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The Effect of Segment Number Variations on Dosimetric Quality and Monitor Unit Requirements in IMRT Planning for Rectal Cancer

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Abstract: Variations in segment configurations in Intensity-Modulated Radiation Therapy (IMRT) can affect dosimetric quality and Monitor Unit (MU) requirements. This study aimed to analyze the effects of four configurations, namely S5, S10, S15, and Sliding Window (default/SSW), on target, organ-at-risk (OAR), and MU parameters in IMRT planning for rectal cancer. This retrospective dosimetric study included 10 patients and generated 40 plans calculated using the Eclipse Treatment Planning System (TPS) (6 MV photons, 50 Gy in 25 fractions, and a fixed grid resolution of 2.5 mm). The evaluated parameters were PTV V95%, Conformity Index (CI), Homogeneity Index (HI), Dmax, Bladder V50, Small Bowel V45, and MU. Data were analyzed using the Friedman test with Kendall's W as the effect size, followed by two-sided Wilcoxon tests with Holm correction at $\alpha = 0.05$. Significant differences were found in PTV V95%, CI, HI, Dmax, and MU ($p < 0.001$; $W = 0.708–1.000$), but not in Bladder V50 ($p = 0.840$; $W = 0.028$) or Small Bowel V45 ($p = 0.172$; $W = 0.167$). SSW yielded the highest mean V95% (99.482%) and CI (0.952), as well as the lowest HI (0.044) and Dmax (5265.22 cGy), but required the highest MU (995.70). S15 required 841.60 MU, which was 15.48% lower than SSW, with a V95% difference of only 0.036 percentage points. Therefore, S15 may be considered a potential compromise between dosimetric quality and MU requirements, subject to verification of OAR dose constraints and treatment-delivery quality assurance.

Keywords: rectal cancer; Intensity-Modulated Radiation Therapy; segment variation; dosimetry; Eclipse TPS; Monitor Unit.

I. INTRODUCTION

Radiotherapy is one of the principal modalities in cancer management, aiming to deliver radiation doses accurately to the target volume while minimizing exposure to the surrounding healthy tissues [7]. In rectal cancer, treatment planning presents anatomical challenges because the target is located in the pelvic cavity and is adjacent to organs at risk (OARs), such as the bladder and small bowel. This requires a delivery technique that provides adequate dose coverage of the Planning Target Volume (PTV) while limiting exposure to normal tissues. IMRT can provide better target coverage and normal-organ sparing than Three-Dimensional Conformal Radiation Therapy (3D-CRT) in patients with rectal cancer [1], while dose parameters for the bladder and small bowel may be affected by variations in patient positioning [2].

IMRT modulates beam intensity by controlling the Multileaf Collimator (MLC), allowing the dose distribution to conform to the target contour. Changes in planning parameters, such as collimator-angle orientation in IMRT and Volumetric Modulated Arc Therapy (VMAT) for rectal cancer, have been shown to alter the dosimetric characteristics of treatment plans [3]. Thus, plan

quality is determined not only by the selected technique but also by the optimization settings in the Treatment Planning System (TPS). Plan quality is commonly evaluated using Dose-Volume Histogram (DVH)-based parameters [7], including PTV V95% for target coverage, the Conformity Index (CI) for the conformity of dose distribution to the target, the Homogeneity Index (HI) for dose uniformity within the PTV, maximum dose (Dmax), and OAR doses [1].

The success of IMRT optimization is also influenced by beam-segmentation settings. The minimum MU threshold at dynamic control points affects dose distribution and operational efficiency in liver-cancer IMRT [4], while variations in the number of fields and MU thresholds per segment have been reported to affect the efficiency and robustness of magnetic resonance-guided plans for brain metastases [5]. Increasing modulation complexity does not always produce a proportional improvement in dose quality, because the number of segments and MU requirements may also increase. However, these two studies involved different tumor sites, modalities, and TPS platforms; therefore, their findings cannot be directly generalized to rectal-cancer IMRT using the Eclipse TPS.

In addition to segmentation, dose-calculation grid resolution affects spatial accuracy and the evaluation of dose-volume parameters, particularly in regions with steep dose gradients [10]. Accordingly, this study used a fixed grid resolution of 2.5 mm to ensure that comparisons among segment configurations were performed using the same computational basis. The aim was to examine the effects of four configurations (S5, S10, S15, and SSW) on PTV V95%, CI, HI, Dmax, Bladder V50, Small Bowel V45, and MU, and to assess their effect sizes. The hypothesis was that at least one pair of configurations would differ in these parameter values.

II. LITERATURE REVIEW

A. Segments, Sliding Window, and Monitor Units

In IMRT, modulated fluence is delivered through MLC apertures. In the discrete-segment mode (step-and-shoot), fluence is formed from a number of segments with fixed apertures, whereas in the sliding-window mode, the MLC leaves move continuously to produce fluence dynamically. The number of segments affects modulation capability, delivery complexity, and MU; more complex plans generally require higher MU [5], [9]. Because SSW is a different modulation mode from the discrete segment limits used in S5, S10, and S15, its results should not be interpreted as a linear relationship between segment number and plan quality.

