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Dosimetric Impact of Multileaf Collimator Versus Dynamic Wedges in 3D Conformal Radiotherapy for Left-Sided Breast and Chest Wall Irradiation: A Retrospective Pilot Study

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Abstract **Original Research Article**

Dose homogeneity and organ-at-risk (OAR) sparing are essential objectives in breast radiotherapy. Conventional tangential irradiation using dynamic wedges may result in dose inhomogeneity with potential hot spots within the planning target volume (PTV). This study aimed to compare multileaf collimator (MLC)-based conformal planning with conventional dynamic wedge-based techniques in terms of PTV dose homogeneity, target coverage, and OAR doses in both breast and chest wall irradiation. Ten cases (five breast in situ and five chest wall) were retrospectively replanned using both techniques. Dosimetric parameters evaluated included homogeneity index (HI), conformity index (CI), mean heart dose (Dmean), and ipsilateral lung dose-volume parameters (V13, V20, and V30). Median values and interquartile ranges were analyzed, and comparisons between techniques were performed. In breast irradiation, MLC-based planning demonstrated improved PTV dose homogeneity compared to wedge-based techniques, with comparable conformity index and no significant differences in mean heart or ipsilateral lung doses. In chest wall irradiation, MLC-based planning did not show a clear dosimetric advantage over conventional wedge-based techniques, with similar PTV coverage and OAR dose distributions observed between both approaches. Overall, MLC-based conformal planning appears to improve dose homogeneity in breast irradiation while maintaining equivalent target coverage and OAR sparing. However, no consistent benefit was observed in chest wall irradiation, suggesting that the dosimetric advantage of MLC-based planning may be site-dependent.

Keywords: Breast radiotherapy - chest wall irradiation - multileaf collimator - dynamic wedge – dosimetric comparison - dose homogeneity - planning target volume.

INTRODUCTION

Breast cancer is the most commonly diagnosed malignancy among women worldwide, with approximately 2.3 million new cases reported in 2022 [IARC, 2022]. Postoperative radiotherapy, either after breast-conserving surgery or following mastectomy in selected high-risk patients, significantly reduces locoregional recurrence and improves breast cancer–specific survival [EBCTCG, 2011, EBCTCG, 2014].

Tangential photon beam irradiation is the standard approach to control subclinical disease following conservative surgery [EBCTCG, 2000]. However, conventional techniques often result in dose inhomogeneity due to irregular breast contours and potential tissue loss after surgery. Several studies have reported dose variations of 15–27% within the irradiated volume [Buchholz TA *et al*, Onal C *et al*].

Physical or dynamic wedges are commonly applied to correct for entrance obliquities. In conventional 3D-CRT for breast cancer, most commonly, either physical or dynamic wedges are used in two tangential fields to achieve optimal three-dimensional dose distribution within the minimal degree of dose inhomogeneity through forward treatment planning. In conventional method of planning, despite all planning efforts, there are about 10% increased dose hot spots encountered in final plans [Murthy KK *et al*].

Advanced techniques such as intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) have been developed to improve dose conformity and homogeneity while reducing the radiation dose to adjacent organs at risk [Haciislamoglu E *et al*, Nicolini G *et al*]. However, three-dimensional conformal radiotherapy (3D-CRT) remains widely used in many institutions due to its accessibility, technical simplicity, and reproducibility [Praveen, 2024]. This widespread use highlights the clinical relevance of optimizing 3D-CRT parameters to improve dose conformity and homogeneity within the PTV without increasing the dose to the heart or ipsilateral lung in both whole-breast and chest wall irradiation.

Among 3D-CRT techniques, strategies such as using multileaf collimators (MLCs) instead of physical wedges may improve dose homogeneity and planning target volume (PTV) coverage while potentially sparing cardiac structures [Murthy KK].

The aim of this retrospective pilot dosimetric study was to compare wedge-based and MLC-based 3D-CRT plans in patients with left-sided whole-breast and chest wall irradiation, assessing their impact on PTV coverage, cardiac dose, and ipsilateral lung dose.

