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

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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.

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
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 the 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-
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.

### 3D-CRT 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 0°, one posterior at 180°, and two lateral beams at 90° and 270°). To reduce the rectal dose, a field-in-field technique was used. The plan was arranged by angles of 0°, 90°, 180°, 270°, 135°, and 240° with energy of 6 MV. The Field-in-field technique was used at angles of 90° and 270° to reduce the rectal dose. At angles 135° and 240°, 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.

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**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

**Table 2: Planning objectives for critical structures**

| Normal Structure | Radiation Thresholds (Gy) |
|------------------|--------------------------|
| Rectum           | D_{60%} < 40             |
| Bladder          | D_{50%} < 45             |
| Right Femur      | D_{50%} < 35             |
| Left Femur       | D_{15%} < 35             |
Homogeneity Index (HI)

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

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)

$$\frac{TV}{PTV}$$. 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 cm³. 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 cm³ 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.

\[
D = M_Q \times N_D,W \times K_{Q,Qo} \times K_{T,P} \times K_S \times K_{pol}
\]

(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.

\[
\%\text{Deviation} = \left( \frac{D_m - D_{ref}}{D_{ref}} \right) \times 100
\]

(2)

Where \(D_m\) is the calculated dose from the TPS and \(D_{ref}\) 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 cm³ to 136.342 cm³, and the average volume was 84.375±29.82 cm³. PTVs ranged from 679.379 cm³ to 1111.494 cm³ with an average of 790.189±134.49 cm³ [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),

| 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                                       | 496±117                                    |
| 2     | Fat           | Wax                 | -152±59                                       | -111±8                                    |
| 3     | Air cavity    | Air                 | -904±161                                      | -909±100                                   |
| 4     | Bladder       | Water               | -4±5                                          | -4±8                                      |
| 5     | Rectum        | Borax Powder        | 15±11                                         | 20±29                                     |

CT: Computed tomography, HU: Hounsfield unit, SD: Standard deviation, RED: Relative electron density
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**Table 4: Dosimetric results for the Planning Target Volume**

| Parameter | IMRT (Mean±SD) with rectal sparing | 3DCRT (Mean±SD) box technique | 3DCRT (Mean±SD) field technique |
|-----------|-----------------------------------|-------------------------------|-------------------------------|
| $D_{\text{max}}$ (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 | 52.56±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

$D_{\text{max}}$ 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 $D_{\text{max}}$ 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 cm³ (range from 34.98 cm³ to 78.06 cm³). In Table 6, we observed that the mean dose $D_{\text{mean}}$ received by the rectum in IMRT and IMRT rectum sparing plan is 38.59 Gy and 38.02 Gy, respectively. Similarly, the values of $D_{5\%}$ 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 $D_{\text{mean}}$, $D_{5\%}$, $V_{30\%}$, $V_{35\%}$ and $V_{40\%}$. Planning objective ($D_{5\%} < 40$ 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 cm³ (range from 238.719 cm³ to 496.132 cm³). The DVH parameter $D_{30\%}$, $D_{40\%}$, and $D_{\text{mean}}$ 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 cm³, 140.46 cm³, 184.59 cm³, and 190.89 cm³ for 3DCRT (FF), 3DCRT (BT), IMRT rectal sparing, and IMRT planning, respectively. On the other hand, $V_{40\%}$ was 84.48 cm³, 91.125 cm³, 121.448 cm³, and 125.56 cm³ and $V_{45\%}$ was 41.27 cm³, 48.07 cm³, 51.82 cm³, and 54.53 cm³ for the afore mentioned techniques, respectively.
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Table 5: Dosimetric results for organ at risks

