ball filled with water was taken. Borax jelly was placed below the bladder to represent the rectum. The molten wax was used to give shape of pelvic region. After completing solidification of the molten wax, the outer container was cut and removed. A cavity was prepared close to the geometrical center of the phantom and a 0.6 cm^3 ion chamber was placed in the prepared cavity (Figure 1).

The cervix was not considered because a cavity was made at the phantom center and an ion chamber was placed there for verification. Three fiducial lead markers were put to make three reference points at two bilaterally symmetrical points and one anterior point on the surface of the phantom in the same cross-sectional plane. Brivo CT 325 2-slice CT (Wipro GE Healthcare) was utilized for the CT scan of the phantom and 3-mm slice thickness images were obtained. The substitute material's CT

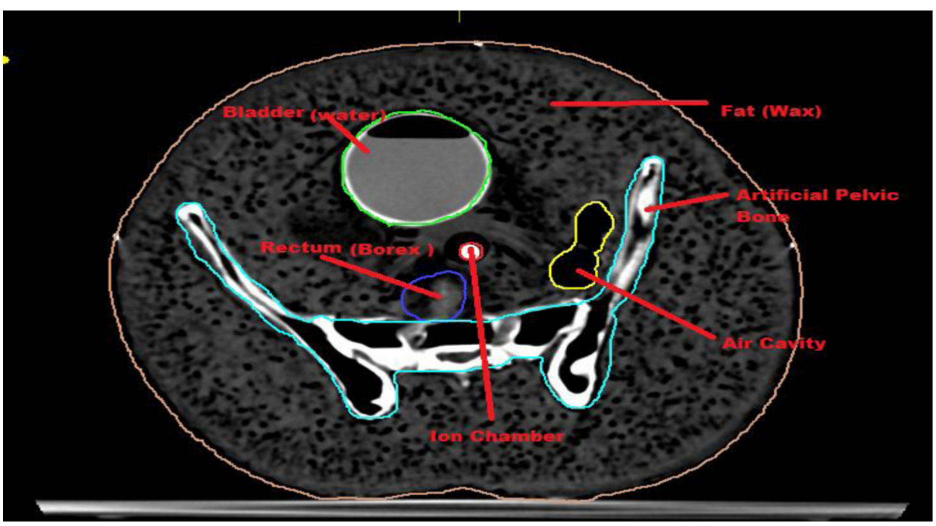

Figure 1: Computed Tomography image of indigenous pelvic phantom

numbers and electron density were measured in the Monaco planning system (Table 3).

Measurements were taken from the volume of interest (VOI) with a diameter of 1.01 cm and a volume of 0.541 cm^3.

IMRT QAs plan were generated on an indigenous pelvic phantom for pre treatment verification. The dose for each plan was measured using an electrometer connected to a 0.6 cm^3 ion chamber according to technical reports series (TRS) 398 protocol [16], published in the International Atomic Energy Agency [16].These measured doses were compared with doses planned on the treatment planning system(TPS). The measured dose was calculated using equation 1.

$$D=M_Q \times N_{D,W} \times K_{Q,Qo} \times K_{T,P} \times K_S \times K_{pol} \quad (1)$$

Where M_Q is the electrometer reading, $N_{D,W}$ is the chamber calibration factor, $K_{Q,Qo}$ is the chamber specific factor, $K_{T,P}$ is the temperature pressure correction factor, K_S is the ion recombination factor, and K_{pol} is the polarization factor. Similarly, 3DCRT plans were also verified by an indigenous pelvic phantom.

Deviation between expected and the measured dose was defined as equation 2.

$$\%Deviation = \frac{D_m - D_{ref}}{D_{ref}} \times 100 \quad (2)$$

Where D_{ref} is the calculated dose from the TPS and D_m is the measured dose result from the designed pelvic phantom for this study. All IMRT plans were also verified by using the Delta4 phantom. All IMRT plans were also verified by using the Delta4 phantom. The TPS calculated dose fluence was compared with measured dose fluence using gamma evaluation method. The acceptance criteria are 3 mm Distance to Agreement (DTA) and 3% Dose Difference (DD).

