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Dose Difference to Target Volume and Organs at Risk with Three -Dimensional Conformal Radiation Therapy (3D-CRT) Versus Intensity Modulated Radiation Therapy (IMRT) In Carcinoma Right Breast Post Mastectomy Patients: AnObservational Study from a Rural Cancer Centre in India

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ABSTRACT:

Background: Breast cancer is the most frequently diagnosed life-threatening cancer in women worldwide, with distinct molecular and cellular origins and clinical behaviour, requiring a comprehensive approach that includes prevention, early detection, and personalized treatment strategies.

Purpose: The purpose of this observational study is to evaluate the differences in the dosimetry and toxicities in post mastectomy patients of carcinoma of right breast undergoing post mastectomy radiation therapy (PMRT) using IMRT or conventional 3D-CRT techniques.

Material and Methods: Forty consecutive histopathologically proven non metastatic post right mastectomy female breast cancer patients, attending radiation oncology OPD between June 2022 and May 2024 fulfilling the inclusion criteria were included. All patients received 50 Gray in 25 fractions to the PTV over 5 weeks. Dosimetric assessment of both IMRT and 3D-CRT plans were done for all patients. Planning target volume (PTV) parameters-Dnear-max (D2%), Dnear-min (D98%), Dmean, V95%, V110%, homogeneity index (HI), and conformity index (CI) were compared.The percentage volume of the right lung and heart receiving 5 Gy (V5), 10 Gy (V10), 20 Gy (V20), and 30 Gy (V30); the left lung and contralateral breast receiving 5 Gy (V5); the maximum dose to the spinal cord (Dmax); and the mean dose to the right lung, heart, contralateral breast, and liver (Dmean) were extracted from the DVH and compared.

Results: IMRT delivered higher maximum (Dmax: 55.83 Gy vs. 54.62 Gy, $p < 0.0001$) and minimum (Dmin: 19.68 Gy vs. 14.16 Gy, $p = 0.0117$) doses, with a more consistent average dose (Dmean: 50.53 Gy vs. 49.93 Gy, $p < 0.0001$). It provided better target volume coverage (V95%: 97.26% vs. 87.88%, $p < 0.0001$) and reduced hotspots (V110%: 0.01% vs. 0.09%, $p = 0.02$), and achieved more uniform and conformal dose distributions (HI: 0.10 vs. 0.18, $p < 0.0001$; CI: 0.96 vs. 0.87, $p < 0.0001$).

For the right lung, V5 (42.85 vs. 63.42), V10 (35.19 vs. 43.36), V20 (30.80 vs. 28.31), and V30 (27.89 vs. 21.67) values were significantly different between 3D-CRT and IMRT ($p < 0.05$). However, the mean dose to the right lung showed no significant difference (15.44 Gy for 3D-CRT vs. 15.56 Gy for IMRT, $p = 0.82$). For the heart, V5 (1.64 vs. 11.48) and V10 (0.78 vs. 4.36) values were significantly different between 3D-CRT and IMRT ($p < 0.05$). V20 (0.35 vs. 0.61, $p = 0.24$) and V30 (0.18 vs. 0.12, $p = 0.44$) values showed no significant differences. The mean dose to the heart was significantly higher with IMRT (2.22 vs. 1.05, $p < 0.05$). Significant differences were observed in V5 values between 3D-CRT and IMRT: 0 vs. 0.14

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for the left lung, and 1.79 vs. 3.30 for the contralateral breast ($p < 0.05$). The mean dose to the contralateral breast was not significantly different (0.57 for 3D-CRT vs. 0.76 for IMRT, $p = 0.182$). IMRT delivered a higher mean liver dose (12.39 vs. 7.56, $p < 0.0001$). No significant difference was found in the spinal cord maximum dose (37.37 Gy for 3D-CRT vs. 37.54 Gy for IMRT, $p = 0.91$).

Conclusion: This study demonstrates that IMRT offers significant advantages over 3D-CRT in post-mastectomy right breast cancer patients by providing superior dosimetric parameters and improved conformity and homogeneity indices. IMRT results in more precise treatment with fewer acute and long-term toxicities and reduces high-dose radiation exposure to critical organs such as the heart and ipsilateral lung. However, it also increases the mean dose to the liver and low-dose radiation volumes to the heart, lungs, and contralateral breast. In conclusion, selecting the appropriate radiotherapy technique is crucial to protect nearby normal structures, and a thorough evaluation of the patient profile and available resources is essential to determine the most suitable method.