B. Dosimetric Parameters

PTV V95% represents the percentage of the PTV volume receiving at least 95% of the prescribed dose. The Conformity Index (CI) was treated as a conformity measure obtained from the Eclipse planning data; its exact operational equation must be consistent with the equation used to generate the study values. The Homogeneity Index (HI), according to ICRU 83 [7], describes dose uniformity within the target, with lower values indicating a more homogeneous dose distribution. Dmax represents the highest dose (hot spot), while Bladder V50 and Small Bowel V45 indicate OAR exposure and are commonly compared with normal-tissue tolerance limits, such as those summarized in QUANTEC [8]. MU reflects the machine output required to deliver a plan, not the actual treatment time.

C. Related Studies

Tali et al. [1] compared 3D-CRT and IMRT for rectal cancer using target and OAR DVH parameters, while Hayashi et al. [2] compared small-bowel and bladder doses in prone and supine positions. Abdulameer et al. [3] demonstrated that collimator rotation alters the dosimetry of IMRT and VMAT for rectal cancer. In other treatment sites, Shi et al. [4] investigated the minimum MU per dynamic control point in liver-cancer IMRT, and Ren et al. [5] assessed the number of fields and MU per segment in radiotherapy for brain metastases. The impact of calculation-grid size on head-and-neck IMRT was reported by Srivastava et al. [10]. The present study extends this body of work by comparing four segment configurations in rectal-cancer IMRT using the Eclipse TPS.

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D. Selection of Statistical Tests and Effect Size

In a repeated-measures design, observations from the same patient are correlated; therefore, paired-sample tests are required. Normality for $n < 50$ was assessed using the Shapiro–Wilk test [16]. The Friedman test [12] is a nonparametric alternative to repeated-measures ANOVA that operates on within-patient ranks and does not require a normal distribution. When the Friedman test is significant, pairwise comparisons are performed using the Wilcoxon signed-rank test [13], with p-values adjusted using the Holm procedure [14] to control the Type I error rate. Kendall's W [17] represents the agreement in the ranking of configurations across patients (0 = no agreement; 1 = identical ranking across all patients) and is interpreted according to Cohen's guidelines [15]. A p-value indicates whether an observed difference may be attributable to chance; in a small sample, statistical power is limited, so p-values should be considered alongside effect sizes and the magnitude of dosimetric differences.

III. RESEARCH METHODS

A. Study Design and Sample

This retrospective dosimetric study used planning data from 10 patients diagnosed with rectal cancer at Dr. Kariadi General Hospital, Semarang, Indonesia. The source records consisted of CT-simulator DICOM images and target/OAR contours prepared for radiotherapy planning. Four IMRT plans were generated or reoptimized for each patient (S5, S10, S15, and SSW), resulting in 40 plans (10 patients × 4 configurations). Each patient served as their own control.

The operational inclusion criteria were: (1) a diagnosis of rectal cancer; (2) availability of CT-simulator DICOM data and the corresponding contoured target and OAR structures; (3) an IMRT planning prescription of 50 Gy in 25 fractions; and (4) sufficient planning and DVH information to evaluate all four segment configurations at a 2.5-mm calculation grid. Records were not eligible if the imaging, contours, plan information, or required DVH endpoints were incomplete, or if all four configurations could not be evaluated. These criteria describe the dataset required for this analysis; the original clinical records should be checked to confirm that each exclusion was applied as stated.

Planning was performed using the Eclipse Treatment Planning System (TPS) with a Varian linear accelerator and 6-MV photon beams. The prescription was 50 Gy in 25 fractions (2 Gy per fraction). Each plan used five coplanar irradiation beams with gantry angles of 0°, 72°, 144°, 216°, and 288°. The dose-calculation grid resolution was fixed at 2.5 mm for all plans. For each patient, the S5, S10, and S15 configurations applied segment-number limits of 5, 10, and 15, respectively, while SSW used the default sliding-window delivery mode. The plans were reoptimized for each segment configuration (reoptimization), rather than being subjected only to dose recalculation after changing the calculation grid.

The exact Eclipse software version, dose-calculation algorithm, Varian LINAC model, and MLC model could not be verified from the retrospective planning documents available for this analysis. These technical identifiers are therefore not specified rather than inferred. The segment limits are reported as the settings used for the four plan configurations; further details of the optimization-control workflow were not retained in the available record.

The study protocol received approval from the Health Research Ethics Committee of Dr. Kariadi General Hospital, Semarang, under approval number 17025/EC/KEPK-RSDK/2026, dated 21 October 2026, with an approval period from 21 October 2026 to 21 October 2027. The analysis used retrospective radiotherapy-planning data. Patient identifiers were not included in the analytical dataset.