MATERIALS AND METHODS

Patients:

This planning study included 10 female patients with left-sided breast invasive ductal carcinoma not otherwise specified (NOS) who had an indication for adjuvant radiotherapy to the whole breast or chest wall at the Onco-Radiotherapy Department of the University Hospital of Marrakesh. All patients had previously undergone breast-conserving surgery or mastectomy. Patients who had previously undergone mastectomy or breast augmentation of the ipsilateral or contralateral breast, as well as those with an indication for boost, lymph node metastasis, or distant metastasis, were excluded from this study.

All patients underwent CT simulation. During CT scanning, patients were positioned supine with the left arm raised above the head using elbow support. CT data were acquired with 5-mm adjacent axial slice spacing, covering the entire thorax, under normal free-breathing conditions.

Target volumes and OAR:

Clinical target volume (CTV), PTV and organs at risk (OAR), which were heart, ipsilateral lung, contralateral lung and contralateral breast, were contoured by the author from the CT simulation images (Figure 1). The definition of the CTV boundaries was based on the European Society for Radiotherapy and Oncology (ESTRO) guidelines [ESTRO, 2015]. Lung volume was contoured using the treatment planning system density-seeking tool with manual exclusion of the hilum, trachea, pulmonary vessels and aortic branches. The heart was contoured manually according to standard anatomical definitions.

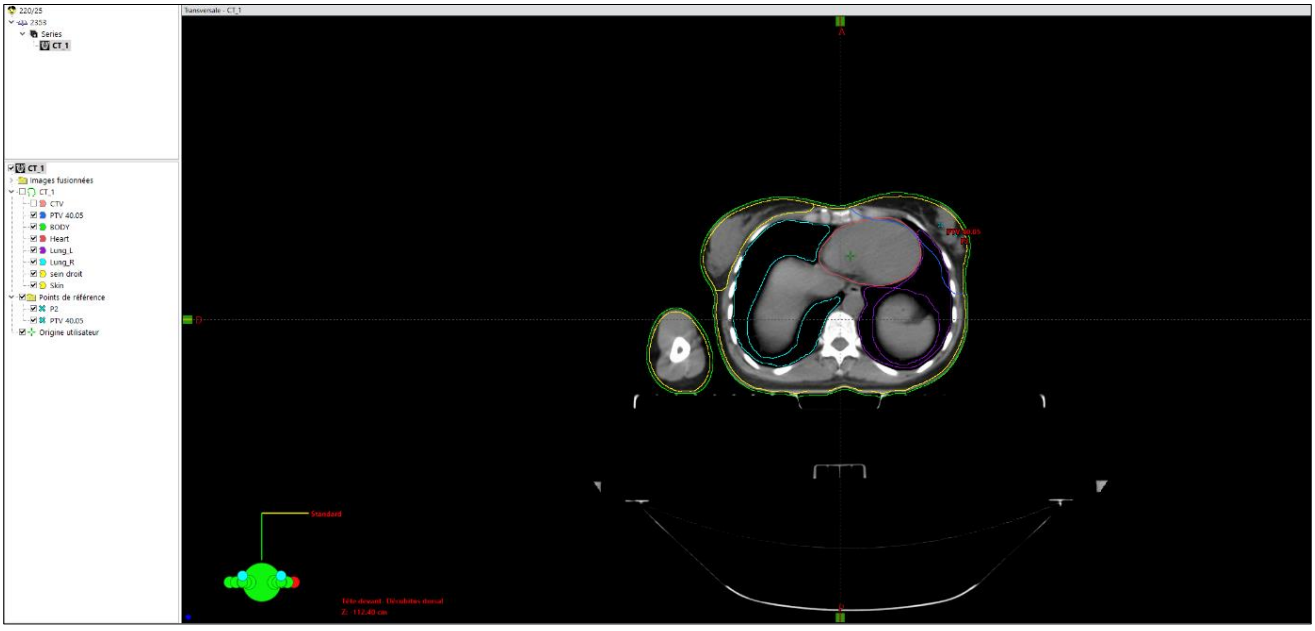

Figure 1: Target volumes and organs at risk for whole left breast irradiation; PTV (blue line), contralateral breast (yellow line), left lung (purple line), right lung (turquoise line), heart (orange contour)

