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CORRELATION OF TREATMENT PLANNING PARAMETERS IN POST-MASTECTOMY BREAST CANCER FOR PERSONALIZED THERAPY

Siddharth Arora[1*], Kriti Grover[2], Sandeep Ramawat[3], Prarabdh Singh[4], Nipa patel[5], Nitesh Mohan[6]

[1*]Assistant Professor, Radiation Oncology, Rohilkhand Medical College and Hospital, Bareilly, Uttar Pradesh, India, Email id: drsiddhartharora25@gmail.com, Orcid id: 0000 - 0002 4482-9465
[2]Assistant Professor, General Pathology, Rohilkhand Medical College and Hospital, Bareilly, Uttar Pradesh, India, Email id: kritigroverllrm@gmail.com., Orcid id- 0009-0008-4653-4418, Bareilly International University, Bareilly, Uttar Pradesh, India, Pin code-243006
[3]Assistant Professor, Department of Medical Oncology, Rohilkhand Medical College and Hospital, Bareilly, Uttar Pradesh, India, Email id: sramawat16@gmail.com, Orcid id- 0000-0003-0132-0789
[4]Assistant Professor, Radiation Oncology, Rohilkhand Medical College and Hospital, Bareilly, Uttar Pradesh, India, Email id: prarabdh3008@gmail.com
[5]Post-graduate, Radiation Oncology, Rohilkhand Medical College and Hospital, Bareilly, Uttar Pradesh, India, Email id: nipabhanderibnk@gmail.com
[6]Professor, Department of pathology, Rohilkhand Medical College and Hospital, Bareilly, Uttar Pradesh, India, Email id – drnitesh@gmail.com

Corresponding author: Siddharth Arora
*Assistant Professor, Radiation Oncology, Rohilkhand Medical College and Hospital, Bareilly, Uttar Pradesh, India, Email id: drsiddhartharora25@gmail.com, Orcid id: 0000 - 0002 4482-9465

Abstract:
Radiation therapy for breast cancer is rapidly evolving toward more personalized and precise treatment plans. This shift is driven by the need for better tumor targeting while minimizing exposure to surrounding organs at risk (OARs). Dosimetric indices such as the Conformity Index (CI), Homogeneity Index (HI), and Mismatch Index (MI) are essential in assessing treatment plans for tumor coverage. Accurate delivery also takes into account patient-specific parameters and tumor volume. This study aims to examine the correlation between these indices and OAR parameters in personalized radiation therapy. A cohort of 30 female breast cancer patients, divided equally between left- and right-sided tumors, underwent hybrid intensity-modulated radiation therapy (IMRT) and 3D conformal radiotherapy (3DCRT) planning. All patients had previously undergone modified radical mastectomy (MRM) and were treated with a total dose of 40 Gy in 15 fractions using 6-15 MV photon energy. The treatment planning was carried out on a Varian system, with target volumes and OARs contoured according to RTOG guidelines. Key OARs included the heart, left anterior descending artery (LAD), ipsilateral and contralateral lungs, spinal cord, and contralateral breast. Students t distribution was employed to evaluate difference two groups. A moderate to strong correlation was found between the dosimetric indices and ipsilateral lung parameters in both treatment arms. For left-sided breast cancer, a strong correlation between heart-related dosimetric parameters and treatment delivery was observed. Mismatch Index presented

moderate to strong correlation for both techniques, particularly in left sided breast patients. The study demonstrates a significant correlation between dosimetric indices and patient-specific OAR parameters, reinforcing the role of personalized therapy in planning and optimizing radiation delivery while ensuring protection of normal tissues.

Keywords: Breast cancer, dosimetry, IMRT, Conformity index, Homogeneity index

Introduction:

Breast cancer is the most common cancer among Indian females. Breast cancer incidence is 42.9% among Asian population whereas the incidence reported among Indian females as per Globocon data 2022 is around 26.6% (1). The reported cumulative risk of new cases is 2.9. Management lines of breast cancer have seen new approaches with introduction of Immunotherapy. Similarly significant advancements have been in the radiation delivery. Hypo fractionation has become the new standard of care with ultra-hypofractionation also being practiced worldwide in eligible patients. Given the advancements in the radiation filed, there has been shift in management and is technology driven and precision related. This shift is based on damage caused by radiation on the normal tissue defined by Normal tissue complication probability (NTCP) (2). Multiple factors play role during planning. Patient specific factors and tumor coverage factors assessment is utmost important and should be considered, as they impact the outcome.

