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Impact of Segment Number on Plan Quality and Delivery Efficiency in IMRT Planning for Left-Sided Breast Cancer

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ABSTRACT

Left-sided breast cancer presents a unique challenge in radiotherapy because of the close proximity of the target volume to critical organs, particularly the heart and ipsilateral lung. Intensity-modulated radiation therapy (IMRT) improves target dose conformity while reducing radiation exposure to surrounding normal tissues. However, treatment plan quality and delivery efficiency remain influenced by optimization parameters such as segment number. This study aimed to evaluate the effect of segment number on plan quality, organ at risk (OAR) dose, and delivery efficiency in IMRT planning for left-sided breast cancer. A retrospective dosimetric study was conducted using CT simulation data from 10 patients with left-sided breast cancer. Three IMRT plans with different segment numbers (20, 30, and 40 segments) were generated for each patient using the Monaco Treatment Planning System with a Monte Carlo dose calculation algorithm while maintaining identical planning conditions. Plan quality was evaluated using V95%, V100%, Conformity Index (CI), and Homogeneity Index (HI), whereas OAR evaluation included Heart Dmean, Left Lung V20Gy, and Right Lung V5Gy. Delivery efficiency was assessed using Monitor Units (MU) and delivery time. Statistical analyses were performed using repeated-measures ANOVA or the Friedman test, followed by appropriate post hoc analyses ($p < 0.05$). Increasing the segment number significantly improved plan quality, as demonstrated by higher V95%, V100%, and CI values together with lower HI values (all $p < 0.05$). Most improvements occurred when the segment number increased from 20 to 30, whereas increasing the number to 40 provided only limited additional dosimetric benefit. No significant differences were observed in Heart Dmean, Left Lung V20Gy, Right Lung V5Gy, or MU (all $p > 0.05$), whereas delivery time increased significantly with increasing segment number ($p < 0.05$). In conclusion, increasing the segment number improves target dose coverage, conformity, and homogeneity but has limited influence on OAR sparing. A 30 segment IMRT plan provides an optimal balance between plan quality and delivery efficiency for left-sided breast cancer, whereas increasing the number of segments to 40 mainly prolongs treatment delivery without providing substantial additional dosimetric benefit.

Keywords: Breast cancer, Segment number, Treatment planning, Plan quality, Delivery efficiency

INTRODUCTION

Breast cancer is the most frequently diagnosed cancer among women worldwide and remains a major global health concern. In 2022, approximately 2.3 million new cases were reported globally. In addition to its high incidence, breast cancer is one of the leading causes of cancer-related mortality among women, accounting for approximately 6.9% of all cancer deaths [1].

Radiotherapy plays a central role in the management of breast cancer by improving local tumor control, reducing the risk of recurrence, and enhancing overall survival [2]. However, radiotherapy for left-sided breast cancer presents unique challenges because of the close anatomical proximity between the target volume and critical organs, particularly the heart and ipsilateral lung. Consequently, these organs are at risk of unintended radiation exposure, making treatment planning essential to achieve adequate target coverage while minimizing radiation-induced toxicities [3]. With the increasing survival of breast cancer patients, the goal of radiotherapy has expanded beyond tumor control to include the preservation of long-term quality of life. Therefore, minimizing radiation exposure to organs at risk (OAR) while maintaining adequate target coverage has become a key consideration in treatment planning to reduce the risk of treatment-related toxicities [4].

Intensity-Modulated Radiation Therapy (IMRT) is an advanced radiotherapy technique capable of producing highly conformal dose distributions through beam intensity modulation. Compared with conventional radiotherapy techniques, IMRT improves Planning Target Volume (PTV) coverage while reducing radiation exposure to surrounding normal tissues. These advantages have made IMRT a widely adopted technique for the treatment of breast cancer, particularly in patients with left-sided disease, where optimal sparing of critical organs is required [5].

Despite these advantages, the quality and efficiency of IMRT treatment planning remain highly dependent on optimization parameters. One important planning parameter is the segment number, which determines the complexity of beam modulation during inverse planning. Increasing the number of segments may improve target coverage, dose conformity, and dose homogeneity. However, it may also increase treatment complexity, monitor units (MU), and treatment delivery time. Therefore, selecting an appropriate segment number is essential to achieve an optimal balance between dosimetric quality and treatment delivery efficiency [6].