Irradiation techniques, dose prescription and calculation:

Each patient was replanned using 3D-CRT. The prescribed total dose was 40.05 Gy in 15 fractions, delivered with 6–18 MV photon beams, and prescribed to the PTV. All treatment plans were generated using the Eclipse Treatment Planning System (version 18.1; Varian Medical Systems, Palo Alto, CA, USA), with heterogeneity correction applied. Treatments were delivered using the TrueBeam linear accelerator (Varian

Medical Systems), a recently installed system in our department, operational since February 2026.

For each patient, two 3D-CRT plans were generated and compared. All plans consisted of two tangential fields, with the posterior borders of the medial and lateral fields aligned to avoid beam divergence. The optimal wedge angles and MLCs were selected based on the calculated dose distribution according to standard protocol.

In the first plan, a conventional tangential technique using dynamic wedge filters was applied to improve dose homogeneity. In the second plan, an MLC-based conformal technique was used (Figure 2).

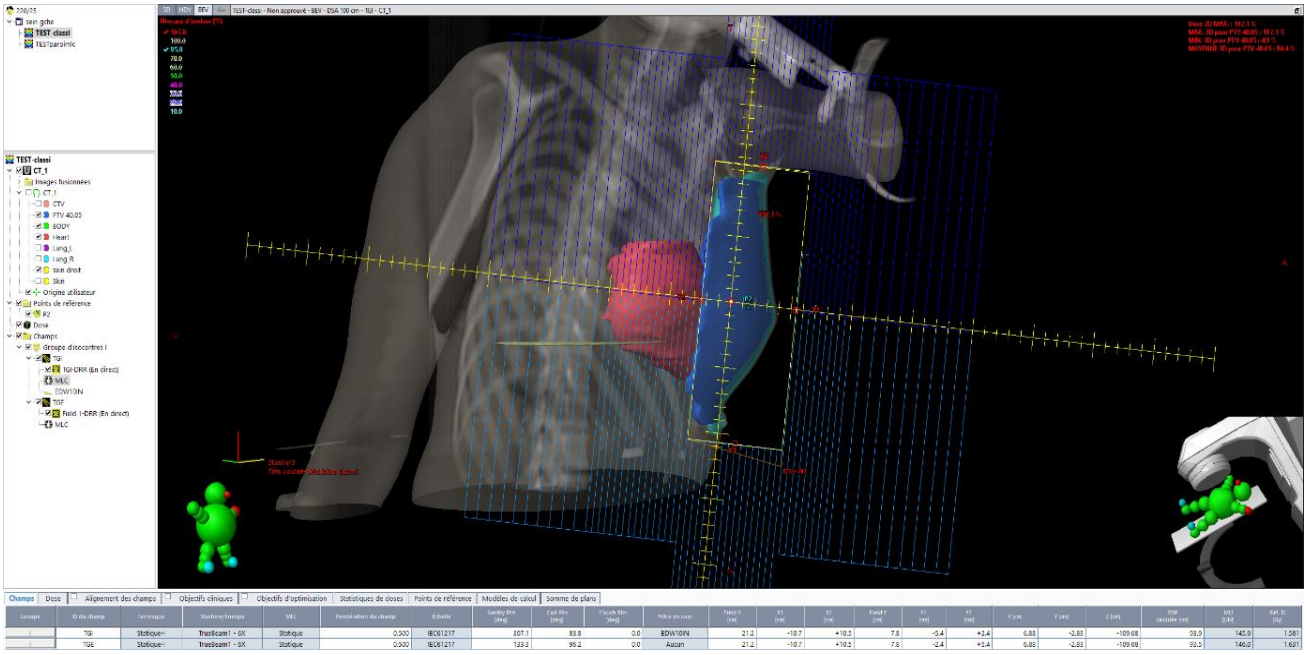

Figure 2: 3D conformal radiotherapy (3D-CRT) plan for left breast irradiation using dynamic wedge filters, showing PTV coverage (blue)