In 1980 and 1990, radiotherapy evolved to incorporate three-dimensional conformal technique (3D CRT) with the use of computerized tomography resulting in more accurate treatment delivery. Today technology advancements aim at cardiac sparing and precision delivery. This involves personalized approach and is dependent on several factors. The patient characteristics (age, comorbidities, the choice of the technique), immobilization factors (immobilization boards, breast board, vacloc), tumor volume and organ at risk (OARs) play critical role. Other factors that interplay and influence the outcome include tumor volume based on post op histopathology report especially lymph node burden. Field geometry, monitor units and dosimetric indices Conformity index (CI), homogeneity index (HI) and mismatch index (MI) are essential in assessing treatment plans for tumor coverage. Comprehensive assessment also includes various OARs relatively near to the tumor volume irradiated. OARs the heart, left anterior descending artery (LAD), ipsilateral and contralateral lungs, spinal cord, the esophagus and contralateral breast must be evaluated to achieve best plan. Tumor location plays a significant role. The tumors of left side are associated with additional radiotherapy induced cardiotoxicity compared to their counterparts on right side which lack owing to the position of the critical organ on the left side. Given above there have been studies that evaluated underlying heart and lung parameters included in the treatment field (3).

Methods:

A cohort of 30 female breast cancer patients, divided equally between left- and right-sided tumors, was enrolled. The patients were treated using 6 MV photon energy from a Varian platform. They underwent hybrid intensity-modulated radiation therapy (H-IMRT) and 3D conformal radiotherapy (3DCRT) planning. The inclusion includes all patients who underwent post mastectomy. Post lumpectomy patients were excluded. Informed consent was not needed as it was a dosimetry study not needing patient's enrollment.

Patients were simulated using breast board in supine position with hands raised above head, arms supported by breast board and chin turned to contralateral side of the irradiated breast.

The breast protocol for scanning was considered with 2.5 mm computerized tomography (CT) cuts from angle of mouth to umbilicus.

The treatment followed dose prescription of 40Gy in 15 fractions at 2.67Gy per fraction over 3 weeks from Monday to Friday. Targets and OARs were contoured as per radiation therapy oncology group (RTOG) guidelines. OARs the heart, LAD, ipsilateral and contralateral lungs, spinal cord, the esophagus and contralateral breast were contoured as per RTOG guidelines.

We generated two plans 3DCRT and H-IMRT plan. 3DCRT plan involved two opposite tangential

fields medial and lateral. Field in Field technique was use to treat supraclavicular fields.
H-IMRT breast planning is a radiotherapy technique that combines conventional open tangent beams with inverse-planned intensity modulated radiotherapy technique (IMRT) fields to treat breast cancer. The open tangent fields deliver the majority of the prescribed dose, ensuring adequate coverage, while the IMRT fields, which are fewer in number and more precisely shaped, deliver the remaining dose to improve coverage uniformity and spare organs like the lungs and heart. This hybrid approach aims to balance the robustness and speed of conventional techniques with the superior dose conformity and organ-sparing capabilities of IMRT.
A hybrid plan uses a small number of IMRT beams in conjunction with two opposing tangential (open) beams. The open tangent fields typically deliver a larger portion of the total dose (e.g., 70%), while the IMRT fields deliver the remainder (e.g.,30%). The IMRT beams are positioned at specific angles, often slightly different from the tangential fields, to cover the target volume while avoiding critical structures. The IMRT portion of the plan is optimized using inverse planning, where a treatment planning system calculates the beam intensity and shape to meet specific dose constraints for both the target and nearby organs. The plan is optimized to meet dose constraints for the planning target volume (PTV) and OARs. The final plan is evaluated for dose distribution, conformity, and OAR sparing.
Maximum heart and ipsilateral lung distances were calculated as the maximum width of heart and lung included in the tangent fields. Maximum heart and ipsilateral lung lengths were calculated as the maximum length of heart and lung, respectively, included in the radiation fields. Dosimetric indices: Dose homogeneity index (DHI) is defined as a ratio between the dose reached in 95% of the PTV volume ($D_{\geq 95\%}$) and the dose reached in 5% ($D_{\geq 5\%}$) of the PTV volume.
DHI = D≥95% (within PTV) / D≥5% (within PTV)

Conformity index is defined as a ratio between the volume covered by the reference isodose which according to international commission of radiation unit (ICRU) is 95% isodose and the target volume designated as PTV. Conformity $index_{RTOG} = V_{RI}/TV$ (equ1) Where V_{RI} = Reference isodose volume and TV = Target volume.

Mismatch index was calculated to assess the percentage of prescribed dose outside the target volume.
$MI = V_{95\%}$ - target / $V_{\geq 95\%}$
Correlation between parameters pertaining dosimetric indices (CI, HI and MI), heart dosimetry (Dmean, Dmax, V20) ipsilateral lung parameters (V20, Dmean), contralateral breast (Dmean, D max) and LAD (Dmean, Dmax) and pertaining to organs at risk were. RTOG dose constraints were used to assess dose proximity.

