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Original research article

DOSIMETRIC COMPARISON OF INTENSITY-MODULATED RADIATION THERAPY (IMRT) AND VOLUMETRIC-MODULATED ARC THERAPY (VMAT) IN RECTAL CANCER PATIENTS: A COMPREHENSIVE ANALYSIS

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Abstract: *This study aimed to conduct a thorough dosimetric comparison between two advanced radiotherapy techniques, Intensity-Modulated Radiation Therapy (IMRT) and Volumetric-Modulated Arc Therapy (VMAT), to ascertain the superior modality in terms of dose distribution and organ-at-risk sparing for rectal cancer patients. Thirty-three patients with ECOG performance status 1, aged between 18 to 60 years, diagnosed with Stage II to III rectal cancer, were included in this prospective study. Each patient underwent treatment planning with IMRT and VMAT techniques using Varian system simulation computed tomography scans. The dosimetric analysis encompassed the evaluation of target volume dose homogeneity, conformity, and doses to at-risk organs. The dosimetric comparison was conducted utilizing seven-field IMRT and dual arc VMAT plans. Statistical analysis was performed using paired t-tests and SPSS 20 software. Treatment plan constraints adhered to the RTOG 9406 guidelines, ensuring adequate planning target volume (PTV) coverage, homogeneity index, conformity index, and dose limits for organs at risk, including small bowel V20 (<200cc), bladder V45 (<21Gy), and femoral head V50 (≤30 Gy). Volumetric arc therapy plans demonstrated superior dose homogeneity to fixed-field intensity-modulated plans (p-value = 0.04), particularly in femoral head dose-limiting toxicity (p-value = 0.00). However, intensity-modulated therapy exhibited equivalent or superior performance in other evaluated parameters. Our findings suggest that while VMAT offers advantages in PTV coverage homogeneity and femoral head dose-limiting toxicity, IMRT remains competitive and potentially preferable in certain dosimetric aspects. The choice between IMRT and VMAT should be carefully considered based on individual patient characteristics and treatment goals. This comprehensive dosimetric comparison contributes valuable insights into optimizing radiotherapy planning for rectal cancer patients, potentially guiding clinical decision-making and improving treatment outcomes.*

Keywords: Dose-Response Relationship, Radiation, Intensity-Modulated Radiation Therapy, Neoplasm Staging, Rectal Neoplasms, Radiotherapy Dosage

Introduction

Radiotherapy is the standard treatment modality in adjuvant and neoadjuvant settings in stage II and III rectal cancers (Sauer et al., 2012). It is an effective mode of sphincter preservation and achieves a pathological complete response (Yang et al., 2019). Short-course and long-course chemoradiotherapy are used, and the overall survival rate is similar (Latkauskas et al., 2016). The techniques used to deliver radiotherapy (RT) are three-dimensional chemoradiotherapy (3D-CRT), intensity-modulated radiotherapy (IMRT), and volumetric arc therapy (VMAT). Numerous studies have demonstrated the comparison between 3D-CRT and IMRT, which proves the superiority of IMRT in terms of target coverage, dose homogeneity, and normal tissue toxicity(Xu et al., 2017)**.** Limited literature is available on the comparison between IMRT and VMAT. Volumetric modulated arc therapy (VMAT), an advanced radiotherapy technique and a rotational form of IMRT, has been applied to clinical practice in various solid tumors.(Ballhausen et al., 2018; Rossi et al., 2019) Few such studies were performed for prostate, rectum, and head and neck cancers. All these studies had shown better tumor conformity and homogeneity with VMAT along with better normal tissue sparing in the studies of pelvic tumors; better tumor control probability is observed in one of the head and neck studies with VMAT; collectively, all demonstrated the superiority of VMAT in terms of planned target volume dose coverage, reduction in organ at risk dose (OAR) and less no of MUs (Kaplan et al., 2019; Kryger et al., 2017; Latkauskas et al., 2016) **.**

We intend to find the difference between the two treatment techniques and establish which technique is superior regarding target volume dose coverage and organs at risk of toxicity. Thus, the Objective of the study was to compare the difference in treatment plans between IMRT and VMAT from aspects; the Objective was to compare the difference in treatment plans between IMRT and VMAT in terms of target volume coverage and OAR toxicity.