B. Treatment Planning and Software

Planning was performed using the Eclipse TPS on a linear accelerator with 6 MV photons and a prescription dose of 50 Gy in 25 fractions. All plans were calculated using a fixed grid resolution of 2.5 mm. The S5, S10, and S15 configurations imposed their respective segment-number limits, whereas SSW used the default sliding-window mode. Each plan used five irradiation beams with gantry angles of 0°, 72°, 144°, 216°, and 288°. The prescribed dose was 50 Gy in 25 fractions (2 Gy per fraction). All plans were calculated using a fixed grid resolution of 2.5 mm.

C. Dosimetric Parameters

The analyzed parameters are summarized in Table 1. The equations for CI and HI are presented in Equations (1) and (2).

Table 1. Operational definitions of dosimetric parameters.

Parameter	Operational Definition	Unit	Preferred Direction
PTV V95%	Percentage of PTV volume receiving at least 95% of the prescription dose	%	Higher
CI	Conformity of the prescription isodose volume to the target volume; Paddick index [11]	Dimensionless	Closer to 1
HI	Dose homogeneity within the PTV according to ICRU 83 [7]	Dimensionless	Lower
Dmax	Maximum dose within the PTV	cGy	Lower (subject to hot-spot constraints)
Bladder V50	Percentage of bladder volume receiving at least 50 Gy	%	Lower
Small Bowel V45	Small-bowel volume receiving at least 45 Gy	cm^3	Lower
MU	Total monitor units for the plan (machine-output indicator)	MU	Lower (more efficient)

Note: The highlighted section must be verified by the authors against the original DVH/TPS export.

$$CI = \frac{(TV_{PIV})^2}{TV \times PIV} \quad (1)$$

where TVPIV is the target volume covered by the prescription isodose, TV is the target volume, and PIV is the volume covered by the prescription isodose [11].

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

where D2%, D98%, and D50% are the doses received by at least 2%, 98%, and 50% of the PTV volume, respectively [7].

D. Hypotheses and Statistical Analysis

H0 stated that there was no difference in parameter values among segment configurations, whereas H1 stated that at least one pair differed; H0 was rejected when $p < 0.05$. Analyses were performed using IBM SPSS Statistics 26 with $\alpha = 0.05$, following the workflow shown in Figure 1. Data were analyzed as paired measurements. Normality was assessed using the Shapiro–Wilk test. The Friedman test (df = 3) was selected to compare the four configurations because of the repeated-measures design, the sample size (n = 10), and the difficulty of confirming the normality assumption with such a small sample. Effect size was reported as Kendall's W (Equation 3), using Cohen's guidelines: 0.1 (small), 0.3 (medium), and 0.5 (large) [15]. If the Friedman test was significant, two-sided Wilcoxon signed-rank tests were performed for the six pairs, with Holm correction. Results are presented as mean ± standard deviation, pairwise mean differences, and boxplots.

$$W = \frac{\chi^2}{n[k-1]} \quad (3)$$

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where χ^2 is the Friedman test statistic, n = 10 patients, and k = 4 configurations; therefore, $W = \chi^2/30$.

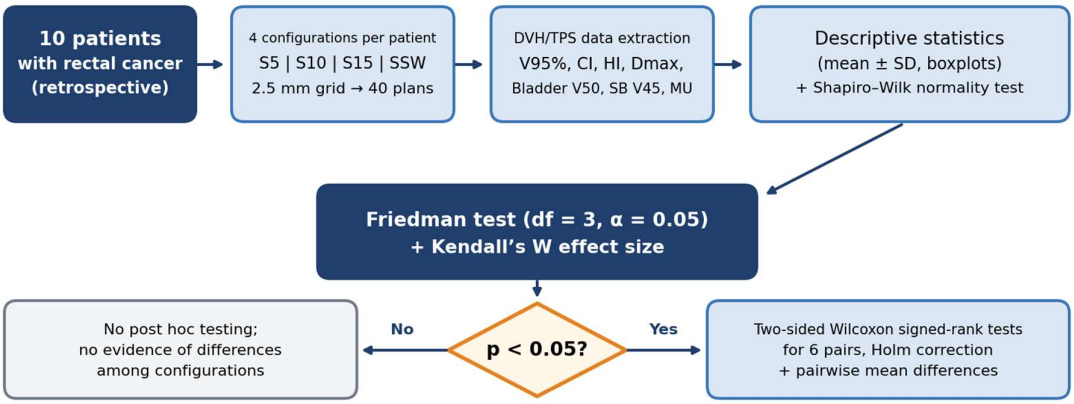


Figure 1. Research workflow and statistical analysis.

IV. RESULTS

A. Descriptive Statistics

Table 2 presents the means and standard deviations of the seven parameters across the four configurations. From S5 to SSW, V95% and CI increased, whereas HI and Dmax decreased progressively. MU did not follow a monotonic pattern: it was lowest in S15 and highest in SSW. Bladder V50 showed no clear pattern, while Small Bowel V45 decreased descriptively.