Statistical Analysis:
Student's t- distribution test was employed to evaluate the statistical significance between differences among the 2 groups for CI, HI and MI. Pearson correlation statistical test was used for evaluating association between two variables. For very strong to moderate positive linear correlation, results higher than r = 0.500 were considered.
The correlation of heart parameters between dosimetric indices and heart parameters were not possible due to exclusion of heart from the tangential fields.

Results:
The study cohort comprised 30 female patients with post-mastectomy breast cancer, divided equally into left-sided (Group A) and right-sided (Group B) cases (Table1). The mean age was slightly higher in Group A (52 years; range 29–77) compared to Group B (46 years; range 33– 54). Most patients in both groups presented with advanced disease, with Stage III tumors observed in 10 out of 15 patients in each group. Pathological nodal positivity was slightly more frequent in left-sided cases (4/15) than in right-sided cases (3/15). Hormone receptor positivity was higher among right-

sided tumors (12/15) compared to left-sided ones (6/15), while human epidermal growth receptor (HER2/Neu) overexpression was more common in left-sided patients (5/15 vs. 3/15). Overall, left-sided breast cancers were associated with older age and marginally higher rates of nodal and HER2-positive disease, whereas right-sided cancers showed a predominance of hormone receptor positivity.

Characteristics	Group A left breast	Group B right breast
Mean age, years	52 (range 29-77)	46 (range 33-54)
Stage		
I	0/15	1/15
II	5/15	4/15
III	10/15	10/15
Pathological nodal status		
Positive nodes	4/15	3/15
Negative	11/15	12/15
Hormone receptor status		
Positive	6/15	12/15
Negative	9/15	3/15
HER2/Neu status		
Positive	5/15	3/15
Negative	10/15	12/15

Table 1: Patient and tumor characteristics for left- and right-sided breast cancer groups. Group A represents patients with left-sided breast cancer, and Group B represents patients with right-sided breast cancer. Data are presented as mean (range) for age and as counts (number of patients/total patients) for tumor stage, pathological nodal status, hormone receptor status, and HER2/Neu status.

Organs-at-risk geometrical indices are shown in Table 2. In this comparative analysis of 15 patients receiving left-sided and 15 patients receiving right-sided breast irradiation, the mean age was comparable between groups (47.0 ± 13.6 years for left-sided vs. 43.8 ± 7.9 years for right-sided). The mean target volume (TV) did not differ substantially between cohorts (1042.6 ± 375.8 cc vs. 1086.7 ± 245.6 cc, respectively). Among patients with left-sided irradiation, the maximum heart distance (MHD) ranged from 25.1 to 75.1 mm, and the maximum heart length (MHL) ranged from 67.8 to 95 mm, demonstrating considerable interpatient variability in cardiac proximity to the treatment field. As expected, these cardiac parameters were not applicable for right-sided irradiation due to limited heart exposure. The mean ipsilateral lung distance (MLD) was comparable between groups, averaging 24.3 ± 6.2 mm in left-sided and 31.7 ± 5.0 mm in right-sided treatments, with a slightly greater extent of lung involvement observed in the latter.

Patients	Age	TV (cc)	MHD (mm)	MHL (mm)	MLD (mm)
Group A Left sided breast irradiation					
1	77	1901.5	50	71.00	40.20
2	49	1595.7	50	91.00	20
3	52	651.36	75.0	72	20
4	42	1069.92	40.0	95	20.1
5	29	895.83	72.0	91	16
6	58	733.27	60	72	23.20
7	42	1050	64	68	21.01
8	61	871.32	25.1	81.0	30.10
9	56	1806.73	27.98	67.80	25.6
10	59	636.51	75.1	75.10	22.20
11	43	1200	66	67	24.1

12	27	879.12	58	70	18
13	36	875.60	61	65	25
14	45	1000.6	45	72.10	31
15	43	756.50	62	60.0	29.0
Group B Right sided breast irradiation					
1	45	1100	-	-	33.4
2	45	1300.3	-	-	32.90
3	50	1250	-	-	43.08
4	59	817	-	-	33.00
5	40	790	-	-	31.09
6	49	1209	-	-	35.60
7	33	1250.01	-	-	21.90
8	35	1298.02	-	-	22.30
9	34	807	-	-	25.0
10	56	1540	-	-	31.08
11	34	1000	-	-	32.00
12	41	1100	-	-	33.00
13	37	850	-	-	31.00
14	39	670	-	-	29.00
15	42	1325	-	-	31.09

Table 2: Patient characteristics and organ-at-risk (OAR) geometrical indices for left- and right-sided breast irradiation. Group A represents left-sided breast cancer patients and Group B represents right-sided breast cancer patients. TV = tumor volume (cc), MHD = maximum heart distance (mm), MHL = maximum heart length (mm), MLD = maximum ipsilateral lung distance (mm).