In the MLC-based plans, beam shaping was performed using the multileaf collimator to better conform the dose to the PTV. This approach aimed to improve dose conformity and homogeneity within the PTV, while ensuring adequate sparing of organs at risk, particularly the heart and ipsilateral lung (Figure 3).

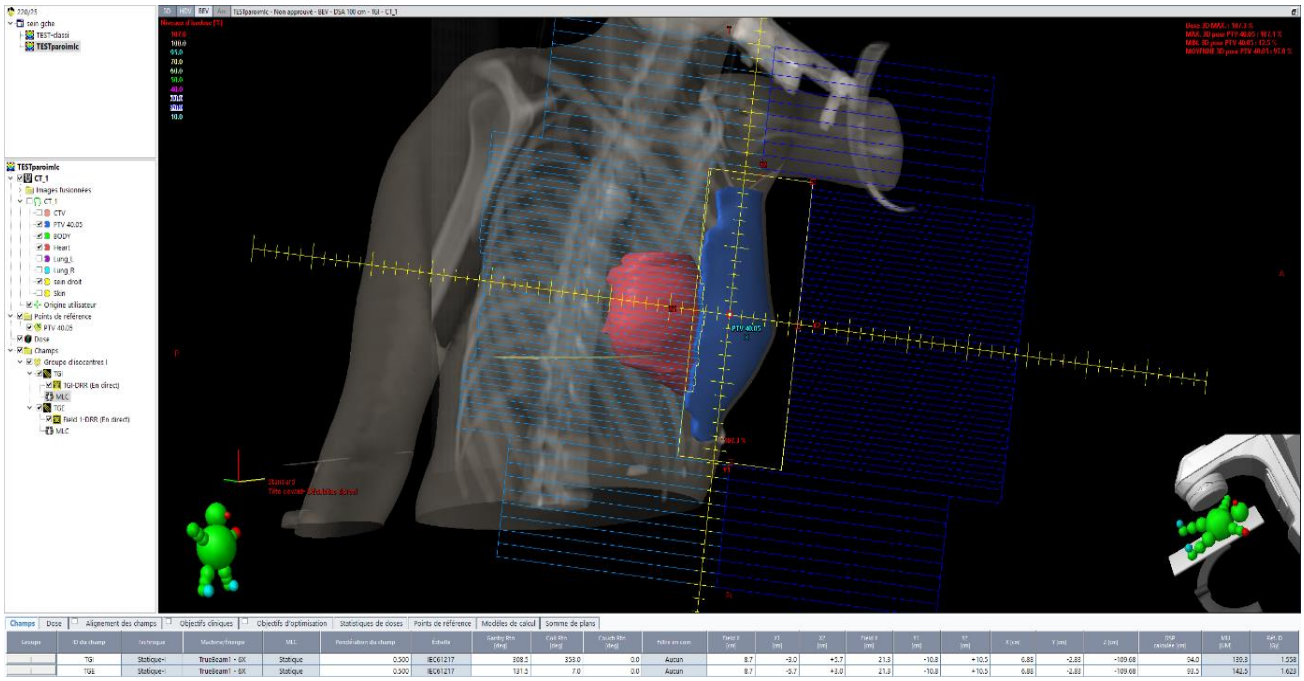

Figure 3: 3D conformal radiotherapy (3D-CRT) plan for left breast irradiation using MLC, showing PTV coverage (blue)

Beam and collimator orientations were individually optimized for each plan. In some cases, minor field adjustments were performed when necessary to better adapt to patient anatomy.