Methodology

This prospective study lasted six months following approval from the hospital's ethical review committee and was

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carried out at the Department of Radiation Oncology, Combined Military Hospital, Rawalpindi.

The sample size calculation was performed using the WHO sample size calculator, with criteria set at a confidence interval of 95%, absolute precision of 5%, and a population standard deviation of 0.004, derived from a reference study. Consecutive convenience sampling was employed to enroll patients who met the inclusion criteria.

Inclusion criteria encompassed patients aged between 18 and 70 years with histopathologically confirmed stage II to III rectal cancer and an Eastern Cooperative Oncology Group performance status (ECOG PS) ≤ 2. Exclusion criteria excluded patients outside the specified age range or with an ECOG PS ≥ 4.

Thirty patients with locally advanced rectal cancer underwent preoperative chemoradiotherapy (CRT) with curative intent. Treatment volumes were delineated according to the Radiation Therapy Oncology Group (RTOG) consensus guidelines. The dosimetric comparison involved generating two treatment plans, Intensity-Modulated Radiation Therapy (IMRT) and Volumetric-Modulated Arc Therapy (VMAT), for each patient using Varian system simulation computed tomography scans.

Dosimetric parameters, including D98% (dose received by 98% of the planning target volume), D2% (dose received by 2% of the planning target volume), and D50% (dose received by 50% of the planning target volume) for PTV, were determined based on the International Commission on Radiation Units and Measurements-83 guidelines. The Homogeneity index was calculated using the formula D98%-D2%/D50%. Organ-at-risk (OAR) doses were evaluated using dose-volume histograms and adhered to specific dose-volume constraints.

Patient data, comprising demographic information, tumor characteristics, ECOG PS, and dosimetric parameters, were collected from Oncology outpatient department records. Radiotherapy treatment planning and delivery were conducted at the Department of Radiation Oncology, CMH Rawalpindi.

Statistical analysis was conducted using SPSS version 20, employing paired sample t-tests to assess differences in outcome variables between IMRT and VMAT treatment plans, with statistical significance set at $p < 0.05$.

Results

The dosimetric comparison of VMAT and IMRT was performed for the dosimetric parameters; their means, standard deviation, confidence interval, and P values were presented in the given tables, Table 1 and ***Table 2.*** VMAT plans appear to be better regarding target coverage and dose distribution for Homogeneity Index (HI) p-value 0.04, -0.1756(-0.29__-0.06) as its mean and confidence interval compared to IMRT plans. The VMAT plans were also associated with slight advantages of femoral head OAR sparing -4.73(-6.55__-2.91) as its mean and confidence interval when compared with IMRT, and the detailed dosimetric parameters of OARs were shown in ***Table 2.*** and femoral heads. For the rest of the at-risk volumes (OARs), IMRT is equal to or superior to the VMAT technique.

Table 1 Comparison of the dosimetric parameters of the PTV.

Parameter	IMRT mean and standard deviation.	VMAT mean and standard deviation.	IMRT vs VMAT Paired mean and confidence interval	P value
HI	0.3554 _+0.0828	0.5310_+0.2999	-0.1756(-0.29__-0.06)	0.04

Table 2 Comparisons of the dosimetric parameters of the OARs.

Parameters	IMRT mean and standard deviation.	VMAT mean and standard deviation.	IMRT vs VMAT paired mean and confidence interval	P Value
Bladder V45 (<21Gy),	18.46 +_5.144	19.50+_3.43	-1.04(-3.33__1.24	0.357
Femoral heads V50 (≤30 Gy).	12.976+_2.23	17.71+_3.63	-4.73(-6.55__-2.91)	0.00
Small bowel V20 (<200cc),	8.953+_2.53	10.304+_14.42	-1.35(-7.04__4.34	0.631

Discussion

IMRT and VMAT are advanced conformal radiation therapy planning and delivery techniques that deliver highly modulated dose fluence from multiple directions to limit high-dose volumes outside the planning target volume.

This provides the advantage of reducing toxicity doses to OARs and increasing conformity and dose homogeneity in planning target volume (Kaplan et al., 2019).