Table 2. Descriptive statistics for the seven parameters across the four segment configurations (mean ± SD; n = 10).

Parameter	S5	S10	S15	SSW
PTV V95% (%)	92.635 ± 6.267	99.247 ± 0.961	99.446 ± 0.627	99.482 ± 0.611
CI	0.701 ± 0.136	0.843 ± 0.097	0.901 ± 0.043	0.952 ± 0.023
HI	0.158 ± 0.054	0.070 ± 0.023	0.054 ± 0.020	0.044 ± 0.016
Dmax (cGy)	5760.450 ± 274.330	5402.910 ± 86.989	5322.700 ± 89.928	5265.220 ± 94.838
Bladder V50 (cm^3)	16.563 ± 14.199	15.981 ± 9.504	17.401 ± 11.371	16.437 ± 10.183
Small Bowel V45 (cm^3)	53.225 ± 31.525	49.735 ± 32.161	49.113 ± 33.150	48.043 ± 32.863
MU	877.600 ± 222.468	868.800 ± 193.196	841.600 ± 206.915	995.700 223.110

B. Normality Test

Table X. Shapiro–Wilk normality test results at a grid resolution of 2.5 mm.

Dosimetric Parameter	S5: W (p)	S10: W (p)	S15: W (p)	SSW: W (p)
PTV V95%	0.840 (0.044)	0.778 (0.008)	0.819 (0.025)	0.805 (0.017)
Conformity Index (CI)	0.970 (0.887)	0.933 (0.476)	0.972 (0.907)	0.928 (0.433)
Dmax	0.823 (0.027)	0.844 (0.049)	0.891 (0.173)	0.758 (0.005)
Homogeneity Index (HI)	0.696 (0.001)	0.748 (0.003)	0.752 (0.004)	0.741 (0.003)
Bladder V50	0.866 (0.091)	0.964 (0.829)	0.931 (0.462)	0.916 (0.326)
Small Bowel V45	0.980 (0.965)	0.957 (0.748)	0.966 (0.851)	0.963 (0.824)
Monitor Unit (MU)	0.934 (0.492)	0.920 (0.354)	0.899 (0.214)	0.885 (0.149)

Note: W = Shapiro–Wilk statistic; p = significance value; n = 10. Values are presented as W (p). Data were considered normally distributed when p > 0.05.

Source: Research data processed using IBM SPSS Statistics.

Visually, the boxplots in Figures 3–6 show asymmetric distributions and outliers for several parameters, particularly PTV V95% and CI in S5, supporting the use of a nonparametric approach.

C. Friedman Test and Effect Size

Significant differences were found in PTV V95%, CI, HI, Dmax, and MU (all $p < 0.001$), with large effect sizes ($W = 0.708–1.000$). In contrast, Bladder V50 ($p = 0.840$; $W = 0.028$) and Small Bowel V45 ($p = 0.172$; $W = 0.167$) did not differ significantly (Table 3, Figure 2). A value of $W = 1.000$ for HI indicates that the configuration rankings were identical for all 10 patients. A significant result indicates a difference in at least one pair, not necessarily in every pair.

Table 3. Friedman test results and Kendall's W effect sizes.

Parameter	$\chi^2(3)$	p	Kendall's W	Effect Size	Result
PTV V95%	25.378	< 0.001	0.846	Large	Significant
CI	22.212	< 0.001	0.740	Large	Significant
HI	30.000	< 0.001	1.000	Large	Significant
Dmax	27.720	< 0.001	0.924	Large	Significant
Bladder V50	0.840	0.840	0.028	Very small (< 0.1)	Not significant
Small Bowel V45	5.000	0.172	0.167	Small	Not significant
MU	21.240	< 0.001	0.708	Large	Significant

Note: Effect sizes are interpreted according to Cohen's guidelines for W (0.1 = small; 0.3 = medium; 0.5 = large) [15].

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D. Post Hoc Wilcoxon Tests with Holm Correction

Table 4 presents the mean differences (the value for the second configuration minus that for the first) and Holm-adjusted p-values. For V95%, S10–S15 was not significantly different (p = 0.051), whereas the other five pairs differed significantly. For CI, only S10–S15 was not significantly different (p = 0.084). All HI and Dmax pairs differed significantly (p = 0.012). For MU, SSW differed significantly from S5, S10, and S15 (p = 0.012), whereas S5–S10, S5–S15, and S10–S15 were not significant. These findings represent inferences based on a small sample (n = 10).

Table 4. Mean differences and Holm-adjusted p-values (in parentheses) for the six configuration pairs.