Dose calculations were performed using the anisotropic analytical algorithm (AAA) with heterogeneity correction for all plans. The following dosimetric parameters were extracted for comparison: PTV coverage (D95% and D107%), mean heart dose (Dmean), and ipsilateral lung dose-volume parameters (V13, V20, and V30).

Dosimetric parameters and outcomes:

Primary outcome: Homogeneity Index (HI) of the PTV, calculated as:

HI = (Dose Max – Dose Min) / Dose mean in PTV

A lower HI indicates greater 3D dose homogeneity within the PTV.

Secondary outcomes: Conformity index (CI), mean heart dose (Dmean), lung V13, V20, and V30 doses in ipsilateral lung.

Statistical analysis:

Statistical analysis was performed using paired comparisons between wedge-based and MLC-based plans. Continuous variables were expressed as median and interquartile range (IQR). The Wilcoxon signed-rank test was used to compare dosimetric parameters between the two techniques. A p-value < 0.05 was considered statistically significant.

RESULTS

In patients treated for left-sided breast irradiation, dosimetric comparison between wedge-based and MLC-based 3D conformal radiotherapy plans showed mixed results regarding target coverage and organ at risk sparing:

Target coverage:

The HI was significantly improved with MLC-based planning compared to wedge-based technique. HI decreased from 1.02 (0.98–1.10) with wedges to 0.97 (0.79–1.05) with MLC ($p = 0.043$), indicating a statistically significant improvement in dose homogeneity within the PTV.

In contrast, the CI showed no statistically significant difference between the two techniques, with values of 0.52 (0.44–0.74) for wedges and 0.71 (0.44–0.75) for MLC ($p = 0.27$).

These results are further illustrated in Figure 4, with representative isodose distributions for (A) the conventional wedged-field technique and (B) the MLC-based planning approach.