Previous studies have shown that segment number is an important optimization parameter in IMRT planning because it influences plan quality, dose calculation accuracy, and treatment delivery efficiency [6,7]. However, evidence regarding the combined effects of different segment numbers on plan quality, OAR sparing, and treatment delivery efficiency in IMRT planning for left-sided breast cancer remains limited. Therefore, this study aimed to evaluate the effects of different segment numbers on plan quality, OAR doses, and treatment delivery efficiency in IMRT planning for left-sided breast cancer.

MATERIALS & METHODS

Study Design and Patient Data

This retrospective dosimetric study was conducted from 1 July to 2 October 2026 at the Integrated Cancer Center (ICC) Tulip, Dr. Sardjito General Hospital. Secondary data consisting of CT simulation images from ten patients with left-sided breast cancer were included in this study. All patients had previously undergone Intensity-Modulated Radiation Therapy (IMRT) planning using 6 MV photon beams with a prescribed dose of 2 Gy per fraction for a total of 25 fractions. All patient data were anonymized prior to analysis.

Treatment Planning

Treatment planning was performed using the Monaco Treatment Planning System (TPS) version 6.1.1.0 with the Monte Carlo dose calculation algorithm. The target volumes and organ at risk (OAR) used for treatment planning were based on contours that had been verified and approved by a radiation oncologist.

For each patient, three IMRT treatment plans were generated using different segment numbers (20, 30, and 40 segments). All other planning parameters, including beam energy, prescribed dose, optimization objectives, and dose calculation settings, were kept constant to ensure that any observed differences were attributable solely to the variation in segment number.

Plan Evaluation

Treatment plans were evaluated using Dose-Volume Histograms (DVHs). Plan quality was assessed using Planning Target Volume (PTV) dosimetric parameters, including V95%, V100%, Conformity Index (CI), and Homogeneity Index (HI). Organ at risk (OAR) evaluation included the mean heart dose (Heart Dmean), left lung V20Gy, and right lung V5Gy. In addition, delivery efficiency was evaluated using Monitor Units (MU) and Delivery Time. All dosimetric parameters were evaluated according to the recommendations of ICRU Report 62 [8] and the clinical dose constraints adopted at Dr. Sardjito General Hospital.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 27. The Shapiro–Wilk test was used to assess data normality. Normally distributed data are presented as mean ± standard deviation (SD), and one-way repeated-measures analysis of variance (ANOVA) was used to compare differences among segment numbers. Data that were not normally distributed are presented as the median (interquartile range, IQR), and the Friedman test was used for comparisons among segment numbers. Pairwise comparisons were performed using the Bonferroni post hoc test for normally distributed data and the Wilcoxon signed-rank test for non-normally distributed data. A p-value < 0.05 was considered statistically significant.

RESULT

The dosimetric parameters and delivery efficiency of IMRT plans generated using 20, 30, and 40 segments are summarized in Table 1. Plan quality was evaluated using Planning Target Volume (PTV) dosimetric parameters, whereas OAR dose and delivery efficiency were assessed using the corresponding dosimetric and treatment delivery parameters. Statistical comparisons among the three segment groups are also presented.

Table 1. Comparison of plan quality and delivery efficiency by segment number.

Parameter	20 Segments	30 Segments	40 Segments	*p*-value
Plan Quality				
V95% (%)	96.34 ± 1.59	96.76 ± 1.45	97.13 ± 1.48	0.001
V100% (%)	72.94 ± 9.71	74.74 ± 8.79	77.17 ± 9.06	0.018
Conformity Index (CI)	0.963 ± 0.016	0.968 ± 0.015	0.971 ± 0.015	0.001
Homogeneity Index (HI)	0.1084 ± 0.0168	0.1047 ± 0.0171	0.1011 ± 0.0174	0.001
Organ At Risk Dose				
Heart Dmean (cGy)	1757.01 ± 288.77	1765.06 ± 290.11	1761.89 ± 296.55	0.688
Left Lung V20Gy (%)	35.11 ± 1.34	35.02 ± 1.48	35.06 ± 1.37	0.616
Right Lung V5Gy (%)	35.53 ± 5.75	34.68 ± 5.12	35.59 ± 5.05	0.405
Delivery Efficiency				
Monitor Unit (MU)	923.68 ± 104.03	931.01 ± 93.92	950.20 ± 95.01	0.144
Delivery Time (s)	366.99 (363.91 – 407.79)	453.11 (428.11– 467.84)	506.27 (461.40 – 518.49)	< 0.001

Values are presented as mean ± standard deviation for normally distributed variables and median (Q1–Q3) for non-normally distributed variables. Statistical significance was set at $p < 0.05$.