Results

The plans were explored to obtain an optimal plan, accepted with the highest prescription dose and maximum rectal sparing. The GTVs ranged from 37.03 cm^3 to 136.342 cm^3, and the average volume was 84.375±29.82 cm^3. PTVs ranged from 679.379 cm^3 to 1111.494 cm^3 with an average of 790.189±134.49 cm^3 [Table 1]. For a prescribed dose of 50 Gy to the PTV, the dosimetric results D_{max}, D_{98}, D_{95}, D_2, D_5, HI, and CI for all 8 patients in both techniques are listed in Table 4. This was reported as mean values±standard deviation (SD) to assess the relative inter-patient variability.

Target coverage, Conformity, and dose homogeneity

All plans met the prescription goal, i.e. more than 95% of the prescribed dose cover 95% of the PTVs. In Table 5, D_{max} was found to be slightly higher for IMRT plans with rectal sparing, i.e. 55.30 Gy than for IMRT plans without rectal sparing 55.14 Gy. In case of the 3DCRT with field-in-field technique (FF),

Table 3: Hounsfield Unit and relative electron densities

S.No.	Pelvic Organs	Material	In CT images of heterogeneous phantom (HU±SD) RED		In CT images of Actual patient (HU±SD) RED	
1	Bone	Pelvic Bone	430±548	1.253±0.354	496±117	1.296±0.072
2	Fat	Wax	-152±59	0.906±0.065	-111±8	0.953±0.007
3	Air cavity	Air	-904±161	0.106±0.165	-909±100	0.098±0.100
4	Bladder	Water	-4±5	1.038±0.004	-4±8	1.038±0.007
5	Rectum	Borax Powder	15±11	1.052±0.008	20±29	1.053±0.020

CT: Computed tomography, HU: Hounsfield unit, SD: Standard deviation, RED: Relative electron density

Table 4: Dosimetric results for the Planning Target Volume

Parameter	IMRT (Mean±SD)	IMRT (Mean±SD) with rectal sparing	3DCRT (Mean±SD) box technique	3DCRT (Mean±SD) field and field technique
D_{max} (Gy)	55.14±0.64	55.30±0.51	52.29±1.02	52.66±1.11
$D_{98\%}$ (Gy)	47.27±0.45	46.94±0.62	47.60±1.06	47.50±1.08
$D_{95\%}$ (Gy)	48.23±0.52	48.32±0.54	48.30±0.61	48.40±0.51
$D_{2\%}$ (Gy)	52.74±0.14	52.50±0.34	51.50±0.37	52.00±0.35
$D_{5\%}$ (Gy)	52.26±0.76	52.12±0.64	51.30±0.71	51.70±0.86
HI	1.08±0.014	1.08±0.024	1.07±0.036	1.08±0.023
CI	0.88±0.037	0.90±0.02	0.87±0.024	0.89±0.03

IMRT: Intensity modulated radiotherapy, SD: Standard deviation, 3DCRT: Three dimensional conformal therapy, HI: Homogeneity index, CI: Conformity index

D_{max} was 52.66 Gy higher compared to the 3DCRT Box technique (BT) 52.29 Gy. When comparing the IMRT plans with rectal sparing 3DCRT (field-in-field) technique, the D_{max} was found to be higher. The results for PTV in terms of dose homogeneity showed that all the four plans were equivalent. IMRT plans with rectal sparing have higher value of conformity as compared to the 3DCRT field-in-field technique. The average CI of the IMRT and IMRT plans with rectal sparing were 0.88 and 0.90, respectively, and the average CI of 3DCRT (BT) and 3DCRT field-in-field technique planning were 0.87 and 0.89, respectively.

Figure 2(a, b, c, d) shows the isodose distributions across the target volumes with IMRT, IMRT rectal sparing, 3DCRT (BT), and 3DCRT (FF) planning.

Organ and risk

The numerical findings from DVH analysis on main OARs (rectum, small bowel, bladder, and femoral heads) has been reported in Table 5.

Rectum

The median volume of the rectum contoured was 50.83 cm^3 (range from 34.98 cm^3 to 78.06 cm^3). In Table 6, we observed that the mean dose D_{mean} received by the rectum in IMRT and IMRT rectum sparing plan is 38.59 Gy and 38.02 Gy, respectively. Similarly, the values of D_{60} is 37.7 Gy and 33.52 Gy without and with rectum sparing respectively. From the numerical findings of the DVH, it can be noticed that the 3DCRT (FF) was superior to 3DCRT (BT) for all the parameters, namely D_{mean}, D_{60}, V_{30}, V_{35} and V_{40}. Planning objective (D_{60}<40 Gy) for IMRT sparing, IMRT, 3DCRT (BT), and 3DCRT (FF) were 33.52 Gy, 37.7 Gy, 48.8 Gy, and 47.00 Gy, respectively. Thus, the dose received by the rectum using IMRT rectum sparing is more suitable plan compare to the other plans.