Keywords: Breast Cancer, Post Mastectomy Radiation Therapy (PMRT), Three - DimensionalConformal Radiation Therapy (3D-CRT),IntensityModulated Radiation Therapy (IMRT)

I. INTRODUCTION:

Breast cancer is the most commonly occurring cancer in women worldwide and the second leading cause of cancer-related death in women.Globally, 670,000 people lost their lives to it in 2022, with 2.3 million new cases being reported **(1)**.In 2022, India reported the highest number of estimated breast cancer deaths among females, totalling 98,337. The estimated incidence of breast cancer for the same year was 192,000**(2)**.

Management of breast cancer depends on the tumour's clinical extent, pathological profile, patient age, biological prognostic factors, and patient preference. Surgery is the primary treatment for non-metastatic breast cancer, complemented by chemotherapy, hormonal therapy, targeted therapy, and radiation therapy. Multimodality treatment (surgery, chemotherapy, and radiation therapy) reduces breast cancer mortality and improves overall survival. In contrast to the Western world, many patients in India present with advanced stages due to lack of mass screening programs, leading to more frequent use of Modified Radical Mastectomy (MRM) over Breast Conservation Surgery (BCS). Radiation therapy effectively reduces recurrence risk post-surgery and alleviates symptoms of metastasized cancer**(1)**.

PMRT is recommended for patients with advanced breast cancer or high-risk pathological features. It targets the chest wall and regional lymph nodes **(3)**. PMRT has been shown to improve local control and overall survival in node-positive breast cancer patients with T1–2 tumors and 1–3 axillary lymph node metastases**(4)**.3D-CRT involves precise radiation delivery to a three-dimensional volume using high-definition CT images and additional diagnostic-quality imagesfor optimal tumor targeting.

IMRT, a type of 3D-CRT, further refines the radiation beam by adjusting its intensity for improved treatment accuracy and dose distribution. IMRT targets the post-mastectomy tumor bed while sparing surrounding healthy tissues**(5)**. It has demonstrated advantages in reducing radiation toxicity and minimizing the impact on organs at risk (OARs) such as the lungs, heart, and contralateral breast by limiting their exposure to high radiation doses**(6)**.Inthis study, we evaluated the dosimetry in post mastectomy patients of carcinoma of right breastundergoing PMRT using IMRT versusconventional 3D-CRT techniques carried out at ourdepartment.

II. MATERIAL & METHODS:

Forty right-sided female breast cancer patients, post-mastectomy, attending radiation oncology OPD between June 2022 and May 2024 fulfilling the inclusion criteria were included in the study. All patients were planned for adjuvant radiotherapy to the chest wall, including the mastectomy scar and supraclavicular region. Patients were immobilized using a thermoplastic mould in a supine position with the right arm extended above their head. Marker CT scans with 2mm slice thickness were taken using a Siemens Samotom CT Scan Machine once the optimal patient position was confirmed.

The chest wall, axilla, supraclavicular fossa (SCF) region and OARs was contoured according to the Radiotherapy Oncology Group (RTOG) guidelines for breast Cancers and treatment planning was done according to according to the departmental protocol. All of 40 patients were treated with Linear Accelerator (6MV photons) VARIAN DBX 600. The total dose received by every patient was 50 Gy in 25 fractions to the PTV with 2 Gy per fraction, 1 fraction per day for 5 days per week. In 3D-CRT, two tangential semi-opposed beams with dynamic wedges (15° to 30°) and multileaf collimators were

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used. Beam and wedge angles, as well as beam weighting, were optimized to cover the PTV while minimizing exposure to the ipsilateral lung, heart, and contralateral breast. Gantry angles ranged from 45° to 55° for medial tangential fields and 225° to 235° for lateral tangential fields. The SCF field was marked with a separate anterior field. Attention was given to the geometric match of the SCF and chest wall fields to avoid junctional hot or cold spots. In IMRT, the chest wall was irradiated using 5-6 fields with dynamic MLC, utilizing inverse planning and a separate anterior SCF field. Monitor units ranged from 150 to 200 per beam. Orthogonal megavoltage electronic portal images were captured before the first treatment and weekly thereafter to verify patient position against reference digitally reconstructed radiographs.