Parameter	S5→S10	S5→S15	S5→SSW	S10→S15	S10→SSW	S15→SSW
PTV V95%	+6.612 (0.012)	+6.811 (0.012)	+6.847 (0.012)	+0.199 (0.051)	+0.235 (0.012)	+0.036 (0.012)
CI	+0.142 (0.027)	+0.200 (0.016)	+0.251 (0.012)	+0.058 (0.084)	+0.109 (0.012)	+0.051 (0.023)
HI	−0.088 (0.012)	−0.104 (0.012)	−0.114 (0.012)	−0.016 (0.012)	−0.026 (0.012)	−0.010 (0.012)
Dmax	−357.54 (0.012)	−437.75 (0.012)	−495.23 (0.012)	−80.21 (0.012)	−137.69 (0.012)	−57.48 (0.012)
MU	−8.8 (0.695)	−36.0 (0.059)	+118.1 (0.012)	−27.2 (0.180)	+126.9 (0.012)	+154.1 (0.012)

Note: Differences are expressed in the respective parameter units (V95% in percentage points; Dmax in cGy). Mean differences were calculated from Table 2.

E. PTV V95% Coverage and CI

Mean V95% increased from 92.635 ± 6.267% (S5) to 99.247 ± 0.961% (S10), 99.446 ± 0.627% (S15), and 99.482 ± 0.611% (SSW). The largest increase, 6.612 percentage points, occurred from S5 to S10, whereas the increase from S15 to SSW was only 0.036 percentage points. Mean CI increased from 0.701 ± 0.136 (S5) to 0.952 ± 0.023 (SSW), with S15 at 0.901 ± 0.043. The boxplots in Figure 3 show substantially greater variation in CI and V95% for S5 than for the other configurations.

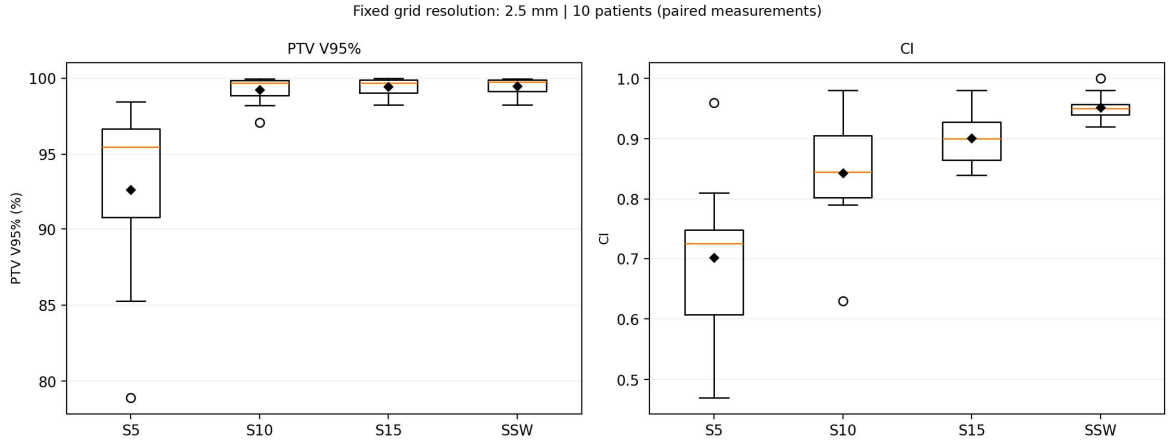


Figure 3. Individual distributions of PTV V95% and CI for S5, S10, S15, and SSW at a 2.5 mm grid resolution (n = 10 patients).

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F. Dose Homogeneity (HI) and Maximum Dose (Dmax)

HI decreased from 0.158 ± 0.054 (S5) to 0.070 ± 0.023 (S10), 0.054 ± 0.020 (S15), and 0.044 ± 0.016 (SSW). Dmax decreased from 5760.45 ± 274.33 cGy (S5) to 5265.22 ± 94.84 cGy (SSW), a reduction of 495.23 cGy or 8.60% relative to S5. Relative to the prescribed dose of 5000 cGy, the mean Dmax values were equivalent to 115.21% (S5), 108.06% (S10), 106.45% (S15), and 105.30% (SSW). Figure 4 shows narrower distributions of HI and Dmax in the configurations with higher modulation.