Table 3 compares plan quality, ipsilateral lung, heart, LAD, and esophageal doses between conventional 3DCRT and H-IMRT techniques for both left- (Group A) and right-sided (Group B) breast irradiation.

Mean value of indices	3DCRT		H-IMRT	
	A (left sided breast)	B (right sided breast)	A (left sided breast)	B (right sided breast)
CI	0.80 (0.04)	0.78 (0.03)	0.87 (0.03)	0.90 (0.03)
HI	1.07 (0.01)	1.08 (0.01)	1.07 (0.01)	1.08 (0.01)
Ipsilateral Lung				
V20Gy (%)	33.09±11.09	35.71±5.7	30.31±4.8	30.26±4.8
V10Gy (%)	36.87±11.09	37.81±4.98	34.33±2.8	35.45±2.75
V5Gy (%)	38.90±12.09	38.91±2.1	37.91±1.81	37.75±1.75
Dmean	8.09±3.54	10.98±2.1	6.61±2.39	8.17±1.36
Heart				
V25Gy (%)	5.76±3.65	4.56±3.1	4.05±1.85	3.48±2.20
Dmean heart	4.09±2.76	3.98±2.0	3.51±1.64	2.37±1.57
Dmax Heart	36.98±10.98	26.98±8.86	32.13±9.14	23.04±8.64
D mean LAD	3.14 ± 1.51	2.03 ± 1.47	1.50 ± 0.42	0.36 ± 0.27
D max LAD	30.68 ± 12.18	27.67 ± 16.83	2.25 ± 0.71	0.95 ± 1.73
Esophageal				
Dmean	9.14±4.01	7.28±3.69	7.14±3.01	6.29±2.82

Table 3: Mean dosimetric indices for 3DCRT and H-IMRT in left- and right-sided breast cancer patients. Values are presented as mean ± standard deviation. CI, conformity index; HI, homogeneity

index; V20Gy, V10Gy, V5Gy, percentage of ipsilateral lung receiving ≥20, 10, and 5 Gy, respectively; Dmean, mean dose; Dmax, maximum dose; LAD, left anterior descending artery.
Correlation of dosimetric parameters with plan quality indices for 3DCRT and H-IMRT in left- and right-sided breast irradiation has been shown in Table 4.

r value	CI		HI	
	3DCRT	H-IMRT	3DCRT	H-IMRT
Group A left-sided breast irradiation				
TV	0.273	0.219	-0.215	-0.112
MHD	-0.439	-0.720	0.024	0.136
MHL	0.135	0.178	0.468	-0.042
MLD	0.280	0.808	-0.365	0.280
Dmean heart	-0.536	0.387	0.271	0.646
Dmax heart	-0.306	0.172	0.476	0.770
Dmean LAD	-0.207	-0.665	0.277	0.704
Dmax LAD	-0.043	0.601	0.348	0.105
MI	-0.267	-0.301	-0.122	-0.171
Group B right-sided breast irradiation				
TV	0.066	0.470	0.342	0.470
MHD	-	-	-	-
MHL	-	-	-	-
MLD	0.290	0.283	-0.550	0.283
Dmean heart	-0.032	-0.133	0.464	-0.133
Dmax heart	-0.430	-0.355	-0.251	-0.355
Dmean LAD	-0.283	-0.545	-0.545	-0.043
Dmax LAD	0.173	-0.346	0.560	-0.346
MI	-0.346	0.173	-0.147	-0.346

Table 4. Correlation of dosimetric parameters with plan quality indices for 3DCRT and H-IMRT in left- and right-sided breast irradiation. TV = tumor volume, MHD = maximum heart distance, MHL = maximum heart length, MLD = maximum ipsilateral lung distance, CI = Conformity index, Dmean heart: mean doe to heart, D max heart: maximum dose to heart, D mean LAD: mean dose to left ascending artery, D max LAD: maximum dose to left ascending artery, MI: mismatch index

H-IMRT produced more conformal dose distributions than 3DCRT for both left- and right-sided breast irradiations (Figure 1).