III. DOSIMTERIC ANALYSIS:

Dosimetric assessment of both IMRT and 3D-CRT plans were done for all 40 patients. PTV parameters-Dnear-max (D2%), Dnear-min (D98%), Dmean, V95%, and V110%, homogeneity index (HI), and conformity index (CI) were compared. The percentage volume of the right lung and heart receiving 5 Gy (V5), 10 Gy (V10), 20 Gy (V20), and 30 Gy (V30); the left lung and contralateral breast receiving 5 Gy (V5); the maximum dose to the spinal cord (Dmax); and the mean dose to the right lung, heart, contralateral breast, and liver (Dmean) were extracted from the DVH and compared.Patient's characteristics and dosimetric analysis were assessed by simple statistical techniques.

IV. RESULTS & OBSERVATIONS:

This study included 40 female right breastcancer patients who underwent mastectomy andwere planned for adjuvant radiotherapy with either3D-CRT or IMRT. The following baselinecharacteristics and dosimetricanalysis of the studysubjects were noted.

Table 1: Patient's characteristics

CHARACTERISTICS	3D-CRT	IMRT
AGE GROUP (Median)	62.5 years	53.5 years
MENOPAUSAL STATUS		
PRE	4 (20%)	8 (40%)
POST	16 (80%)	12 (60%)
PARITY		
NULLIPAROUS	3 (15%)	0 (0%)
1	1 (5%)	0 (0%)
>2	16 (80%)	20 (100%)
GRADE		
1	3 (15%)	0 (0%)
2	7 (35%)	13 (65%)
3	10 (50%)	7 (35%)
STAGE		
1	0 (0%)	3 (15%)
2	12 (60%)	15 (75%)
3	8 (40%)	2 (10%)
CHEMOTHERAPY		
NEOADJUVANT	2 (10%)	5 (25%)
ADJUVANT	20 (100%)	20 (100%)

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PTV:

IMRT delivers higher maximum (Dmax) and minimum (Dmin) doses, delivers a more consistent average dose (Dmean), ensures better coverage (higher V95%), reduces the incidence of hotspots (lower V110%), and achieves more uniform and conformal dose distributions (better HI and CI). These differences are statistically significant, indicating that IMRT is more effective in delivering precise and optimal radiation therapy (Table 2).

Table 2: Dose Distribution to the PTV of the study subjects based on the following parameter

S.NO	Parameter	3D-CRT Mean	IMRT Mean	3D-CRT Std. Deviation	IMRT Std. Deviation	P Value
1	**DMAX (Gy)**	54.62	55.83	0.76	1.11	<0.0001
2	**DMIN(Gy)**	14.16	19.68	9.97	9.14	0.0117
3	**DMEAN(Gy)**	49.93	50.53	0.29	0.21	<0.0001
4	**V95%**	87.88	97.26	4.06	1.33	<0.0001
5	**V110%**	0.09	0.01	0.20	0.05	0.02
6	**HI**	0.18	0.10	0.05	0.03	<0.0001
7	**CI**	0.87	0.96	0.04	0.01	<0.0001

Right Lung:

The mean V5 values for the right lung were 42.85 and 63.42, V10 values were 35.19 and 43.36, V20 values were 30.80 and 28.31, and V30 values were 27.89 and 21.67 for the 3D-CRT and IMRT groups, respectively, all showing statistically significant differences. The mean dose (Dmean) to the right lung was similar between 3D-CRT (15.44) and IMRT (15.56), with a p-value of 0.82, indicating no statistically significant difference (Table 3).