IMRT and VMAT are widely used nowadays. Literature shows VMAT to be more conformal than IMRT in various tumors. Limited data is available regarding rectal cancer, and our study aimed at finding this difference (Ingle et al., 2023).

We compared the dosimetric parameters of the two techniques. In Our study, the two techniques of radiation planning, IMRT intensity modulated radiation therapy and volumetric arc therapy (VMAT), were compared and observed for the planning target volume (PTV) homogeneity index HI and at-risk normal organs Bladder, bowel, and femoral for their tolerance dose constraints. Our study results were statistically significant for HI and showed VMAT as a better option. However, doses of OAR apart from the femoral head were not statistically significant among the two groups, contrary to the following study that showed better HI in IMRT (Kaplan et al., 2019) Several other studies were also performed that compared the dosimetric differences between the two techniques discussed below.

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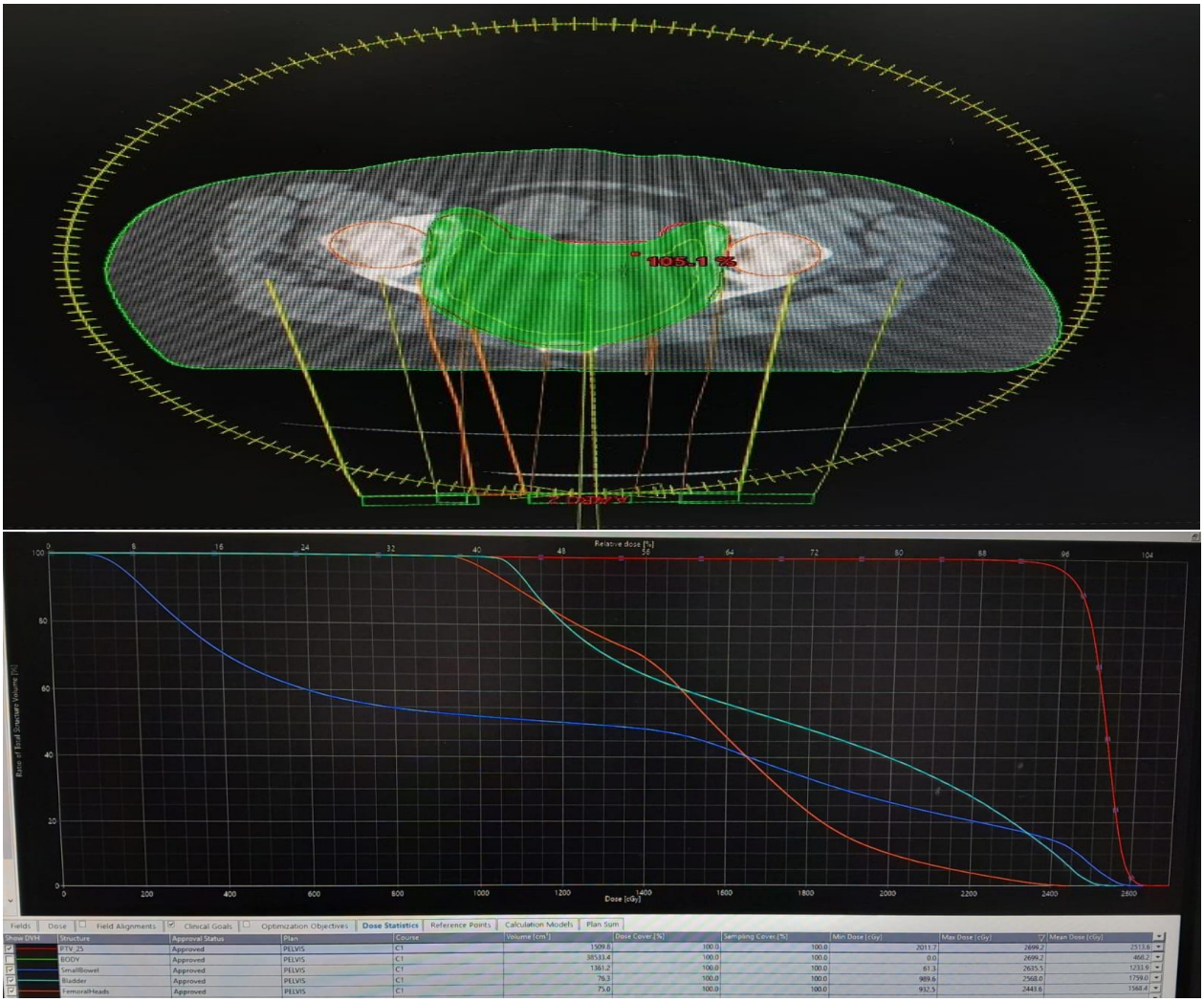
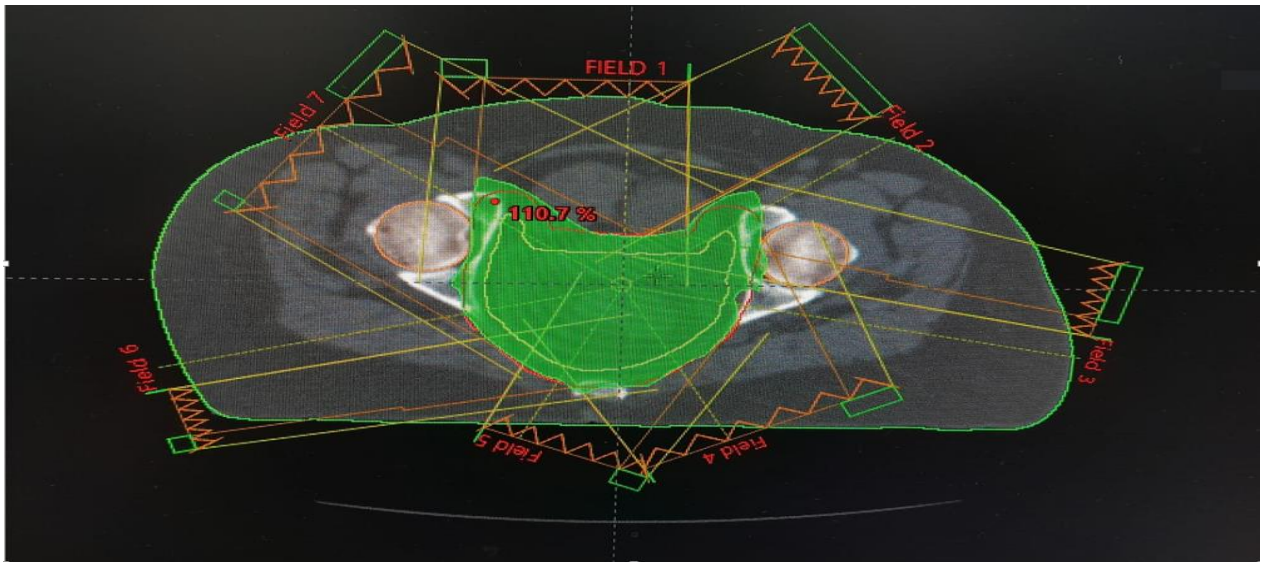