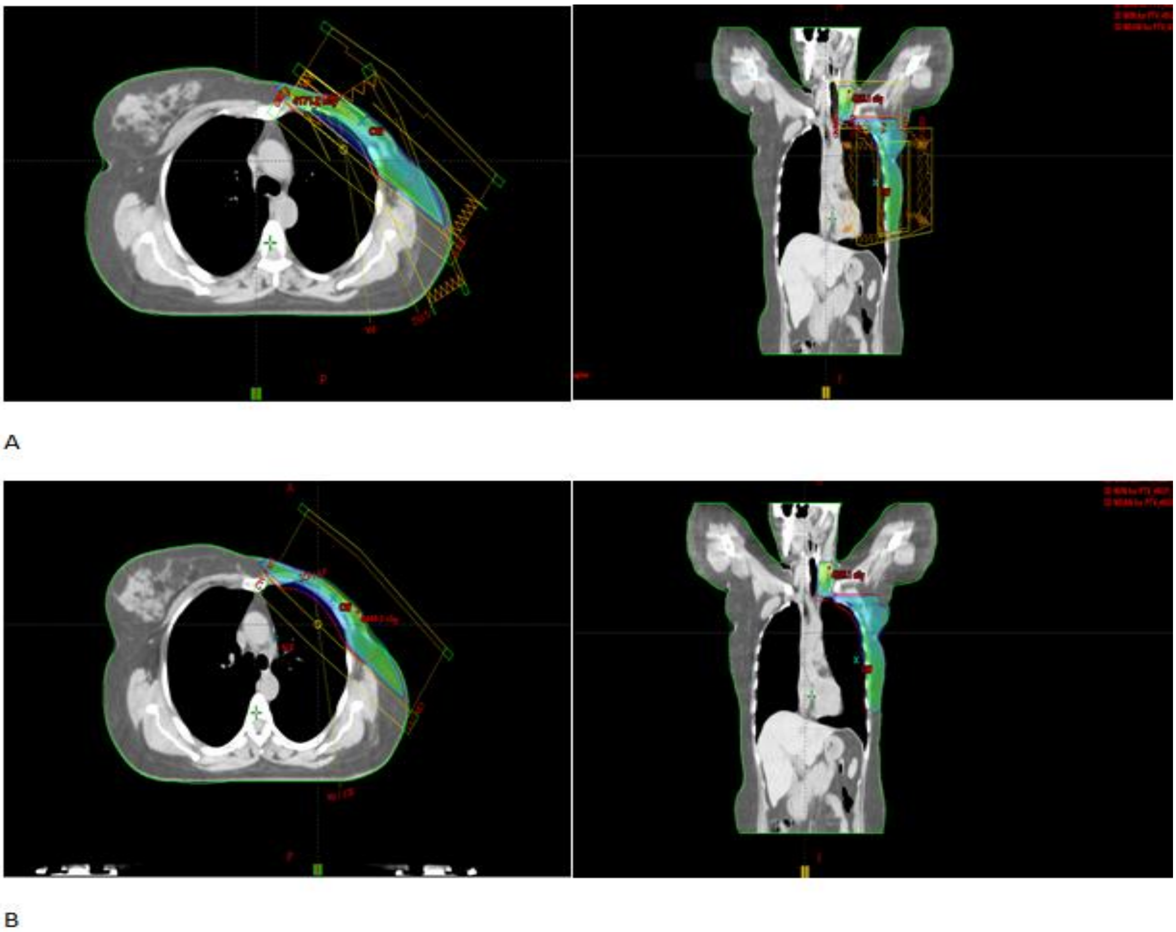

Figure1: Comparison between H- IMRT versus 3DCRT in Axial and sagittal section in left sided breast patients: A: H- IMRT; B: 3DCRT
H- IMRT: Hybrid intensity modulated radiotherapy, 3CDRT: 3- dimensional radiotherapy

For left-sided cases (Group A), the mean CI improved significantly from 0.80 ± 0.04 with 3DCRT to 0.87 ± 0.03 with H-IMRT ($p < 0.05$). For right-sided cases (Group B), CI increased from 0.78 ± 0.03 (3DCRT) to 0.90 ± 0.03 (H-IMRT) ($p < 0.05$).
The HI remained consistent across both sides and techniques (≈ 1.07–1.08), confirming that the improved conformity with H-IMRT did not compromise target dose uniformity.
Tumor volume (TV) showed weak positive correlations with CI in both techniques for Group A (r = 0.273 for 3DCRT; r = 0.219 for H-IMRT) and a moderate positive correlation in Group B H- IMRT (r = 0.470), while 3DCRT demonstrated negligible correlation (r = 0.066).
These findings indicate that larger targets tended to yield slightly better conformity, particularly with modulation.