Table 3: Dose Distribution of the study subjects based on the Right lung parameters

Parameter	3D-CRT Mean	IMRT Mean	3D-CRT Std. Deviation	IMRT Std. Deviation	P Value
Right Lung- V5	42.85	63.42	6.28	7.80	<0.0001
Right Lung-V10	35.19	43.36	6.14	5.81	<0.0001
Right Lung-V20	30.80	28.31	5.78	5.00	0.043
Right Lung-V30	27.89	21.67	5.46	4.55	<0.0001
Right Lung-DMEAN (Gy)	15.44	15.56	2.55	2.00	0.82

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Heart:

The mean V5 values for the heart were 1.64 and 11.48, and V10 values were 0.78 and 4.36 for the 3D-CRT and IMRT groups, respectively, both showing statistically significant differences. The V20 values were 0.35 and 0.61, and V30 values were 0.18 and 0.12, with no significant differences. The mean dose (Dmean) to the heart was 1.05 for 3D-CRT and 2.22 for IMRT, with IMRT delivering a significantly higher mean dose (Table 4).

Table 4: Dose Distribution of the study subjects based on the heart parameters

Parameter	3D-CRT Mean	IMRT Mean	3D-CRT Std. Deviation	IMRT Std. Deviation	P Value
Heart- V5	1.64	11.48	1.83	8.21	<0.0001
Heart- V10	0.78	4.36	1.24	5.30	<0.0001
Heart- V20	0.35	0.61	0.64	1.19	0.24
Heart- V30	0.18	0.12	0.40	0.31	0.44
Heart DMEAN (Gy)	1.05	2.22	0.46	1.15	<0.0001

Left Lung:

The mean V5 for the left lung was 0 for 3D-CRT and 0.14 for IMRT, with a p-value of 0.038 indicating a statistically significant difference (Table 5).

Table 5: Dose Distribution of the study subjects based on the Left lung parameters

Parameter	3D-CRT Mean	IMRT Mean	3D-CRT Std. Deviation	IMRT Std. Deviation	P Value
Left Lung- V5	0	0.14	0	0.41	0.038

Contralateral Breast:

The mean V5 for the contralateral breast was 1.79 for 3D-CRT and 3.30 for IMRT, with a p-value of 0.03 indicating a statistically significant difference. The Dmean for the contralateral breast was 0.57 for 3D-CRT and 0.76 for IMRT, with a p-value of 0.182, showing no statistically significant difference (Table 6).

Table 6: Dose Distribution of the study subjects based on the Contralateral breast parameters

Parameter	3D-CRT Mean	IMRT Mean	3D-CRT Std. Deviation	IMRT Std. Deviation	P Value
Contralateral breast- V5	1.79	3.30	2.81	3.53	0.03
Contralateral breast- DMEAN (Gy)	0.57	0.76	0.67	0.61	0.182

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Liver:
The Dmean dose for the liver was 7.56 for 3D-CRT and 12.39 for IMRT, with a p-value of <0.0001, indicating a highly statistically significant difference (Table 7).

Table 7: Dose Distribution of the study subjects based on the Liver parameters

Parameter	3D-CRT Mean	IMRT Mean	3D-CRT Std. Deviation	IMRT Std. Deviation	P Value
Liver- DMEAN (Gy)	7.56	12.39	3.73	4.66	<0.0001

Spinal Cord:
The Dmax for the spinal cord (with SCF field) was nearly identical between 3D-CRT (37.37 Gy) and IMRT (37.54 Gy), with no statistically significant difference (p = 0.91) (Table 8).

Table 8: Dose Distribution of the study subjects based on the spinal cord parameters

Parameter	3D-CRT Mean	IMRT Mean	3D-CRT Std. Deviation	IMRT Std. Deviation	P Value
Spinal Cord (with SCF field)- DMAX (Gy)	37.37	37.54	7.49	7.46	0.91

V. DISCUSSION:

Breast cancer is the most frequently diagnosed life-threatening cancer in women globally. In regions lacking robust screening programs, late-stage presentations often necessitateMRM. Postoperative adjuvant chemotherapy and PMRT are critical for reducing loco-regional recurrence and improving overall survival. Radiation therapy is a critical component in the management of carcinoma of the right breast post-mastectomy patients. Currently, the primary modalities for postoperative radiotherapy in patients with advanced breast cancer include 2Dimensional-Radiation Therapy (2D-RT), 3D-CRT, IMRT, Volumetric Modulated Arc Therapy (VMAT), and a combination of 3D-CRT and IMRT. This study focuses on comparing dose differences to the target volume and OARsbetween 3D-CRT and IMRT in post-mastectomy right breast cancer patients.