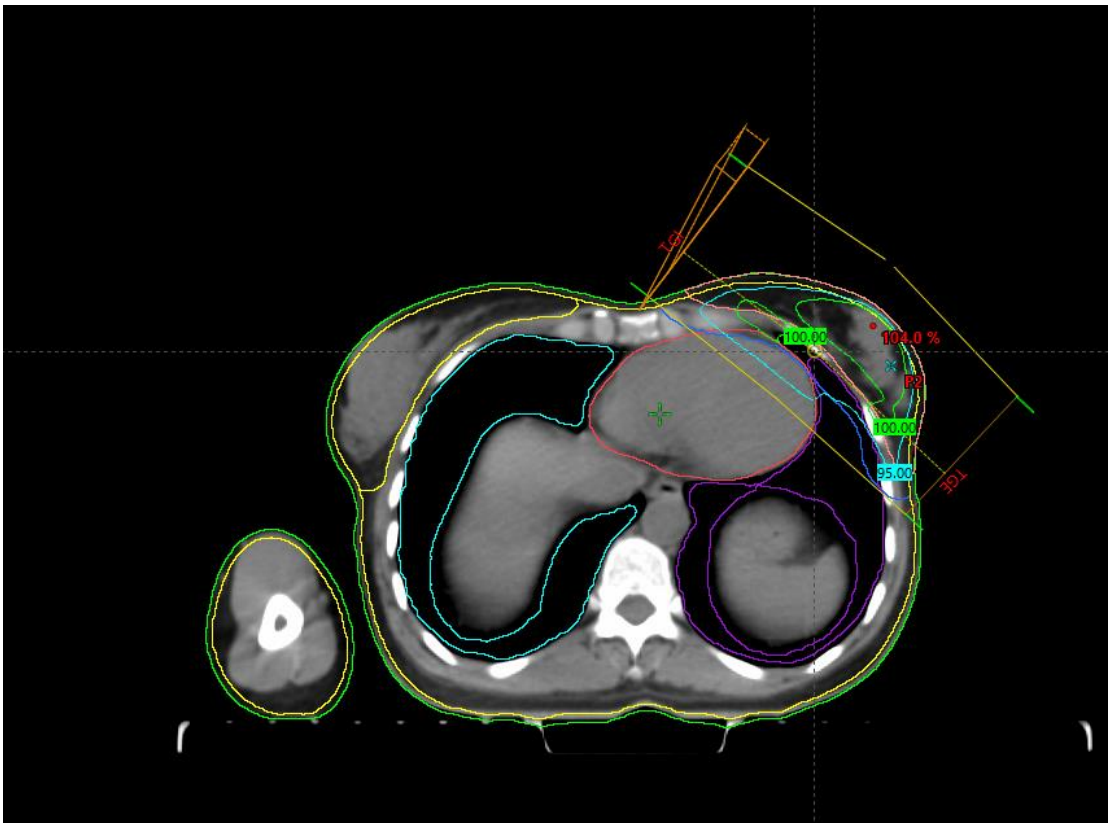

Fig 4A.

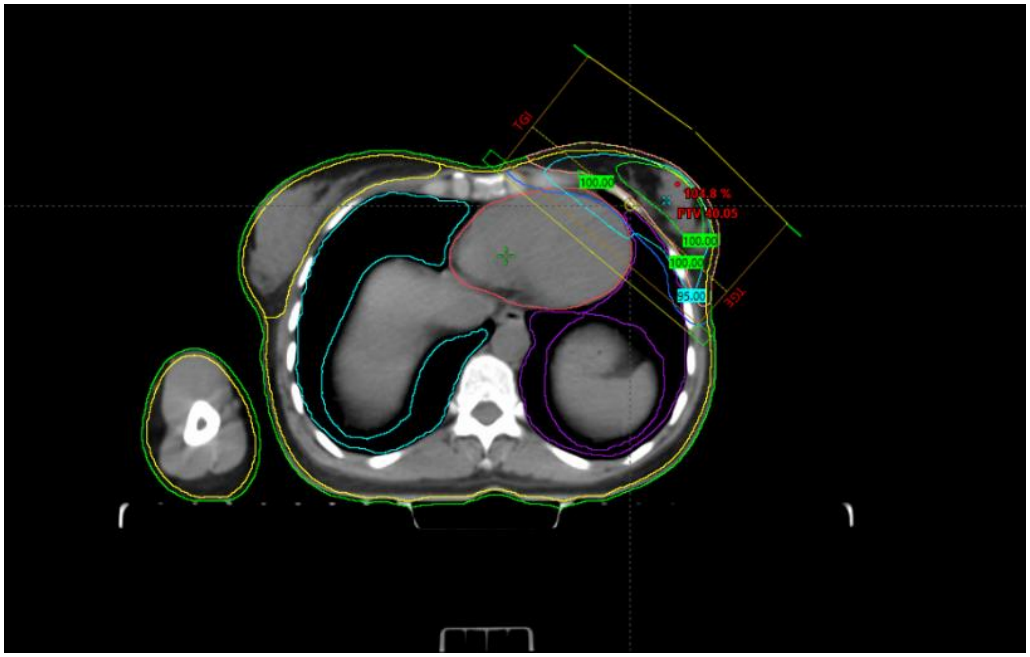

Fig 4B.

Figure 4: Representative isodose distributions for target coverage: (A) conventional wedge-based 3D-CRT technique and (B) MLC-based 3D-CRT technique

Cardiac dose:

The Dmean was slightly lower with MLC planning, although the difference was not statistically significant.

Dmean heart was 4.90 (4.66–4.97) Gy for wedges versus 4.83 (4.70–4.89) Gy for MLC (p = 0.71).