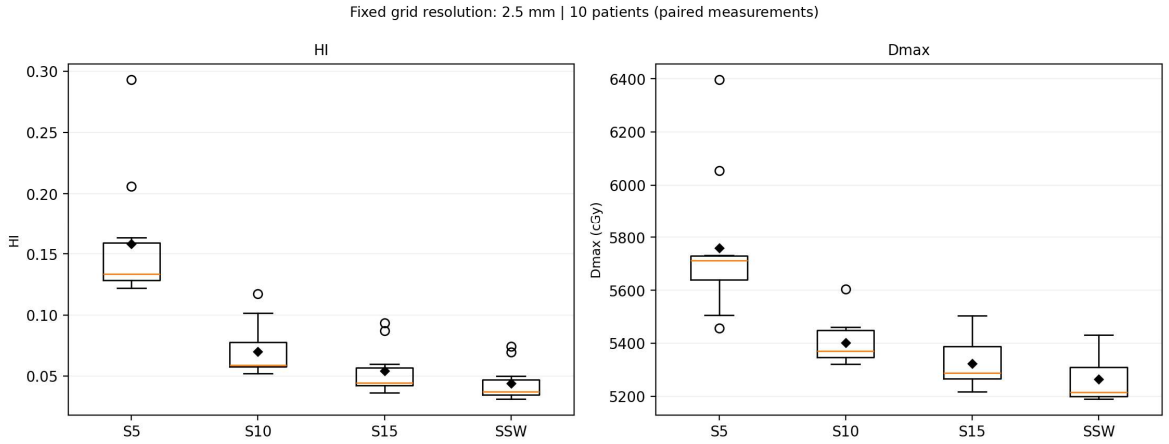


Figure 4. Individual distributions of HI and Dmax for S5, S10, S15, and SSW at a 2.5 mm grid resolution (n = 10 patients).

G. Organs at Risk: Bladder V50 and Small Bowel V45

Mean Bladder V50 values were 16.563 ± 14.199 (S5), 15.981 ± 9.504 (S10), 17.401 ± 11.371 (S15), and 16.437 ± 10.183 (SSW); the pattern was non-monotonic and the differences were not significant ($p = 0.840$; $W = 0.028$). Small Bowel V45 decreased descriptively from 53.225 ± 31.525 (S5) to 48.043 ± 32.863 (SSW), but the difference was not significant ($p = 0.172$; $W = 0.167$). The large standard deviations indicate substantial interpatient variability (Figure 5).

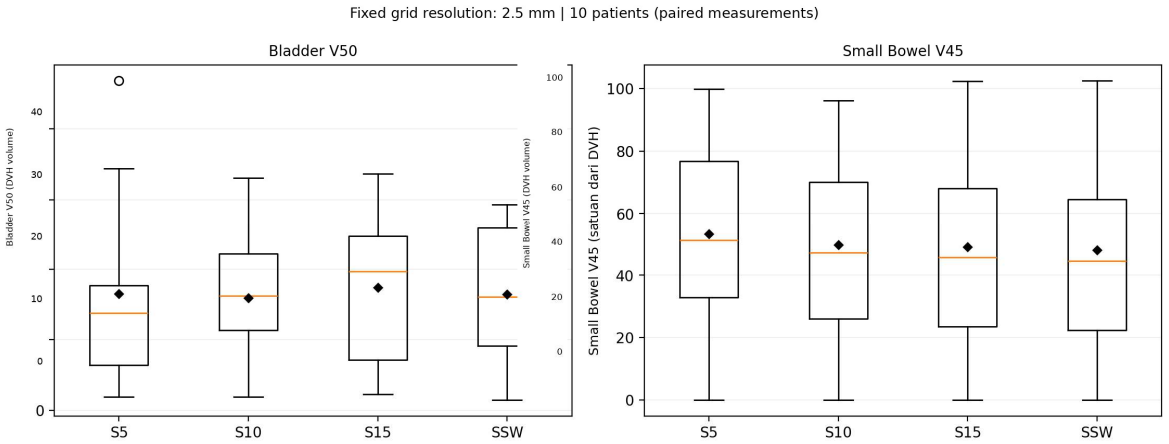


Figure 5. Individual distributions of OAR parameters for S5, S10, S15, and SSW at a 2.5 mm grid resolution (n = 10 patients).

H. Monitor Unit Requirements

Mean MU values for S5, S10, S15, and SSW were 877.60 ± 222.47, 868.80 ± 193.20, 841.60 ± 206.92, and 995.70 ± 223.11, respectively. The lowest value was observed in S15 and the highest in SSW ($\chi^2 = 21.240$; $p < 0.001$; $W = 0.708$). After

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Holm correction, SSW differed significantly from all three other configurations, whereas the three pairwise comparisons among S5, S10, and S15 were not significant. The mean difference between S15 and SSW was 154.10 MU, or 15.48% lower for S15 when SSW was used as the reference (Equation 4; Figure 6).

$$\text{Pengurangan MU (\%)} = \frac{MU_{\text{SSW}} - MU_{\text{S15}}}{MU_{\text{SSW}}} \times 100\% = 15{,}48\% \quad (4)$$