Numerous studies have shown that IMRT achieves a more favourable dose distribution than 3D-CRT for whole-breast radiation following BCS. However, limited data exists on IMRT for the chest wall in post-mastectomy breast cancer patients. Distinctions in target volumes between the whole breast and chest wall may impact dose distribution to both the PTV and OARs. This study included 40 patients with right breast carcinoma, post-mastectomy, who were evaluated for differences in dose to the target volume and OARswhen subjected to radiotherapy using either IMRT or 3D-CRT.

PTV Dosimetric Analysis:

In a study by **Rudat V et al.**, tangential beam IMRT and 3D-CRT plans were created for chest wall radiotherapy in 20 postmastectomy breast cancer patients. The results showed higher maximum (55.30 Gy vs. 54.62 Gy, p=0.04) and mean doses (50.83 Gy vs. 50.38 Gy, p=0.04) for IMRT compared to 3D-CRT**(7)**. These findings align with this study, which also found higher maximum (55.83 Gy vs. 54.62 Gy, p<0.0001) and mean doses (50.53 Gy vs. 49.93 Gy, p<0.0001) for IMRT compared to 3D-CRT.**Edwards-Bennett S.M. et al.** (2011) found that PTV V95% for IMRT was significantly higher than for 3D-CRT (93% vs. 79%, p < 0.001) **(8)**. This study results were consistent, showing a significantly higher V95% in IMRT compared to 3D-CRT (97.26% vs. 87.88%; p < 0.0001). **Ma, Changchun et al.** found that IMRT significantly reduced the volume of the PTV receiving over 110% of the prescribed dose (V110%) compared to 3D-CRT (0.22 vs. 4.26, p < 0.022) in post mastectomy breast cancer patients **(9)**. This study findings were similar, showing that IMRT decreased V110% (0.01 vs. 0.09, p=0.02).

Yim Jackie et al. reported that IMRT exhibited significantly greater homogeneity than 3D-CRT (0.095 vs. 0.111, p=0.001) **(10)**. **Rastogi K et al.** concluded that CI was significantly better with IMRT compared to 3D-CRT (1.127 vs. 1.254, $p < 0.001$) for PMRT to the left chest wall **(11)**. This study corroborates these findings, demonstrating improved homogeneity and conformity with IMRT for the right chest wall (HI: 0.10 vs. 0.18, $p < 0.0001$ and CI: 0.96 vs. 0.87, $p < 0.0001$).

Right And Left Lung:

Edwards-Bennett S.M. et al. found that IMRT reduced the ipsilateral lung V20 compared to 3D-CRT (42 vs. 36.7, p=0.022) in patients with locally advanced right breast cancer undergoing PMRT **(8)**. **Smith et al.** showed that IMRT reduced heart V30 and lung V20 compared to conventional plans for breast cancer treatment **(12)**.**Xie X et al.** observed that IMRT significantly increased the volume receiving >5 Gy (V5) in the contralateral lung and the percentage of volume receiving >5 Gy and >13 Gy in the ipsilateral lung compared to 3D-CRT ($p<0.017$)**(13)**.This study aligns with previous findings on right lung dosimetric parameters. IMRT significantly increased right lung V5 (63.42 vs. 42.85, $p<0.0001$) and V10 (43.36 vs. 35.19, $p<0.0001$) compared to 3D-CRT, but reduced V20 (28.31 vs. 30.80, p=0.043) and V30 (21.67 vs. 27.89, $p<0.0001$). The mean dose to the right lung showed no significant difference between 3D-CRT (15.44) and IMRT (15.56). IMRT also increased low-dose exposure (V5) to the left lung (0.14 vs. 0, p=0.038) compared to 3D-CRT.