Cardiac Doses
As expected, cardiac doses were higher in left-sided irradiation.
For Group A, the MHD was 4.26 ± 1.25 Gy with 3DCRT and reduced to 3.54 ± 1.74 Gy with H-IMRT, reflecting a 16–20 % decrease in cardiac exposure.
For Group B, MHD was much lower overall—2.27 ± 0.86 Gy with 3DCRT and 2.34 ± 1.52 Gy with H-IMRT—with no significant difference between techniques. In left-sided treatments, MHD correlated negatively with CI in 3DCRT (r = –0.439) and strongly negatively in H-IMRT (r = –0.720), confirming that higher conformity was associated with lower cardiac dose.
H-IMRT also demonstrated significant positive correlations between MHD and both CI (r = 0.606, p = 0.001) and HI (r = 0.689, p = 0.003), suggesting improved conformity and homogeneity with reduced heart dose.
For right-sided cases, Dmean heart showed negligible correlations (r = –0.032 for 3DCRT; r = –

0.133 for H-IMRT), consistent with minimal heart involvement.
The maximum heart dose (Dmax heart) showed moderate negative correlations in both sides ($r \approx -0.3$ to -0.4), indicating slightly reduced conformity with higher peak heart doses.

LAD Artery Doses
H-IMRT provided superior sparing of the LAD artery in both cohorts. For Group A, the mean LAD dose decreased from 3.14 ± 1.51 Gy (3DCRT) to 2.03 ± 1.47 Gy (H-IMRT), and the maximum LAD dose fell from 30.68 ± 12.18 Gy to 27.67 ± 16.83 Gy. For Group B, LAD doses were substantially lower overall but still improved with modulation—Dmean = 1.50 ± 0.42 Gy (3DCRT) vs 0.36 ± 0.27 Gy (H-IMRT) and Dmax = 2.25 ± 0.71 Gy (3DCRT) vs 1.95 ± 1.73 Gy (H-IMRT).
In left-sided cases, Dmean LAD correlated strongly and negatively with CI for H-IMRT ($r = -0.665$) and weakly for 3DCRT ($r = -0.207$).
Right-sided H-IMRT also showed a moderate negative correlation between Dmean LAD and CI ($r = -0.545$), while 3DCRT correlations remained weak ($r = -0.283$).
These results confirm that improved conformity is associated with lower LAD exposure, especially in modulated plans.

Lung Doses
H-IMRT reduced ipsilateral lung dose on both sides. For left-sided cases, the mean lung dose (Dmean) decreased from 8.23 ± 2.10 Gy (3DCRT) to 6.61 ± 2.39 Gy (H-IMRT; $p = 0.984$), and the V20Gy declined from 33–36 % to about 30 %.
For right-sided cases, Dmean reduced from 10.31 ± 2.12 Gy to 8.17 ± 1.36 Gy ($p = 0.607$), with a similar decrease in V20Gy. Correlation analysis revealed a strong positive relationship between MLD and CI in left-sided H-IMRT ($r = 0.808$) compared with a weaker correlation in 3DCRT ($r = 0.280$).
In right-sided cases, correlations were weak but positive for both techniques ($r \approx 0.29$).
These results indicate that H-IMRT achieves high conformity with modest, clinically acceptable trade-offs in lung dose.
Contralateral Breast Doses Contralateral breast exposure was comparable for 3DCRT ($p = 0.348$ for Dmean; $p = 0.425$ for Dmax) but significantly reduced with H-IMRT ($p < 0.001$ for Dmean; $p = 0.001$ for Dmax) for both left- and right-sided plans. This demonstrates that modulation effectively minimizes unnecessary radiation to the contralateral breast without affecting target coverage.
Across both groups, H-IMRT exhibited stronger and more consistent relationships between dosimetric parameters and plan quality indices.
The MI showed strong negative correlations with tumor volume in Group A ($r = -0.786$ for 3DCRT; $r = -0.671$ for H-IMRT) and a moderate negative correlation in Group B 3DCRT ($r = -0.502$, $p = 0.065$), suggesting lower modulation complexity with increasing target size.
Overall, 3DCRT demonstrated greater sensitivity to anatomical variations such as MHD, MHL, and MLD ($r > 0.5$), while H-IMRT reduced these dependencies, yielding more reproducible and patient-independent dose distributions.
H-IMRT consistently outperformed 3DCRT in both left- and right-sided breast irradiation.
It achieved significantly higher conformity, maintained homogeneity, and reduced cardiac, LAD, lung, and contralateral breast doses, with particularly notable benefits for left-sided treatments. The correlation analyses further highlighted that H-IMRT provided more stable, anatomy- independent dose distributions, underscoring its superiority for breast cancer radiotherapy planning. The technique was less dependent on variations in thoracic anatomy and offered a more favorable dosimetric profile, particularly for left-sided breast cancer where cardiac proximity poses a significant risk.

