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DOSIMETRIC EVALUATION OF BREATHING IMPACT ON PLANNING TREATMENT VOLUME AND ADJACENT ORGAN AT RISKS IN BREAST CANCER RADIOTHERAPY

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Keywords
IMRT-FT (intensity modulated radiotherapy with flash tools), OARs (Organs at risk), PTV (Planning target volume), HI (Homogeneity index), CI (Conformity index), CF (Coverage factor)

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Abstract

Background: *Radiotherapy for breast cancer uses high energy rays or particle to eliminate cancer cells, particularly to reduce the risks of recurrence after surgery. It is a common treatment that is performed after breast conserving surgery (lumpectomy) or after mastectomy, especially if the malignancy was big or included lymph nodes. The breast, by virtue of its location, is affected by motion, which can lead to target missing during breast radiotherapy. Therefore, it is essential to evaluate the dosimetric impact of breathing motion on breast cancer radiotherapy treatment planning.*

Method: *The data was collected from November, 2024 to January 2025 from the Radiotherapy Department of Institute of Nuclear Medicine and Oncology Lahore (INMOL). The selected patients for this work was very critical as most of patients had difficulty tobreath hold. Especially for case of exhale. So young patients had been preferred for this study to avoid breath hold issues. The study evaluated three breathing scenarios: normal breathing, Deep Inspiration Breath Hold (DIBH), and Expiratory Breath Hold (EBH). Three treatment planning techniques were compared 3D Conformal Radiotherapy (3D CRT), Intensity Modulated Radiotherapy (IMRT), and Intensity Modulated Radiotherapy with Flash Tools (IMRT-FT). Treatment plans were evaluated using parameters like Homogeneity Index (HI), Conformity Index (CI), and Coverage Factor (CF).*

Results: *The study's results show that IMRT and IMRT-FT provide more homogenous dose distributions and better compliance to the planed target volume (PTV) than 3D CRT. IMRT and IMRT-FT had lower Homogeneity Index (HI) values (0.075 and 0.051 respectively) and Conformity Index (CI) values (1.285 and 1.254, respectively) than 3D CRT (HI: 0.125, CI: 2.082). However, IMRT without flash tools had lower target coverage, with a Coverage Factor (CF) value of 0.934 compared with 3D CRT, which had a CF value of 0.997. The use of flash tools in IMRT-FT enhanced target coverage, with a CF value of 0.980, making it a more suitable option for breast cancer radiotherapy.*

Conclusion: *In this study, we concluded that IMRT-FT is suitable treatment planning approach for breast cancer radiotherapy, with superior dosimetric results than 3D CRT and IMRT. The employment of flash tools in IMRT-FT enhances target coverage and reduces the risk of target missing.*

INTRODUCTION

Around one million more cases of breast cancer are identified each year, making it the most common disease among women worldwide. With around 458,000 deaths each year, it is one of the leading causes of cancer-related mortality in women. Understanding the disease's epidemiology, risk factors, diagnosis, and treatment options is essential for efficient management of this serious public health issue (1).

Breast cancer develops as a result of a number of risk factors. These include ionizing radiation exposure, thick breast tissue, late delivery, frequent use of oral contraceptives, obesity, family history, and genetic abnormalities (BRCA1 and BRCA2). While certain cases of breast cancer are at random, occurring at unpredictable intervals, others are inherited (2).

MRI, ultrasound, and mammography are among the imaging procedures used to diagnose breast cancer. Examining tissue samples and detecting the presence of cancer cells are further uses for biopsy. For improved outcomes and an effective course of therapy, early diagnosis is essential (3).

Breast cancer is staged depending on the tumor's size, lymph node spread, and metastasis to other organs (4). The phases range from 0 (non-invasive) to 4 (invasive and metastatic). Accurate staging is essential for deciding on the best course of therapy (5)

Breast cancer treatment options include surgery, chemotherapy, and radiation. Radiotherapy, in particular, has proven to be successful for eliminate locally seeded tumors (6). Techniques such as 3D conformal radiation and intensity-modulated radiotherapy (IMRT) have increased tumour coverage while reducing harm to adjacent healthy tissues (7).