Ipsilateral lung doses:

No significant differences were observed in lung dose parameters between the two techniques: V13 lung: 29.2 (15.1–34.0) % vs 27.4 (15.45–42.0) %, p = 0.50. V20 lung: 22.8 (12.85–25.95) % vs 22.5 (13.25–36.25) %, p = 0.50. V30 lung: 17.2 (11.53–22.85) % vs 19.5 (11.86–32.25) %, p = 0.50

Overall, MLC-based planning demonstrated a significant improvement in PTV dose homogeneity, while no statistically significant differences were observed for CI, Dmean heart, or lung dose parameters (Table 1)

Table 1: Dosimetric comparison between wedge and MLC plans for breast irradiation

Outcomes	Wedge technique	MLC technique	P value
Mean HI	1.02 (0.98–1.10)	0.97 (0.79–1.05)	0.043
Mean CI	0.52 (0.44–0.74)	0.71 (0.44–0.75)	0.27
Mean heart dose (Gy)	4.90 (4.66–4.97)	4.83 (4.70–4.89)	0.71
Mean left lung V13 %	29.2 (15.1–34.0)	27.4 (15.45–42.0)	0.5
Mean left lung V20 %	22.8 (12.85–25.95)	22.5 (13.25–36.25)	0.5
Mean left lung V30 %	17.2 (11.53–22.85)	19.5 (11.86–32.25)	0.5

In patients treated for left-sided chest wall irradiation, dosimetric parameters of wedge-based and MLC-based 3D conformal radiotherapy plans were compared:

Target coverage:

The HI showed no significant difference between the two techniques: HI was 0.84 (0.77–0.96) with wedge-based planning versus 0.78 (0.70–1.11) with MLC-based planning (p = 0.50)

Similarly, the CI was not significantly different between the two approaches, with values of 0.64 (0.61–0.72) for wedges and 0.77 (0.63–0.86) for MLC (p = 0.26).

These results are further illustrated in Figure 4, with representative isodose distributions for (A) the conventional wedged-field technique and (B) the MLC-based planning approach.

Cardiac dose:

The Dmean was lower with MLC-based planning compared to wedge-based planning, although this difference did not reach statistical significance. Dmean heart was 7.14 (4.21–10.12) Gy for wedges versus 4.88 (4.69–4.94) Gy for MLC (p = 0.22).

Ipsilateral lung doses:

No statistically significant differences were observed in lung dose parameters between the two techniques: V13 lung: 31.2 (28.15–36.35) % vs 30.3 (28.6–37.85) %, p = 0.68. V20 lung: 27.8 (25.1–31.75) % vs 27.0 (25.5–33.4) %, p = 0.68. V30 lung: 25.5 (23.15–28.85) % vs 24.9 (23.35–30.75) %, p = 0.68

Overall, MLC-based planning showed a trend toward reduced heart dose, while maintaining comparable target coverage and lung dose parameters compared to wedge-based planning. However, none of the differences reached statistical significance (Table 2).

Table 2: Dosimetric comparison between wedge and MLC plans for chest wall irradiation

Outcomes	Wedge technique	MLC technique	P value
Mean HI	0.84 (0.77–0.96)	0.78 (0.70–1.11)	0.5
Mean CI	0.64 (0.61–0.72)	0.77 (0.63–0.86)	0.26
Mean heart dose	7.14 (4.21–10.12)	4.88 (4.69–4.94)	0.22
Mean left lung V13 %	31.2 (28.15–36.35)	30.3 (28.6–37.85)	0.68
Mean left lung V20 %	27.8 (25.1–31.75)	27 (25.5–33.4)	0.68
Mean left lung V30 %	25.5 (23.15–28.85)	24.9 (23.35–30.75)	0.68

DISCUSSION

Our findings suggest that in breast irradiation, MLC-based conformal planning may improve PTV dose homogeneity compared to conventional dynamic wedge-based techniques, while maintaining comparable target coverage and OAR doses. This finding suggests that the use of MLC-based forward planning allows better modulation of beam conformation, leading to a more uniform dose distribution within the planning target volume (PTV). Improved homogeneity is clinically relevant, as it may reduce the risk of hot spots, which have been associated with acute skin toxicity and inferior cosmetic outcomes.