Small Bowel

The median volume of the small bowel contoured in the 8 patients was 337.968±138.136 cm^3 (range from 238.719 cm^3 to 496.132 cm^3). The DVH parameter $D_{30\%}$, $D_{5\%}$, and D_{mean} were similar for all four plans. However, V_{30}, V_{35}, V_{40}, and V_{45} significantly increased from 3DCRT (FF) to 3DCRT (Box tech) as compared to IMRT rectal sparing and IMRT planning. V_{30} was 133.93 cm^3, 140.46 cm^3, 184.59 cm^3, and 190.89 cm^3 for 3DCRT (FF), 3DCRT (BT), IMRT rectal sparing, and IMRT planning, respectively. On the other hand, V_{40} was 84.48 cm^3, 91.125 cm^3, 121.448 cm^3, and 125.56 cm^3 and V_{45} was 41.27 cm^3, 48.07 cm^3, 51.82 cm^3, and 54.53 cm^3 for the afore mentioned techniques, respectively.

Table 5: Dosimetric results for organ at risks

Parameter	IMRT (Mean±SD)	IMRT (Mean±SD) with sparing rectum	3DCRT (Mean±SD) box technique	3DCRT (Mean±SD) field and field technique
Rectum 50.83±13.93 cm^3				
D_{mean} (Gy)	38.59±0.72	38.02±0.56	47.48±0.50	46.29±0.73
D_{60} (Gy)	37.7±1.2	33.52±0.9	48.8±1.1	47.50±0.5
V_{30} cm^3	34.85±15.0	33.95±14.08	47.2±17.3	47.01±17.13
V_{35} cm^3	26.10±12.1	25.74±11.2	46.69±16.95	45.23±15.7
V_{40} cm^3	21.69±7.8	20.729±8.87	43.97±15.5	41.1±13.28
Small Bowel 337.968±138.136 cm^3				
D_5 (Gy)	47.1±2.5	46.94±3.53	48.3±1.3	47.2±1.4
D_{30} (Gy)	31.84±1.8	31.42±2.51	28.65±0.55	28.10±0.54
D_{mean} (Gy)	25.69±3.6	25.57±3.9	24.05±1.17	23.35±0.58
V_{30} (cm^3)	190.89±96.5	184.59±108.5	140.46±52.2	133.93±58.7
V_{35} (cm^3)	125.56±65.5	121.448±75.78	91.125±34.79	84.48±40.87
V_{40} (cm^3)	86.56±42.1	80.97±53.2	68.3±28.05	60.85±31.11
V_{45} (cm^3)	54.53±29.9	51.82±37.96	48.07±20.92	41.27±23.04
Left Femoral Head 56.101±14.45 cm^3				
D_{mean} (Gy)	27.61±0.19	22.15±0.21	29.98±0.16	30.55±0.335
V_{30} cm^3	16.35±0.21	2.82±0.51	10.84±0.17	26.63±4.42
D_{15} (Gy)	27.91±0.18	27.19±0.42	30.60±0.54	33.50±0.65
Right Femoral Head 57.03±10.68 cm^3				
D_{mean} (Gy)	23.51±1.2	24.20±1.3	31.05±1.57	31.11±1.34
V_{30} cm^3	7.97±2.1	3.06±1.8	10.67±1.6	18.28±1.56
D_{15} (Gy)	32.17±1.6	28.57±1.7	30.60±1.6	35.70±1.3
Bladder 394.26±121.20 cm^3				
D_5 (Gy)	51.20±0.6	51.25±0.5	51.60±0.7	51.10±0.5
D_{mean} (Gy)	31.85±1.2	31.33±1.4	42.65±1.6	41.31±1.7
D_{35} (Gy)	44.58±0.5	39.01±0.2	50.60±0.4	49.60±0.7
V_{30} cm^3	172.75±46.23	155±50.64	257.32±69.29	230.15±60.0
V_{35} cm^3	154.0±41.75	135.31±38.02	213.16±57.41	205.14±45.01
V_{40} cm^3	133.71±36.0	116±36.0	191.76±51.7	176.13±54.1
V_{45} cm^3	107.45±28.91	91±20.13	172.40±46.4	160.5±40.5