As summarized in Table 1, increasing the segment number generally improved plan quality. Significant differences were observed for V95%, V100%, CI, HI, and delivery time (all $p < 0.05$). In contrast, no significant differences were found in heart Dmean, left lung V20Gy, right lung V5Gy, or monitor units (all $p > 0.05$).

Plan Quality

The effects of segment number on plan quality were evaluated using the dose–volume histogram (DVH)-derived parameters V95%, V100%, Conformity Index (CI), and Homogeneity Index (HI). The distributions of these parameters for the 20 segment, 30 segment, and 40 segment plans are presented in Figure 1, while the statistical results are summarized in Table 1.

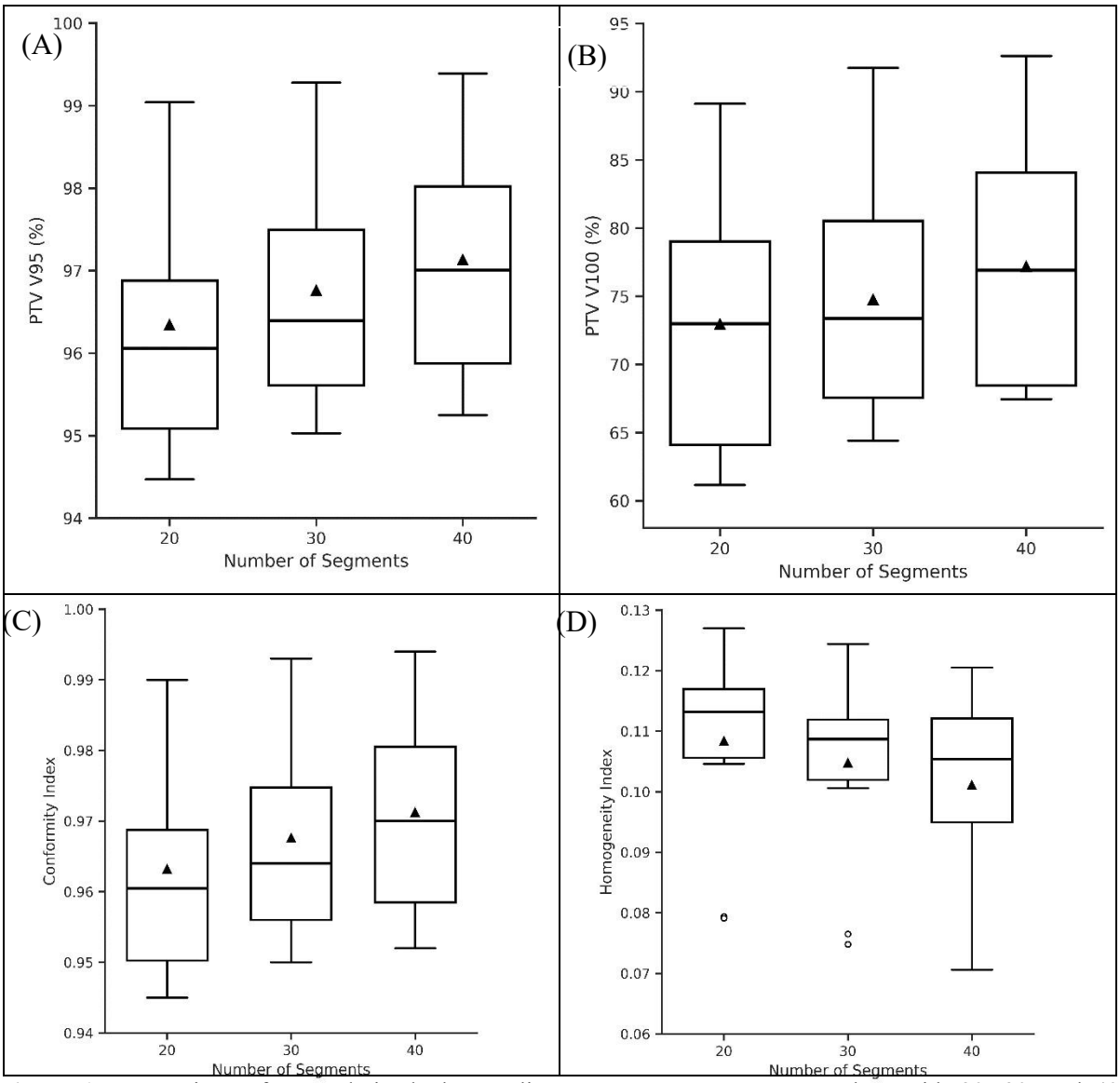


Figure 1. Comparison of DVH-derived plan quality parameters among IMRT plans with 20, 30, and 40 segments: (A) V95%, (B) V100%, (C) Conformity Index (CI), and (D) Homogeneity Index (HI). Boxplots show the median, interquartile range (IQR), mean (triangle), minimum and maximum values (whiskers), and outliers (circles).

As shown in Figure 1A, V95% exhibited an increasing trend with increasing segment number. Both the median and mean V95% values increased from the 20 segment plan to the 40 segment plan, indicating improved target coverage. Statistical analysis