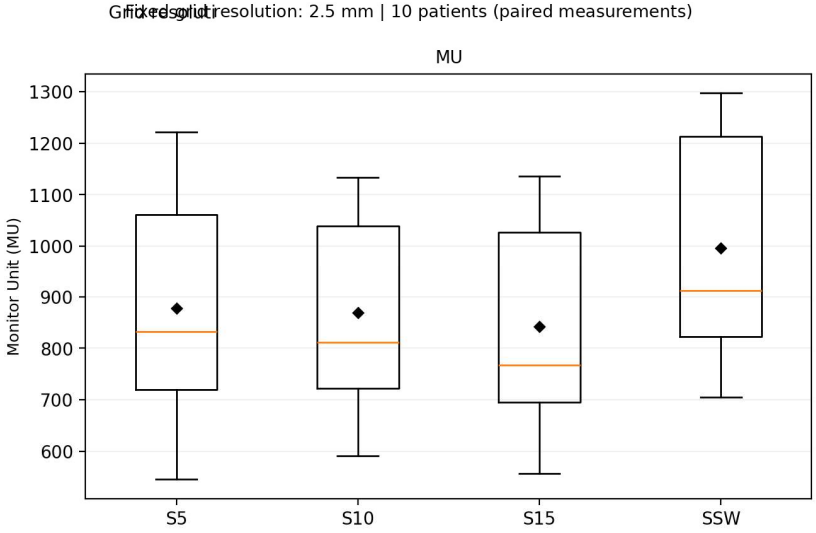


Figure 6. Individual distributions of MU for S5, S10, S15, and SSW at a 2.5 mm grid resolution (n = 10 patients).

V. DISCUSSION

A. Overview of the Main Findings

Five of the seven parameters showed statistically significant differences with large effect sizes, whereas neither of the two OAR parameters did. The greatest improvement in target quality occurred in the transition from S5 to S10, while subsequent transitions (S10 to S15 to SSW) produced progressively smaller improvements. This pattern suggests diminishing additional benefits from increased modulation, consistent with the concept that greater complexity does not necessarily correspond to improved dose quality [5].

B. Target Coverage and Conformity

The V95% difference between S15 and SSW was only 0.036 percentage points, despite being statistically significant ($p = 0.012$); therefore, the magnitude of the difference should be distinguished from its clinical significance. A similar consideration applies to CI: S10–S15 was not significantly different ($p = 0.084$), whereas S15–SSW was different ($p = 0.023$; difference = 0.051). Interpretation of CI depends on its operational definition, and numerical comparisons across studies should be made cautiously [1], [3]. Therefore, the CI definition must be confirmed before publication.

C. Dose Homogeneity and Maximum Dose

HI and Dmax improved with each increase in modulation, and all pairwise comparisons were significant. The mean Dmax for S5 was equivalent to 115.21% of the prescribed dose, compared with 105.30% for SSW. This reduction indicates better hot-spot control, but it is insufficient to conclude that all plans met clinical constraints. Another rectal-cancer study reported that HI characteristics and target dosimetry were affected by beam configuration [3], although that study varied the collimator angle rather than the number of segments.

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D. Organs at Risk

Bladder V50 and Small Bowel V45 did not differ significantly. The effect for Bladder V50 was very small (W = 0.028), whereas that for Small Bowel V45 was small (W = 0.167), with large standard deviations (approximately 32–33), indicating that interpatient variability substantially exceeded the differences among configurations. With n = 10, statistical power was limited; therefore, the absence of statistical significance does not establish equivalence or demonstrate compliance with organ dose constraints. Individual DVH evaluation remains necessary, including assessment against tolerance limits such as those in QUANTEC [8]. Patient positioning, which has been reported to affect OAR doses [2], was not investigated in this study.

E. Monitor Units and the Trade-Off in Configuration Selection

SSW provided the best target quality but required the highest MU, whereas S15 produced the lowest MU with V95% coverage close to that of SSW (Figure 7, Table 5). Compared with SSW, S15 had a V95% that was 0.036 percentage points lower, a CI that was 0.051 lower, an HI that was 0.010 higher, and a Dmax that was 57.48 cGy (1.08%) higher, while requiring 154.10 fewer MU. S15 may therefore be regarded as a potential technical compromise. The term “potential” is used because this study did not define a combined objective function or test clinical equivalence between the two configurations. Literature on MU per control point and the number of fields [4], [5] supports the importance of considering dose quality together with delivery efficiency; however, those studies were conducted in liver cancer (Monaco TPS) and brain metastases and therefore provide technical context rather than direct validation for Eclipse.