| Parameter          | IMRT (Mean±SD) | IMRT (Mean±SD) with sparing rectum | 3DCRT (Mean±SD) | 3DCRT (Mean±SD) field and field technique |
|--------------------|----------------|------------------------------------|------------------|-------------------------------------------|
|                    | Rectum 50.83±13.93 cm³ |                                   |                  |                                           |
| \( D_{\text{mean}} \) (Gy) | 38.59±0.72 | 38.02±0.56 | 47.48±0.50 | 46.29±0.73 |
| \( D_{3\text{5}} \) (Gy) | 37.7±1.2 | 33.52±0.9 | 48.8±1.1 | 47.50±0.5 |
| \( V_{30} \) cm³ | 34.85±15.0 | 33.95±14.08 | 47.2±17.3 | 47.01±17.13 |
| \( V_{35} \) cm³ | 26.10±12.1 | 25.74±11.2 | 46.69±16.95 | 45.23±15.7 |
| \( V_{40} \) cm³ | 21.69±7.8 | 20.729±8.87 | 43.97±15.5 | 41.1±13.28 |

| Small Bowel 337.968±138.136 cm³ |
|----------------------------------|
| \( D_{\text{mean}} \) (Gy) | 47.1±2.5 | 46.94±3.53 | 48.3±1.3 | 47.2±1.4 |
| \( D_{3\text{0}} \) (Gy) | 31.84±1.8 | 31.42±2.51 | 28.65±0.55 | 28.10±0.54 |
| \( V_{30} \) cm³ | 190.89±96.5 | 184.59±108.5 | 140.46±52.2 | 133.93±58.7 |
| \( V_{35} \) cm³ | 125.56±65.5 | 121.448±75.78 | 91.125±34.79 | 84.48±40.87 |
| \( V_{40} \) cm³ | 86.56±42.1 | 80.97±53.2 | 68.3±28.05 | 60.85±31.11 |
| \( V_{45} \) cm³ | 54.53±29.9 | 51.82±37.96 | 48.07±20.92 | 41.27±23.04 |

| Left Femoral Head 56.101±14.45 cm³ |
|-----------------------------------|
| \( D_{\text{mean}} \) (Gy) | 27.61±0.19 | 22.15±0.21 | 29.98±0.16 | 30.55±0.335 |
| \( V_{30} \) cm³ | 16.35±0.21 | 2.82±0.51 | 10.84±0.17 | 26.63±4.42 |
| \( D_{1\text{5}} \) (Gy) | 27.91±0.18 | 27.19±0.42 | 30.60±0.54 | 33.50±0.65 |

| Right Femoral Head 57.03±10.68 cm³ |
|-----------------------------------|
| \( D_{\text{mean}} \) (Gy) | 23.51±1.2 | 24.20±1.3 | 31.05±1.57 | 31.1±1.34 |
| \( V_{30} \) cm³ | 7.97±2.1 | 3.06±1.8 | 10.67±1.6 | 18.28±1.56 |
| \( D_{1\text{5}} \) (Gy) | 32.17±1.6 | 28.57±1.7 | 30.60±1.6 | 35.70±1.3 |

| Bladder 394.26±121.20 cm³ |
|---------------------------|
| \( D_{\text{mean}} \) (Gy) | 51.20±0.6 | 51.25±0.5 | 51.60±0.7 | 51.10±0.5 |
| \( D_{\text{mean}} \) (Gy) | 31.85±1.2 | 31.33±1.4 | 42.65±1.6 | 41.31±1.7 |
| \( D_{3\text{0}} \) (Gy) | 44.58±0.5 | 39.01±0.2 | 50.60±0.4 | 49.60±0.7 |
| \( V_{30} \) cm³ | 172.75±46.23 | 155±50.64 | 257.32±69.29 | 230.15±60.0 |
| \( V_{35} \) cm³ | 154.0±41.75 | 135.31±38.02 | 213.16±57.41 | 205.14±45.01 |
| \( V_{40} \) cm³ | 133.71±36.0 | 116±36.0 | 191.76±51.7 | 176.13±54.1 |
| \( V_{45} \) cm³ | 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 cm³ (range from 230.028 cm³ to 570.153 cm³). 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. \( D_{3\text{5}} \), \( D_{\text{mean}} \), and \( D_{3\text{5}} \) 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 cm³, 135.31 cm³, 116 cm³, and 91 cm³, respectively, which is much lesser than the 3DCRT (FF) plans.
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 be-

![Isodose distributions](image)

**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
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

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**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

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

**Figure 4:** Dose distribution in Delta4 phantom; Computed Tomography (CT) slice for 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 (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 ef-
fectively 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

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