demonstrated that segment number significantly affected V95%. Bonferroni post hoc analysis revealed significant differences between the 20 segment and 30 segment plans and between the 20 segment and 40 segment plans, whereas no significant difference was observed between the 30 segment and 40 segment plans.

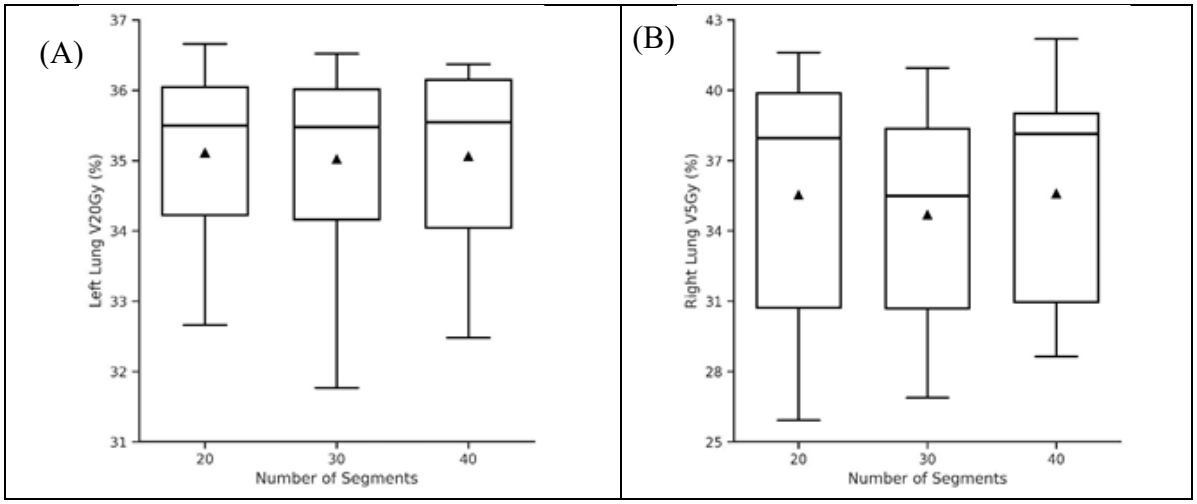
A similar trend was observed for V100% (Figure 1B), with both the median and mean values increasing as the segment number increased. All treatment plans achieved V100% values above 50%, meeting the evaluation criteria established by Dr. Sardjito General Hospital. Statistical analysis showed that segment number significantly affected V100%. However, Bonferroni post hoc analysis did not reveal significant differences among any pairwise segment comparisons.

The Conformity Index (CI) also improved with increasing segment number, as illustrated in Figure 1C. The highest median and mean CI values were observed in the 40 segment plan. Statistical analysis demonstrated a significant effect of segment number on CI. Bonferroni post hoc analysis showed significant differences between the 20 segment and 30 segment plans and between the 20 segment and 40 segment plans, whereas no significant difference was observed between the 30 segment and 40 segment plans.