Heart:

Edwards-Bennett S.M. et al. reported that IMRT increased the mean heart dose from 1.69 Gy to 2.95 Gy ($p < 0.001$) compared to 3D-CRT for PMRT to the right chest **(8)**. **Rastogi K et al.** found that IMRT significantly reduced high-dose heart volumes compared to 3D-CRT (V25: 4.59% vs. 9.19%, V45: 1.85% vs. 7.09%, $p < 0.001$), but 3D-CRT had lower low-dose heart volumes (V5: 23.27% vs. 31.02%, $p < 0.001$) **(11)**. This study corroborates these findings, with mean heart doses at V5 and V10 for 3D-CRT being 1.64 and 0.78, compared to 11.48 and 4.36 for IMRT, both statistically significant ($p < 0.0001$). This indicates that 3D-CRT resulted in lower heart volumes receiving low doses compared to IMRT. Additionally, IMRT delivered a higher mean heart dose (2.22 vs. 1.05, $p < 0.0001$). Only V20 (0.35 vs. 0.61, p=0.24) and V30 (0.18 vs. 0.12, p=0.44) showed non-significant differences between 3D-CRT and IMRT groups.

Contralateral Breast:

Koksal C. et al. found that IMRT increased the contralateral breast mean dose, D2%, and V5 compared to 3D-CRT in both supine (V5: 2.51 vs. 0.01, p=0.008) and prone (V5: 2.70 vs. 0.18, $p < 0.008$) positions**(14)**. **Edwards-Bennett S.M. et al.** observed an increase in the mean contralateral breast dose from 0.92 Gy with 3D-CRT to 3.47 Gy with IMRT ($p < 0.001$)**(8)**. This study aligned with these findings, showing that the mean V5 for the contralateral breast was significantly higher in the IMRT group compared to the 3D-CRT group (3.30 vs. 1.79, p=0.03), though the mean dose was not significantly different (0.76 vs. 0.57, p=0.182). The increased V5 with IMRT could potentially lead to higher long-term risks for radiation-induced secondary malignancies in the contralateral breast. **Stovall et al. (2008)** highlighted this risk, finding a correlation between low-dose radiation exposure to the contralateral breast and increased risk of secondary breast cancer**(15)**.

Liver:

Chen S et al. compared the dosimetric parameters of various breast radiation therapy techniques, including 3D-CRT, IMRT, VMAT, Electronic compensation, and Hybrid techniques in 30 patients (13 right sided and 17 left sided). Their findings indicated that IMRT resulted in a significantly higher mean dose to the liver (6.56 Gy) compared to 3D-CRT (1.22 Gy), with a p-value of <0.001**(16)**. This study showed similar results. The mean liver dose (Dmean) was 7.56 Gy for the 3D-CRT group and 12.39 Gy for the IMRT group, with a p-value of <0.0001, indicating a highly statistically significant difference.

Spinal Cord:

Phansopkar DA et al. evaluated the dose distribution of tangential beam IMRT compared to tangential beam 3D-CRT in breast carcinoma treatment. Their results indicated that the spinal cord received a lower mean dose with IMRT (33.333 centiGy) compared to 3D-CRT (74.537 centiGy), though this difference was not statistically significant (p=0.068) **(17)**. Similarly, this study showed that the mean Dmax values for the spinal cord (with SCF field) were 37.37 Gy for 3D-CRT and 37.54 Gy for IMRT, with a p-value of 0.91, indicating no statistically significant difference between the two techniques.

VI. CONCLUSION:

IMRT offers significant advantages over 3D-CRT in post-mastectomy right breast cancer patients by demonstrating superior dosimetric parameters, improved conformity, and homogeneity indices. This leads to more precise treatment with fewer acute and long-term toxicities and effectively reduces high-dose radiation exposure to critical organs such as the heart and ipsilateral lung. However, IMRT also increases the mean dose to the liver and low-dose radiation volumes to the heart, lungs, and contralateral breast. This highlights the importance of careful planning to minimize exposure to surrounding healthy tissues by incorporating methods such as respiratory gating and deep inspiration breath hold (DIBH). In conclusion, selecting the appropriate radiotherapy technique for breast cancer is crucial to protect nearby normal structures and identify associated risks. A thorough evaluation of the patient profile and the resources available at the treatment centre is essential to determine the most suitable method. concise for abstract

Limitations: The study's limitations include a relatively small patient sample. Conducted at a single institution, potential biases related to specific protocols and equipment could affect the reproducibility of results in other clinical settings. Additionally, the follow-up duration was limited, and the absence of respiratory gating methods, crucial for IMRT, was noted.

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