In contrast, in chest wall irradiation, it doesn't show clear dosimetric advantage over conventional wedge-based techniques, with comparable PTV coverage and OAR doses. This may be explained by the more regular geometry of the chest wall compared to the intact breast, as well as reduced variations in tissue thickness, which limit the potential benefit of additional beam conformation with MLC-based techniques. Therefore, both planning approaches appear to provide comparable dose homogeneity in this subgroup.

These results are consistent with previous studies reporting that MLC-based field-in-field techniques improve dose uniformity mainly in patients with more heterogeneous breast contours, whereas their benefit may be less pronounced in post-mastectomy chest wall irradiation where geometrical complexity is reduced.

Dose inhomogeneity is a well-recognized limitation of conventional tangential breast irradiation using wedge filters. Several studies have reported the presence of areas receiving excessive dose exceeding 105–110% of the prescribed dose in wedge-based 3D-CRT plans known as radiation hot spots [Donovan E *et al*.]. This inhomogeneity is mainly related to the complex geometry of the breast and variations in tissue thickness within the irradiation field [Pignol JP *et al*.].

The improvement in dose distribution observed in our study with MLC-based planning is consistent with previously published data. Cem Onal *et al.,* demonstrated that MLC-based techniques significantly reduce dose inhomogeneity and improve PTV coverage compared to conventional wedged tangential fields [Onal C *et al*.]. Similarly, K. Krishna Murthy *et al.,* reported that the use of multileaf collimators improves dose distribution by reducing hot spots and enhancing target coverage [Murthy KK *et al*.]. Although these studies mainly evaluated field-in-field techniques, the benefit of MLC-based beam shaping alone remains relevant for improving dose conformity.

Adequate PTV coverage is essential in breast radiotherapy, as insufficient dose delivery to the target volume may compromise local control [ICRU 62]. In addition, improved dose homogeneity within the PTV has been associated with better cosmetic outcomes and reduced treatment-related toxicity, including fibrosis and breast pain [Taylor ME, *et al*]. Therefore, techniques that enhance dose uniformity without increasing dose to surrounding organs are of significant clinical interest.

Regarding organs at risk, our study showed no significant increase in mean heart dose or ipsilateral lung dose when using MLC-based plans. This finding is particularly important in left-sided breast irradiation, where cardiac exposure remains a major concern. Sarah C. Darby *et al.,*demonstrated a linear increase of 7.4% in the risk of major coronary events per Gy increase in mean heart dose [Darby SC *et al*.]. In our study, the absence of a significant difference between the two techniques may be explained by the use of similar beam arrangements and the intrinsic limitations of tangential irradiation.

Although advanced techniques such as IMRT and deep inspiration breath hold (DIBH) have shown superior sparing of cardiac and pulmonary structures, they are not universally available, particularly in resource-limited settings [Jin GH *et al*., Hayden AJ *et al*.]. Therefore, optimization of widely accessible

techniques such as 3D-CRT remains clinically relevant. In this context, MLC-based conformal planning represents a simple and effective strategy to improve PTV dosimetry without increasing treatment complexity.

This study has several limitations. First, the sample size was small, including only ten patients, which may limit the statistical power of the analysis. Second, this was a retrospective dosimetric study, and clinical outcomes such as toxicity, cosmetic results, and local control were not evaluated. Third, advanced techniques such as IMRT or DIBH were not included for comparison.

Despite these limitations, our results suggest that MLC-based 3D-CRT improves PTV coverage and dose homogeneity compared to conventional wedge-based techniques, without increasing doses to the heart or ipsilateral lung. This approach may therefore represent a practical and accessible optimization strategy in routine breast radiotherapy.

CONCLUSION

Overall, these findings highlight that MLC-based optimization may be particularly advantageous in whole-breast irradiation to enhance dose homogeneity without compromising target coverage. However, its dosimetric advantage appears less evident in chest wall treatments, where conventional wedge-based 3D-CRT may remain an appropriate and efficient option.

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