IMRT: Intensity modulated radiotherapy, SD: Standard deviation, 3DCRT: Three dimensional conformal therapy

Bladder

The median volume of the bladder contoured was 394.26 cm^3 (range from 230.028 cm^3 to 570.153 cm^3). From the numerical findings of the DVH graphs, it can be noticed that IMRT with rectal sparing is giving better results with regard to bladder sparing as compared to IMRT, 3DCRT (FF), and 3DCRT (BT) for all the parameters. D_5, D_{mean}, and D_{35} in IMRT rectal sparing were 51.25 Gy, 31.33 Gy, and 39.01 Gy, respectively. Additionally, V_{30}, V_{35}, V_{40}, and V_{45} were 155 cm^3, 135.31 cm^3, 116 cm^3, and 91 cm^3, respectively, which is much lesser than the 3DCRT (FF) plans.

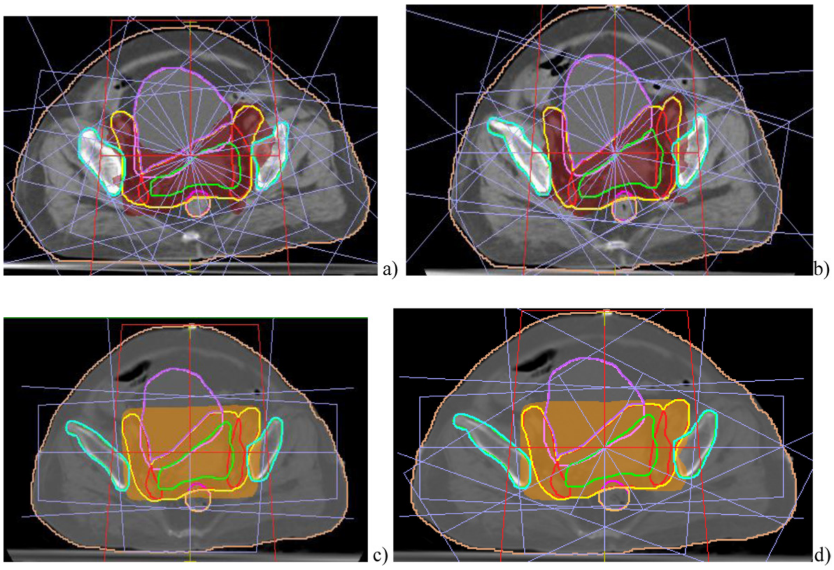

Figure 2: Isodose distributions a) Intensity Modulated Radiotherapy (IMRT). b) IMRT rectum sparing. c) Three Dimensional Conformal Therapy (3DCRT) Box Technique (BT). d) 3DCRT Field-in-field technique (FF).

Table 6: Percentage variation between planned dose and measured dose using an indigenous heterogeneous pelvic phantom

Plan Name	Quality Assurance plan is done on heterogeneous phantom		
	Mean Planned Dose (cGy)±SD	Mean Measured Dose (cGy)±SD	% Variation
IMRT	223.18±0.46	219.16±0.54	(-)1.80
IMRT rectum	224.20±0.37	220.14±0.68	(-)1.81
3DCRT (BT)	221.06±0.41	217.11±0.56	(-)1.78
3DCRT (FF)	218.65±0.58	215.14±0.52	(-)1.60

IMRT: Intensity modulated radiotherapy, 3DCRT: Three dimensional conformal therapy, SD: Standard deviation, BT: Box technique, FF: Field-in-field technique

Femoral Heads

The planning objective of 15% of the volume of the femoral head receiving less than 35 Gy was met by all techniques. IMRT planning achieved better sparing of femoral heads in comparison to 3DCRT. D_{15} for 3DCRT (FF), 3DCRT (BT), IMRT rectal sparing, and IMRT planning were 33.50 Gy, 30.60 Gy, 27.19 Gy, and 27.91 Gy, respectively, in the left femoral head. Similarly, D_{15} for 3DCRT (FF), 3DCRT (BT), IMRT rectal sparing, and IMRT planning were 35.70 Gy, 30.60 Gy, 28.57 Gy, and 32.17 Gy, respectively, in the case of the right femoral head.

Plan verification

The percentage difference between the planned dose on TPS and measured dose on Linac using a heterogeneous phantom are given in Table 6.