Conversely, the Homogeneity Index (HI) decreased as the segment number increased (Figure 1D), which indicates improved dose homogeneity within the Planning Target Volume. The 40 segment plan exhibited the lowest median and mean HI values among the three planning configurations. Statistical analysis demonstrated that segment number significantly affected HI. Bonferroni post hoc analysis revealed significant differences between the 20 segment and 30 segment plans and between the 20 segment and 40 segment plans, whereas no significant difference was observed between the 30 segment and 40 segment plans.

Organ At Risk Dose

Organ at Risk (OAR) dosimetric analysis was performed to evaluate the ability of IMRT planning to minimize radiation exposure to surrounding healthy tissues while maintaining adequate dose coverage of the PTV. An optimal treatment plan should not only provide sufficient target dose coverage but also keep OAR doses below clinically accepted tolerance limits to reduce the risk of radiation-induced toxicity [9]. OAR evaluation was performed using Dose-Volume Histogram (DVH) based parameters selected according to the clinical dose constraints for each organ [10]. The evaluated parameters included Heart Dmean, Left Lung V20Gy, and Right Lung V5Gy. The distributions of these OAR dosimetric parameters across the three segment configurations are presented in Figure 2.



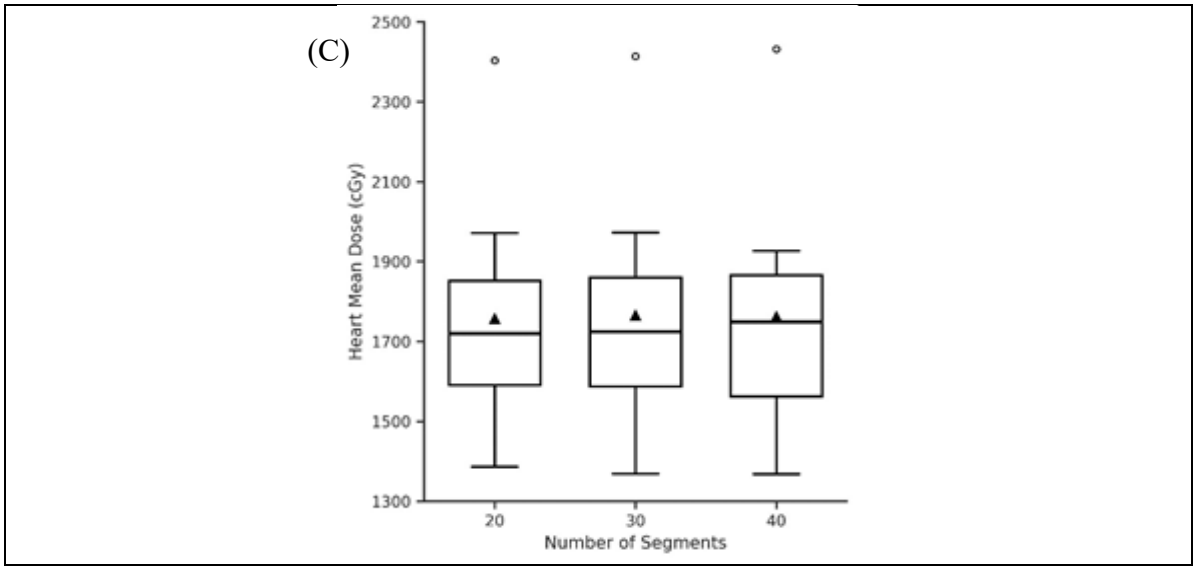


Figure 2. Comparison of DVH-derived OAR dosimetric parameters among IMRT plans with 20, 30, and 40 segments: (A) Left Lung V20Gy, (B) Right Lung V5Gy, and (C) Heart Mean Dose. Boxplots show the median, interquartile range (IQR), mean (triangle), minimum and maximum values (whiskers), and outliers (circles).

The left lung is the ipsilateral OAR in left-sided breast radiotherapy and is therefore more likely to receive a higher radiation dose than surrounding healthy tissues. The V20Gy parameter represents the percentage of the left lung receiving at least 20 Gy and is commonly used to evaluate lung dose exposure [11]. In this study, all treatment plans satisfied the institutional dose constraint adopted at Dr. Sardjito General Hospital, with Left Lung V20Gy values below 37%, ranging from 31.77% to 36.66%. As shown in Figure 2A, the Left Lung V20Gy values were comparable among the 20, 30, and 40 segment plans. Both the median and mean values showed only slight variations, with no consistent trend as the segment number increased. As summarized in Table 1, the segment number did not significantly affect Left Lung V20Gy, indicating that increasing the segment number from 20 to 40 did not produce a statistically significant change in the volume of the left lung receiving 20 Gy or more.