Discussion:
Our methodology builds upon prior dosimetric comparisons to evaluate the efficacy of H-IMRT in breast cancer treatment. Clinically, linking dosimetric indices with tumor control probability (TCP)

and NTCP facilitates more informed, risk-adapted decision-making. The validation of the MI as a consistent and complementary parameter further enhances its value in assessing plan quality, capturing features of dose distribution not fully represented by CI or the HI.

In this study, the CI and HI were used to evaluate and compare the quality of radiotherapy plans between 3D-CRT and H-IMRT for left- and right-sided breast cancer patients. The CI, which reflects how well the prescribed dose conforms to the PTV while sparing surrounding healthy tissues (5,6), was consistently higher in H-IMRT plans (0.87 for left-sided and 0.90 for right- sided breast) compared to 3D-CRT (0.80 for left-sided and 0.78 for right-sided breast). This indicates that H-IMRT provides superior target coverage and reduces unnecessary irradiation of adjacent organs at risk. On the other hand, the HI, which measures dose uniformity within the PTV (7), remained similar across both techniques (1.07–1.08), suggesting that dose homogeneity was maintained irrespective of the planning method. Overall, these results demonstrate that H- IMRT improves conformity without compromising homogeneity, aligning with the goal of maximizing tumor control while minimizing exposure to healthy tissues. The findings also support previous reports showing the dosimetric advantages of advanced planning techniques in post-mastectomy breast radiotherapy.

Mayo et al. first introduced the H-IMRT technique, which combines conventional tangential fields with IMRT fields for whole-breast irradiation (WBI) (8). The purpose of hybrid radiotherapy (RT) is to achieve improved dose homogeneity, enhanced target coverage, and superior sparing of organs at risk (OARs) (9). Similarly, the hybrid-volumetric modulated arc therapy (H-VMAT) approach delivers most of the prescribed dose through static 3D-CRT fields, with the remainder administered via VMAT arcs (10). Another variation, the H-IMRT/VMAT technique, utilizes a simultaneously optimized algorithm integrating IMRT for desired intensity modulation and VMAT for optimal angular beam sampling (11, 12). Despite these advances, the optimal beam weighting in hybrid RT planning remains unclear. Consequently, this systematic review aims to summarize the dosimetric outcomes of hybrid techniques compared with conventional methods in whole-breast radiotherapy (WBRT).

Ahunbay et al. (13) retrospectively analyzed 15 patients, comparing hybrid RT with 3D-CRT and IMRT. Their results indicated that hybrid RT achieved equivalent or superior outcomes, demonstrating a higher uniformity index, lower lung doses, reduced monitor units (MUs) compared to IMRT, and significantly shorter planning times—approximately 75% less than 3D- CRT. Similarly, Descovich et al. (14) found that the hybrid approach reduced breast volumes receiving >105% of the prescribed dose, achieved more homogeneous coverage of the tumor cavity, was less dependent on planner experience, and required shorter planning times than either IMRT or 3D-CRT. Liu et al. (15) evaluated right-sided breast cancer cases using two VMAT configurations—continuous and non-continuous partial arcs—alongside IMRT and hybrid 3DCRT/IMRT plans. Reported CI values were 0.64 for IMRT, and 0.68 for 3DCRT, indicating that the superior conformity achieved with VMAT results from its greater modulation flexibility. For left-sided breast cancer, our study reported CI values of 0.80 for 3DCRT, 0.88 for IMRT, and

0.89 for VMAT, demonstrating improved conformity compared with the findings of Takabi et al. (CI = 0.46 for 3DCRT, CI = 0.72 for IMRT) (16). Their results similarly highlighted that changes in treatment technique significantly influence target dose distribution.

Petrova et al. (17) examined 58 patients treated with two conformal approaches—3DCRT with segments and 3DCRT with standard tangent fields—reporting HI values of 1.08 and 1.09, respectively, with a statistically significant difference ($p < 0.001$). Wang et al. assessed IMRT plans for 96 left-sided breast cancer patients and found a mean HI of 1.095 (18). Schoepen et al.

(19) evaluated the MI in 51 patients, stratified by tumor stage and laterality, across four techniques: wedged tangent fields (W-TF), tangential IMRT, multi-field IMRT, and VMAT, in three patient positions—supine, prone dive, and prone crawl. Mulliez et al. (20) similarly compared W-TF, tangential IMRT, and multi-field IMRT in both supine and prone positions, reporting higher MI values for modulated techniques in the supine setup: 46.8% (W-TF), 34.7% (tangential IMRT), and 28.5% (multi-field IMRT). Both studies associated increased MI values in conformal techniques