The percentage difference between the planned dose and measured dose was 1.80% in the case of the IMRT QA plan, delivered to the pelvic phantom, as seen in Figure 3.

Similarly, in the case of the IMRT rectal sparing QA plan, the percentage variation between the planned dose and measured dose was noted to be 1.81% when verified using the pelvic phantom. For 3DCRT (BT), the percentage variation between the planned dose and measured dose was noted to be 1.78%, when was delivered to the pelvic phantom. When the 3DCRT (FF) QA plans were tested with a pelvic phantom, the percentage variation was 1.60%.

The gamma analysis results of one IMRT case and one IMRT rectal sparing case, including DD, DTA, and gamma index passing rates, are presented in Table 7.

Dose distribution at the axial projection on a Delta4 phantom for one IMRT plan is shown in Figure 4.

The gamma index results are also provided in Figure 5.

Discussion

Initially, radiotherapy for cervical cancer was 2-dimensional, resulting in severe short-term and long-term side effects. With advancement in imaging, three-Dimensional Conformal Radiotherapy (3D-CRT) and Intensity-Modulated Radiotherapy (IMRT) have

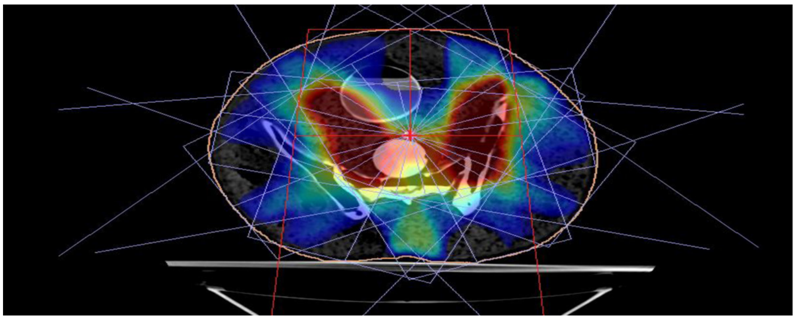

Figure 3: Dose distribution in heterogeneous phantom; Computed Tomography (CT) slice for Intensity Modulated Radiotherapy (IMRT) Quality Assurance (QA) plan

Table 7: Result of dose difference, distance to agreement, and gamma index

Plan No.	Dose difference (%)	DTA (%)	Gamma Index (%)
IMRT	80.5	95.2	97.8
IMRT rectum	80.1	95.1	97.3

IMRT: Intensity modulated radiotherapy, DTA: Distance to agreement

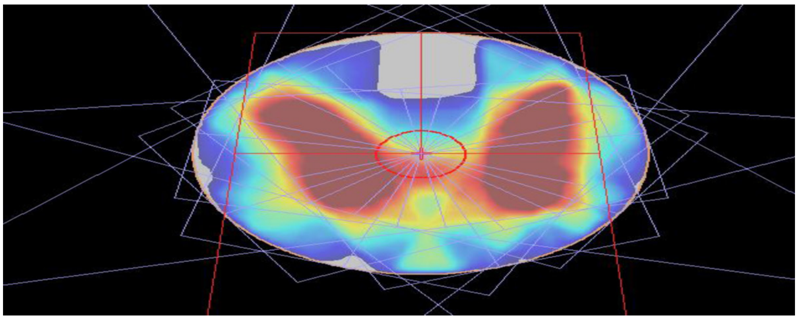

Figure 4: Dose distribution in Delta4 phantom; Computed Tomography (CT) slice for Intensity Modulated Radiotherapy (IMRT) plan