In addition to the ipsilateral lung, low-dose irradiation to the contralateral lung was evaluated using the Right Lung V5Gy parameter. This parameter represents the percentage of the right lung receiving at least 5 Gy and is commonly used to assess low-dose exposure to the contralateral lung [11]. In this study, Right Lung V5Gy values ranged from 25.92% to 42.18%. Most treatment plans satisfied the institutional dose constraint adopted at Dr. Sardjito General Hospital (Right Lung V5Gy < 42%), although one 40 segment plan slightly exceeded this limit (42.18%). As shown in Figure 2B, the Right Lung V5Gy values were comparable among the 20, 30, and 40 segment plans. Both the median and mean values showed only slight variations, with no consistent trend as the segment number increased. As summarized in Table 1, the segment number did not significantly affect Right Lung V5Gy, indicating that increasing the segment number from 20 to 40 did not produce a statistically significant change in the volume of the right lung receiving 5 Gy or more.

In addition to lung dose, cardiac dose was also evaluated because the heart is one of the primary OAR in left-sided breast radiotherapy. Heart Dmean represents the mean radiation dose delivered to the entire heart and is widely used to evaluate cardiac dose exposure [11]. In this study, Heart Dmean values ranged from 1367.80 to 2432.30 cGy. All treatment plans satisfied the institutional dose constraint adopted at Dr. Sardjito General Hospital (Heart Dmean

< 2600 cGy). As shown in Figure 2C, the Heart Dmean values were comparable among the 20, 30, and 40 segment plans. Both the median and mean values showed only slight variations, with no consistent trend as the segment number increased. As summarized in Table 1, segment number did not significantly affect Heart Dmean, indicating that increasing the segment number from 20 to 40 did not produce a statistically significant change in the mean dose delivered to the heart.

Delivery Efficiency

Following the evaluation of plan quality and OAR dose, treatment delivery efficiency was assessed using Monitor Units (MU) and delivery time. MU represents the amount of radiation output required to deliver the prescribed dose, whereas delivery time represents the time required to complete treatment delivery. Previous studies have reported a strong positive correlation between MU and delivery time, indicating that higher MU values are generally associated with longer treatment delivery times [12]. The distribution of MU and delivery time across the 20, 30, and 40 segment plans is presented in Figure 3.

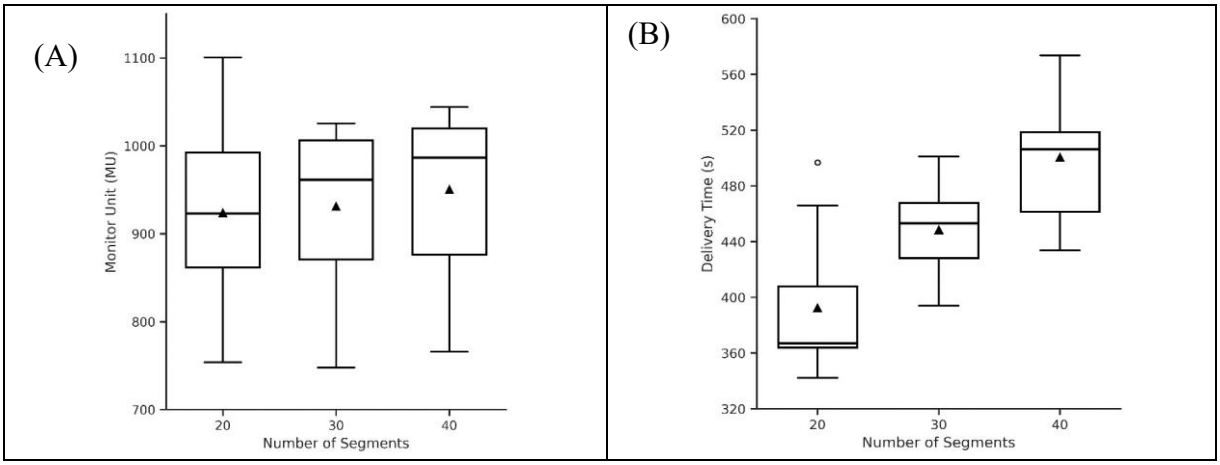


Figure 3. Comparison of treatment delivery efficiency among IMRT plans with 20, 30, and 40 segments: (A) Monitor Units (MU) and (B) delivery time. Boxplots show the median, interquartile range (IQR), mean (triangle), minimum and maximum values (whiskers), and outliers (circles).