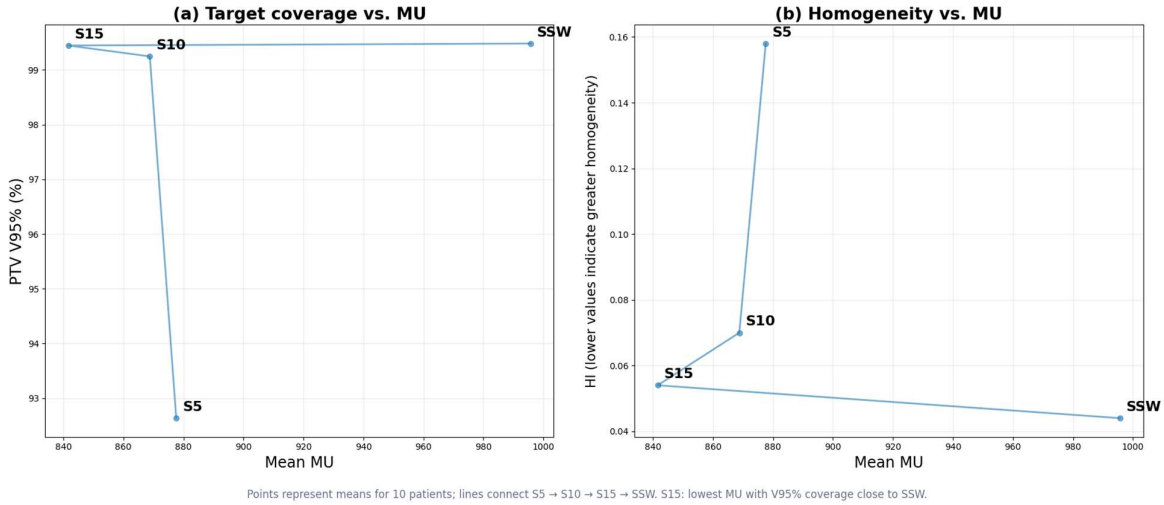


Figure 7. Relationship between mean MU and PTV V95% (a) and HI (b) across the four configurations.

Table 5. Comparison of S15 and SSW.

Parameter	S15	SSW	Difference (SSW − S15)	Holm-adjusted p
PTV V95% (%)	99.446	99.482	+0.036	0.012
CI	0.901	0.952	+0.051	0.023
HI	0.054	0.044	−0.010	0.012
Dmax (cGy)	5322.70	5265.22	−57.48 (−1.08%)	0.012
MU	841.60	995.70	+154.10 (+18.31%)	0.012

Note: Percentages are relative to S15. Compared with SSW, the MU for S15 was 15.48% lower.

F. Statistical Significance and Effect Size

The Holm-adjusted p-value of 0.012 observed for many pairwise comparisons represents the lowest value attainable in a two-sided exact Wilcoxon test with n = 10 after Holm correction for six comparisons ($2/1024 \times 6 \approx 0.012$). Consequently, p-values cannot distinguish the strength of evidence among these pairs, and the magnitude of the differences and Kendall's W are more informative. The opposite pattern was observed for OAR parameters: small effects and substantial interpatient variability resulted in nonsignificant p-values. Effect size indicates how consistently the configurations were ranked in this sample, whereas generalization requires a larger sample.

G. Clinical Implications

These findings suggest that S5 was less adequate than the other configurations in this sample, particularly because of poorer coverage, conformity, and hot-spot control, as well as greater interpatient variability. The choice between S15 and SSW represents a trade-off: SSW performed better on target indicators, whereas S15 required fewer MU. Because MU is not a measurement of treatment time and delivery time, patient-specific QA, and OAR dose-constraint compliance were not assessed, the configuration with the lowest MU cannot be declared clinically optimal. Final selection should consider deliverability and quality assurance [6].

H. Limitations, Contribution, and Recommendations

The limitations of this study include: (1) the small sample (n = 10) from a single institution and the retrospective design; (2) analysis restricted to a single grid resolution (2.5 mm); (3) SSW being a modulation mode distinct from the discrete segment limits used in S5, S10, and S15; (4) the clinical stage and individual PTV volumes not being available in the anonymized dataset; (5) the Eclipse software version, dose-calculation algorithm, LINAC model, and MLC model not being recoverable from the archived planning information; (6) the exact CI calculation requiring confirmation against the original Eclipse export and calculation worksheet; (7) the absence of patient-specific QA and treatment-time measurements; and (8) modulation complexity not being quantified. These limitations should be considered when interpreting the findings and their applicability to clinical practice.

This study provides preliminary evidence that, in rectal-cancer IMRT using Eclipse, increasing the segment limit from S5 consistently improves target quality, although the additional benefit becomes progressively smaller, and that the trade-off with MU should be considered. In addition to p-values, this study reports effect sizes and mean differences. Future studies should include larger samples, multiple grid-resolution settings, treatment-time measurements, patient-specific QA, modulation-complexity metrics [9], and an equivalence assessment of S15 relative to SSW.

VI. CONCLUSION

Evaluation of 40 IMRT plans for 10 patients with rectal cancer (Eclipse TPS, 2.5 mm grid resolution) showed that segment configuration significantly affected PTV V95%, CI, HI, Dmax, and MU ($p < 0.001$; $W = 0.708–1.000$), but not Bladder V50 ($p = 0.840$) or Small Bowel V45 ($p = 0.172$). SSW provided the best target quality (V95% = 99.482%; CI = 0.952; HI = 0.044; Dmax = 5265.22 cGy) but required the highest MU (995.70). S15 (V95% = 99.446%; CI = 0.901; HI = 0.054; Dmax = 5322.70 cGy) required 841.60 MU, or 15.48% fewer than SSW, with a V95% difference of 0.036 percentage points. Thus, S15 may be considered a potential configuration that balances dosimetric quality and MU efficiency. Determining the clinically optimal configuration still requires patient-specific evaluation of OAR dose constraints, verification of treatment-delivery quality, and consideration of the clinical relevance of the observed dosimetric differences.

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