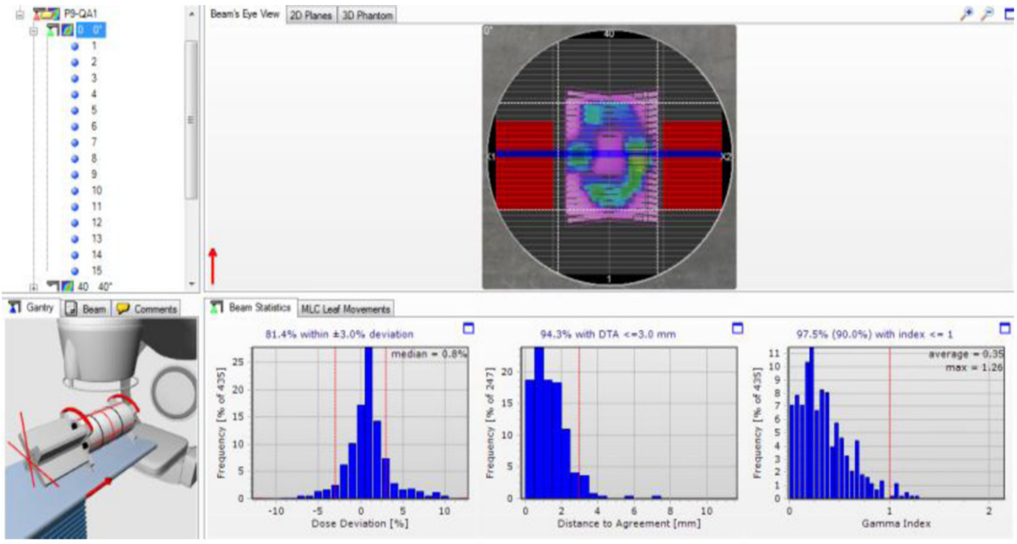

Figure 5: Dose distribution, dose deviation, distance to agreement, and gamma index of one Intensity Modulated Radiotherapy (IMRT) plan

been widely implemented in the treatment of cervical cancer [17]. IMRT possesses obvious superiorities over 3D-CRT technology, but in this study, we have designed the IMRT and 3DCRT plans by modifying the beams so that it reduces the dose to OARs.

The present analysis was aimed to compare two IMRT plans and two 3DCRT plans. In this investigation, we have compared the degree of target coverage, conformity, and normal tissue avoidance. One IMRT plan was optimized by giving the constraint to OARs. Another IMRT plan was optimized after subtracting the rectal volume from the PTV. In the case of the 3DCRT plans, those were created according to the box technique. To reduce the dose to the rectum, a Field-in-Field technique was applied. From this study, we found that 3DCRT with the Field-in-Field technique was much better than the Box Technique for reducing the dose to the rectum. But with an increase of number of fields in the 3DCRT (FF) technique, femoral head dose increased. In the case of IMRT, the plan was optimized by giving the cost function for all the OARs. In this study, we found that the IMRT plan with reduced rectal volume achieved better OAR sparing. From the statistical analysis, IMRT with rectal sparing was the best plan for PTV dose coverage with a 95% isodose line of 48.32 Gy and a rectum mean dose of 38.02 Gy. In the case of 3DCRT (FF) planning, PTV dose coverage with 95% isodose line was 48.40 Gy and rectum means dose was 46.29 Gy.

It has been proven by many researchers that IMRT is better than 3DCRT, given the small number of side effects in IMRT [18], involving an additional effort for planning, safety checks, and quality control before the patients start the treatment. Therefore, all plans were verified using indigenous phantom (for 3DCRT, IMRT) and Delta4 (for IMRT).

In Part B, the percentage difference between the planned dose and measured dose with the pelvic phantom was less than the tolerance limit (<±3%) according to the International Commission on Radiation Units and Measurements (ICRU) 83 [13]. Our results were within the tolerance limit, and Gamma evaluation results, as shown in Table 3, were within the critically acceptable criteria of 3 mm Distance To Agreement (DTA) and 3% Dose Difference (DD).

Conclusion

IMRT can deliver radiation doses more effectively and safely to the PTV as compared to the 3D conformal techniques. Due to the complexity of IMRT, it can achieve better OARs sparing as compared to 3DCRT. IMRT requires safety checks and quality control before patients start the treatment. The QA results were within the tolerance limit and it can increase the confidence in treating patients with new techniques.

Acknowledgment

We are thankful to our radiotherapy team for their encouragement and support.

Authors' Contribution

Introduction, Manuscript of the paper was written by P. Raina. The experimental studies and measurement were also carried out by P. Raina. The research work was proofread and supervised by S. Singh. All the authors read, modified and approved the final version of the manuscript.

Ethical Approval

The patients had voluntarily referred to the mentioned center for treatment, and the CT scan imaging performed for the patients was a part of their treatment process, there was no intervention in the treatment of the patients, the patient data is used only for computerised planning, therefore there is no need to take permission.