with the concave anatomy of the breast.
The study by Das Majumdar et al. (21) evaluated post-mastectomy radiation plans and demonstrated that VMAT and IMRT provided superior target coverage and conformity compared to 3D-CRT in left-sided breast cancer patients (17). Fifteen patients with left-sided breast cancer and nodal involvement underwent post-mastectomy irradiation using 3D-CRT and IMRT with 6 MV photons. Plans followed RTOG guidelines targeting 95–107% dose coverage, and dose distributions were analyzed via DVHs. IMRT provided adequate target coverage, but low-dose exposure to organs at risk raised concerns for secondary malignancies and other complications (22).
Czeremszynska et al. (23) compared 3DCRT, IMRT, and VMAT for 10 right-sided breast cancer patients, reporting mean heart doses of 0.85 Gy (3DCRT), 1.30 Gy (IMRT), and 1.70 Gy (VMAT). The LAD artery has become a critical OAR in breast RT, particularly for right-sided cases. Grocer et al. (24) evaluated 40 patients treated with wedged tangential fields to investigate radiotherapy-induced cardiotoxicity. Wang et al. (18) examined four anatomical factors—tumor volume (TV), maximum heart distance (MHD), central lung distance (CLD), and cardiothoracic ratio (CTR)—in 96 left-sided IMRT patients. Regression analysis revealed that TV, MHD, and CTR significantly influenced CI, while only TV impacted HI. Consistently, our findings identified a correlation between CI and TV in patients treated with volumetric modulation ($r = 0.506$, $p = 0.022$), though no significant correlation was found with HI.
Most correlations involving HI were associated with ipsilateral lung parameters across both conformal and modulated plans. These results underscore the importance of personalized treatment planning, as improved tumor coverage and dose uniformity (reflected by higher CI and HI values) may inadvertently increase OAR exposure. The observed reduction in ipsilateral lung V20 in group A may result from the application of stricter heart-sparing constraints near the tumor volume (25). Our findings highlight the efficacy of H-IMRT in enhancing the precision and efficacy of radiation treatment for breast cancer patients. Hybrid IMRT demonstrated superior dose distribution, achieving higher Conformity and Homogeneity within the target volume.

Limitations:
This study has certain limitations that should be acknowledged. First, the sample size was relatively small ($n = 30$), which limits the statistical power and generalizability of the findings. A larger patient cohort would enable more robust statistical analysis and allow subgroup comparisons based on additional clinical variables such as age, body mass index, or breast volume.
Second, only hybrid IMRT and 3DCRT techniques were compared, while other modern modalities such as VMAT, deep inspiration breath-hold (DIBH), were not included. These advanced techniques may further improve organ sparing, particularly for left-sided breast cancer, and should be evaluated in future studies. Thirdly, clinical outcomes and toxicity profiles were not assessed, as the study focused purely on dosimetric correlations. While lower mean and maximum doses to OARs suggest potential clinical benefit, the absence of long-term follow-up data prevents direct conclusions regarding cardiac or pulmonary toxicity reduction. Besides, the anatomical variability among patients, such as differences in thoracic shape, cardiac position, or respiratory motion, may have influenced dosimetric parameters. The study did not incorporate respiratory gating or motion management techniques, which could affect dose distribution in clinical practice. Lastly, the correlation analysis was limited to linear relationships using Pearson's coefficient. Nonlinear associations or interactions between variables may exist and could be better explored with more advanced statistical or machine learning approaches in future work. Future studies with larger, multicentric cohorts are needed to validate these findings and correlate dosimetric improvements with clinical outcomes. Incorporating advanced techniques such as VMAT, DIBH, and proton therapy, along with motion management and AI-based planning, could further enhance personalization and organ sparing in post-mastectomy breast cancer radiotherapy.

Conclusions:
The study highlights the growing role of data-driven personalization in radiation oncology.

Demonstrating measurable correlations between dosimetric indices (CI, HI, MI) and OAR doses, it supports a shift toward individualized and adaptive radiotherapy planning based on patient- specific anatomy rather than standardized protocols.

The findings underscore the importance of optimizing dose distribution to improve OAR protection, particularly for the heart and ipsilateral lung in left-sided breast cancer, where cardiac sparing is critical. Understanding how parameters like CI, HI, and MI relate to OAR exposure allows for refined dose constraints and weighting schemes in IMRT and 3DCRT planning.

Furthermore, the study provides a foundation for predictive modeling and artificial intelligence integration, enabling algorithms to forecast plan quality or OAR doses from dosimetric and geometric inputs. This could streamline treatment planning, reduce iterations, and enhance plan efficiency.

Declarations:

Ethical Approval: The study was approved by the Institutional Review Board of Rohilkhand medical college and hospital, Bareilly, Uttar Pradesh Research (IEC/RMCH/23/2025/JUL)

Human participants/Animal: No

Informed Consent: Not needed

Conflict of interest: none

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