Figure 1: *Axial section of simulation CT scan showing VMAT Plan and its Dose-volume histogram; the x-axis displays dose in Gray Gy, and the y-axis shows volume in percentage. The solid lines represent the PTV and OARs relationship of the dose received by the organ's volume. The dark blue line represents the small bowel, the light blue line represents the bladder, the orange line represents the femoral head, and the PTV is shown as a red line.*



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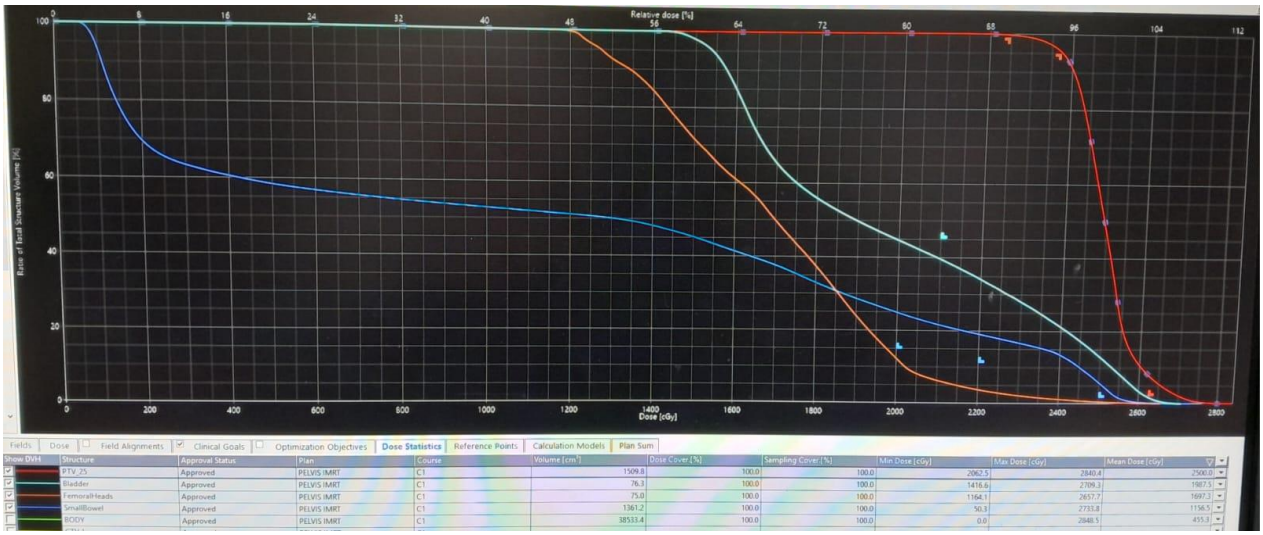

Figure 2: *Axial section of simulation CT scan showing IMRT Plan and its Dose-volume histogram. The x-axis displays the dose in Gray Gy, and the y-axis shows the volume in percentage. The solid lines represent the relationship between the PTV and OAR dose received by the volume of their respective organs. The small bowel is displayed in dark blue, the PTV in red, the femoral heads in orange, and the Bladder in light blue.*

A similar study observed superior dose distribution compared with the IMRT plan. However, VMAT was shown to be a better option regarding limiting unnecessary exposure to the small bowel and reducing its toxicity. Hence, VMAT is declared a better treatment option than IMRT(Shi et al., 2017). Another study showed that IMRT is better at reducing OAR toxicity and normal tissue sparing (Zhao et al., 2016). In some other studies, the mean CI for the PTV was 0.77 (0.73–0.81) for IMRT and 0.82 (0.79–0.84) for VMAT, with a significant difference (P=.034). The mean HI was 0.21 (0.19–0.22) for IMRT and 0.20 (0.19–0.21) for VMAT, and there was an insignificant difference when VMAT compared with IMRT (P=.613); the VMAT plans were associated with slight advantages of OARs sparing when compared with IMRT.(Wang et al., 2022)

The results of our study showed that IMRT is equal to or superior to VMAT in terms of sparing normal tissue in the small bowel and urinary bladder. However, VMAT is a better option concerning dose homogeneity to the target volume.

Nevertheless, our study encountered several limitations. Firstly, the sample size remained small, highlighting the necessity for more extensive studies involving a broader patient population. Additionally, patient positioning lacked monitoring, potentially overlooking intra-fraction organ motion and introducing slight variations in the delivered dose to tumor targets and OARs. Nonetheless, this analysis yielded fresh insights into the utilization of VMAT in patients with Stage three and four rectal cancers.

Conclusion

In summary, VMAT plans demonstrated better homogeneity of the planning target volumes compared to IMRT for patients with stage II to III rectal cancer. VMAT also showed a slight advantage in sparing the femoral head at risk volume of the treatment field. Moreover, target coverage and preservation of other healthy tissues were similar between the two techniques, and IMRT may be superior. Consequently, VMAT is a promising approach for treating rectal cancer target volume coverage. However, IMRT is also equally important regarding at-risk tissue tolerance and dose preservation.

Declarations

Data Availability statement
All data generated or analyzed during the study are included in the manuscript.
Ethics approval and consent to participate.
Approved by the department Concerned.
Consent for publication
Approved
Funding
Not applicable

Conflict of interest

The authors declared an absence of conflict of interest.

Authors Contribution

SANA SHAFIQUE
Concept & Design of Study, final approval of study.
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Drafting, proof reading, data analysis
TAHREEM BAIDAR
Drafting, proof reading
MUHAMMAD OKASHA
Revisiting Critically, proof reading, data collection

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