Monitor Units (MU) represent the amount of radiation output required from the linear accelerator to deliver the prescribed dose [12]. In this study, MU values ranged from 747.95 to 1100.68. As shown in Figure 3A, MU exhibited a slight increasing trend with increasing segment number, with the highest median and mean values observed in the 40 segment plan. However, the differences in MU distribution among the three planning configurations were relatively small. As summarized in Table 1, segment number did not significantly affect MU. These results indicate that increasing the segment number from 20 to 40 did not result in a statistically significant increase in the MU required for treatment delivery, although a slight increase in MU was observed as the segment number increased.

In addition to MU, treatment delivery efficiency was also evaluated using delivery time, which represents the time required to deliver the prescribed radiation dose during a single treatment fraction, measured from beam-on to beam-off [13]. In this study, delivery time ranged from 342.24 to 573.72 s. As shown in Figure 3B, delivery time increased as the segment number increased, with the highest median and mean values observed in the 40 segment plan. Statistical analysis summarized in Table 1 demonstrated that segment number had a significant effect on delivery time. These results indicate that increasing the segment

number from 20 to 30 and 40 significantly prolonged treatment delivery time.

DISCUSSION

Effect of Segment Number on Plan Quality

The present study demonstrated that increasing the segment number generally improved treatment plan quality. This improvement can be explained by the characteristics of Intensity-Modulated Radiation Therapy (IMRT), an inverse planning technique that employs beam intensity modulation through a multileaf collimator (MLC) to produce highly conformal dose distributions to the Planning Target Volume (PTV) while minimizing radiation exposure to surrounding normal tissues [14]. Increasing the number of segments provides greater flexibility for the Treatment Planning System (TPS) to optimize fluence distribution and MLC movement, enabling the dose distribution to conform more accurately to the PTV and thereby improving target coverage, dose conformity, and dose homogeneity [6,15].

Despite the overall improvement in plan quality, the dosimetric benefit was not proportional to the increase in segment number. The greatest improvement was observed when the segment number increased from 20 to 30, whereas increasing the segment number from 30 to 40 provided only marginal additional benefit. This finding suggests that once an adequate level of beam modulation has been achieved, the ability of the TPS to further optimize dose distribution becomes increasingly limited. In other words, the optimization process approaches a plateau, and additional segments contribute only minimal dosimetric improvement.

These findings are consistent with previous studies reporting that increasing the number of segments enhances beam modulation capability, resulting in improved target coverage and dose conformity. However, once a sufficient level of beam modulation has been achieved, further increases in segment number provide only limited dosimetric benefit while increasing treatment plan complexity [6]. Previous studies have also demonstrated that dose homogeneity within the PTV is influenced by the number of segments, with the greatest improvement occurring during the initial increase in segment number, whereas additional segmentation beyond an optimal threshold yields only minimal gains in overall plan quality [15].

From a clinical perspective, these findings suggest that using a larger number of segments does not necessarily provide a proportional improvement in treatment plan quality. Although the 40 segment plans exhibited slightly better dosimetric performance than the 30 segment plans, the additional benefit was relatively small when compared with the increased complexity of treatment planning and delivery. Therefore, the use of approximately 30 segments may represent a more appropriate balance between plan quality and treatment complexity for IMRT planning in left-sided breast cancer.

Effect of Segment Number on Organ at Risk Dose

The present study demonstrated that increasing the segment number from 20 to 40 did not significantly influence the dose delivered to the organs at risk, including the left lung, right lung, and heart. These findings indicate that increasing the number of segments provides only limited benefit for improving normal tissue sparing in IMRT planning for left-sided breast cancer.