Conflict of Interest

None

References

1. Bortfeld T. IMRT: a review and preview. *Phys Med Biol*. 2006;**51**(13):R363-79. doi: 10.1088/0031-9155/51/13/R21. PubMed PMID: 16790913.
2. Purdy JA. Dose to normal tissues outside the radiation therapy patient's treated volume: a review of different radiation therapy techniques. *Health Phys.* 2008;**95**(5):666-76. doi: 10.1097/01.HP.0000326342.47348.06. PubMed PMID: 18849701.
3. Cash JC. Changing paradigms: intensity modulated radiation therapy. Semin Oncol Nurs. 2006;22(4):242-8. doi: 10.1016/j.soncn.2006.07.007. PubMed PMID: 17095400.
4. Spirou SV, Chui CS. Generation of arbitrary intensity profiles by dynamic jaws or multileaf collimators. *Med Phys*. 1994;**21**(7):1031-41. doi: 10.1118/1.597345. PubMed PMID: 7968833.
5. Van Dyk J, Smathers JB. The modern technology of radiation oncology: A compendium for medical physicists and radiation oncologists. *Medical Physics*. 2000;**27**(3):626-7. doi: 10.1118/1.598908.
6. Webb S. The physical basis of IMRT and inverse planning. *Br J Radiol.* 2003;**76**(910):678-89. doi: 10.1259/bjr/65676879. PubMed PMID: 14512327.
7. Kallman P, Lind B, Eklof A, Brahme A. Shaping of arbitrary dose distributions by dynamic multileaf collimation. *Phys Med Biol.* 1988;**33**(11):1291-300. doi: 10.1088/0031-9155/33/11/007. PubMed PMID: 3231672.
8. Taylor A, Powell ME. Intensity-modulated radiotherapy—what is it? *Cancer Imaging*. 2004;**4**(2):68-73. doi: 10.1102/1470-7330.2004.0003. PubMed PMID: 18250011. PubMed PMCID: PMC1434586.
9. Rehman JU, Ahmad ZN, Khalid M, et al. Intensity modulated radiation therapy: a review of current practice and future outlooks. J*ournal of Radiation Research and Applied Sciences*. 2018;**11**(4):361-7. doi: 10.1016/j.jrras.2018.07.006.
10. Stein J, Bortfeld T, Dörschel B, Schlegel W. Dynamic X-ray compensation for conformal radiotherapy by means of multi-leaf collimation. *Radiother Oncol.* 1994;**32**(2):163-73. doi: 10.1016/0167-8140(94)90103-1. PubMed PMID: 7972910.
11. Brahme A. Optimization of stationary and moving beam radiation therapy techniques. *Radiother Oncol*. 1988;**12**(2):129-40. doi: 10.1016/0167-8140(88)90167-3. PubMed PMID: 3406458.
12. Boyer AL, Desobry GE, Wells NH. Potential and limitations of invariant kernel conformal therapy. *Med Phys.* 1991;**18**(4):703-12. doi: 10.1118/1.596663. PubMed PMID: 1921874.
13. International Commission on Radiation Units and Measurements (ICRU). Prescribing, recording, and reporting photon-beam Intensity-Modulated Radiation Therapy (IMRT). ICRU Report 83; Bethesda: ICRU; 2010.
14. Yoon M, Park SY, Shin D, Lee SB, Pyo HR, Kim DY, Cho KH. A new homogeneity index based on statistical analysis of the dose–volume histogram. *J Appl Clin Med Phys.* 2007;**8**(2):9-17. doi: 10.1120/jacmp.v8i2.2390. PubMed PMID: 17592460. PubMed PMCID: PMC5722417.

15. Feuvret L, Noël G, Mazeron JJ, Bey P. Conformity index: a review. *Int J Radiat Oncol Biol Phys.* 2006;**64**(2):333-42. doi: 10.1016/j.ijrobp.2005.09.028. PubMed PMID: 16414369.
16. International Atomic Energy Agency. Absorbed dose determination in external beam radiotherapy: An International Code of Practice for Dosimetry based on standards of absorbed dose to water. Technical Reports Series No. 398; Vienna: IAEA; 2001.
17. Cozzi L, Dinshaw KA, Shrivastava SK, Mahantshetty U, 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. doi: 10.1016/j.radonc.2008.06.013. PubMed PMID: 18692929.
18. Shawata AS, Akl MF, Elshahat KM, Baker NA, Ahmed MT. Evaluation of different planning methods of 3DCRT, IMRT, and RapidArc for localized prostate cancer patients: planning and dosimetric study. *Egyptian Journal of Radiology and Nuclear Medicine.* 2019;**50**(1):1-8. doi: 10.1186/s43055-019-0021-z.