The absence of a significant reduction in Left Lung V20Gy suggests that increasing the segment number does not substantially improve ipsilateral lung sparing. Although additional segments provide greater flexibility during fluence optimization, the dose delivered to the left lung remains largely determined by the beam geometry relative to the target volume. Consequently, once a treatment plan satisfies the clinical dose constraints, further increasing the number of segments produces only minimal changes in the volume of the left lung

receiving high-dose radiation. This finding is consistent with previous studies reporting that lung dose is influenced primarily by beam geometry, whereas increasing the number of segments provides only limited benefit for lung sparing [6].

A similar pattern was observed for the right lung. The lack of significant changes in Right Lung V5Gy indicates that increasing the segment number has little influence on reducing low-dose irradiation to the contralateral lung. This finding suggests that dose spread to the right lung is governed mainly by beam arrangement and treatment geometry rather than by the number of segments. Therefore, additional beam segmentation does not result in a meaningful reduction in the dose delivered to the contralateral lung. This observation is also consistent with previous studies demonstrating that increasing the number of segments provides only limited benefit for contralateral lung sparing [6].

A comparable result was observed for Heart Dmean. Although IMRT is capable of producing highly conformal dose distributions, increasing the segment number did not result in a meaningful reduction in the mean heart dose. This finding suggests that cardiac sparing depends primarily on beam geometry and optimization strategies during the inverse planning process rather than on the number of beam segments. Once the desired cardiac dose constraints have been achieved, additional segmentation produces only minimal changes in the mean heart dose. This finding is consistent with previous reports showing that increasing the number of segments has only a limited impact on reducing the mean heart dose [6].

Effect of Segment Number on Delivery Efficiency

The present study demonstrated that increasing the segment number had different effects on the two delivery efficiency parameters. While the number of segments did not significantly influence MU, it significantly increased delivery time. These findings indicate that increasing the number of segments has only a limited impact on the radiation output required for treatment delivery but directly affects the time needed to complete treatment.

The absence of a significant increase in MU suggests that increasing the number of segments does not necessarily require substantially greater radiation output from the linear accelerator. Although additional segments provide greater flexibility for beam modulation, the optimization process is able to improve dose distribution without markedly increasing the total MU. Consequently, increasing the segment number within the investigated range has only a limited effect on MU requirements. This finding is consistent with previous studies reporting that increasing the number of segments can improve dose distribution without substantially increasing plan MU [6].

In contrast, Delivery Time increased as the number of segments increased. This finding indicates that treatment delivery efficiency is influenced not only by the total radiation output but also by the complexity of treatment delivery. A larger number of beam segments requires the linear accelerator to execute more individual irradiation segments during each treatment fraction, thereby extending the beam-on and overall treatment delivery time. This observation is consistent with previous studies reporting that reducing the number of segments significantly decreases planning treatment delivery time, whereas increasing the number of segments tends to prolong treatment delivery [16].

These findings also support previous reports describing the positive relationship between MU and delivery time, although the present study suggests that delivery time is more sensitive to increases in segment number than MU. Therefore, increasing the number of segments mainly affects treatment delivery efficiency by prolonging treatment time rather than by substantially increasing the radiation output required for dose delivery [12,16].

CONCLUSION

This study evaluated the effect of segment number on plan quality, organ at risk (OAR) dose, and delivery efficiency in IMRT planning for left-sided breast cancer. Increasing the segment number improved plan quality, as demonstrated by higher V95%, V100%, and Conformity Index (CI) values together with lower Homogeneity Index (HI) values. However, most of these improvements were achieved when the segment number increased from 20 to 30, while further increasing the number of segments to 40 provided only limited additional dosimetric benefit.

In contrast, the segment number did not significantly influence the doses delivered to the left lung, right lung, or heart, indicating that increasing the number of segments alone has a limited effect on OAR sparing. Regarding treatment delivery efficiency, segment number did not significantly affect Monitor Units (MU), although delivery time increased significantly as the number of segments increased.

Overall, the findings suggest that a 30 segment IMRT plan provides a favorable balance between target dose coverage, dose conformity, dose homogeneity, and treatment delivery efficiency. Increasing the segment number beyond 30 increases treatment delivery time without providing substantial improvements in plan quality or OAR dose. Therefore, the use of approximately 30 segments may be considered an optimal planning strategy for IMRT in patients with left-sided breast cancer.

Declaration by Authors

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