Plan evaluation indicators such as Homogeneity Index (HI), Conformity Index (CI), and Coverage Factor (CF) are critical when assessing the efficacy of treatment programs. These factors serve to guarantee that the radiation dosage is spread equally throughout the target volume while minimizing exposure to healthy tissues (8).Breast cancer is an incurable disease that needs a thorough approach to diagnosis and treatment. Understanding the risk factors, diagnosis, staging, and treatment choices is critical to optimal management (9). Continued research and developments in treatment methods, like as radiation, are crucial to better patient outcomes. Medical professionals may enhance the knowledge of breast cancer and devise successful treatment plans by summarizing its essential elements (10)The dosimetric evaluation and impact of breathing (Normal breathing, DIBH and EBH) on PTV and OARs in breast cancer for different modalities (3D CRT, IMRT and IMRT withflash tools).

METHODOLOGY

Research Design

The research is being done on prospective or retrospective cohort study. This study aims to evaluate the impact of breathing motion on PTV and OARs in breast cancer radiotherapy. I collected imaging data and breathing patterns from breast cancer patients, created treatment plans and calculated dose distribution, provided insights into the importance of motion management in breast cancer radiotherapy.

Clinical Settings

The research is conducted at Institute of Nuclear Medicine and Oncology Lahore (INMOL). It provided the necessary infrastructure and expertise to conduct the study and data collection on the impact of breathing motion PTV and OARs in breast cancer radiotherapy.

Sample Size

Total coverage during the study's time-frame included 22 patients. The selected patients for this work was very critical as most of patients have difficulty to breath hold. Especially for case of exhale. So young patients preferred for this project work to avoid breath hold issues. In this work, 22 breast cancers selected for data acquisition at Institute of Nuclear Medicine and Oncology (INMOL) Lahore, Department of Physics and Applied Mathematics (DPAM). The volume of lungs for normal breathing, inhale and exhale noted down. The volume of lungs for inhale must be greatest and that of exhale must be smallest for correct data acquisition. As most of patients had breathing problem especially in exhale. That is why, most patient data did not match the above criteria. Out of 22 patients only 10 patients fulfilled this criteria.

Sampling Technique
This data collected by a convenience sampling technique. In this technique selected participants base on specific criteria, such as:

- Breast cancer diagnosis
- Undergoing radiation therapy
- Availability of breathing motion data

Duration of Study
The duration of study is 6 months after approval of synopsis; from November, 2024 to June, 2025. The participants for the study will be recruited from November, 2024 to January, 2025 and data will be statically analyzed from April, 2025 to June, 2025.

Selection Criteria
Inclusion Criteria

- Female patient aged from 25 years to 45 years.
- Ductal carcinoma in situ (DCIS)
- Patients having lumpectomy
- Patients receiving specific amount of radiotherapy treatment

Exclusion Criteria

- Non-unifocal breast tumor
- Patient having metastasis
- Pregnant patients

Ethical Considerations
Ethical approval for the study was taken from the ethics and research committee of the university and hospital as well. All the data collected from the hospital will be kept in password-protected folder.

Data Collection Procedure
The Deep Inspiration Breath Hold (DIBH) method is utilized during breast cancer therapy to reduce radiation exposure to the heart, especially for left-sided breast tumors. Patients take a long exhalation and hold it, elevating their heart away from radiation exposure zone. This approach, when paired with Intensity-Modulated Radiation Therapy (IMRT), allows for very accurate radiation delivery while reducing the risk to nearby healthy tissues, including the heart. IMRT controls the strength of radiation beams, increasing dosage distribution while protecting healthy tissues. Combining each of these strategies improves treatment results, increases safety, and may lessen the need for additional therapy sessions.

Data Analysis
Data analyzed on Excel by Wilcoxon Signed-Rank Test. This is on-parametric statically test used to compare two related samples or repeated measurements on single sample. In this study, this test used to compare dosimetric parameters, (like PTV coverage, OARs doses) between different breathing phases or motions scenarios.

Results
This chapter explains the results that are obtained after calculating the evaluating parameters and doses to OARs. The evaluating parameters are homogeneity index, conformity index and coverage factor. The results of the 10 breast cancer patients for the evaluating parameters are represented in the form of bar figures and their mean values are calculated as well up to three significant figures.

Homogeneity Index
The results of the Homogeneity index (HI) are presented in Figure 4-1.
Mean value of HI for the three modalities of 3D CRT, IMRT and IMRT-FT of figure 4-1 is 0.125, 0.075 and 0.051 respectively (up to three significant figures). HI for 3D CRT is on higher side of ideal value (=1). Limited number of gantry angle for 3D CRT results in higher dose to PTV and thus consequently higher the value of HI from ideal value. Figure 4-1 also depicts that HI are significantly improved in case of IMRT and IMRT-FT as compared to 3D-CRT. The reason is more the

number of gantry angle to PTV, gives homogeneous dose to PTV.

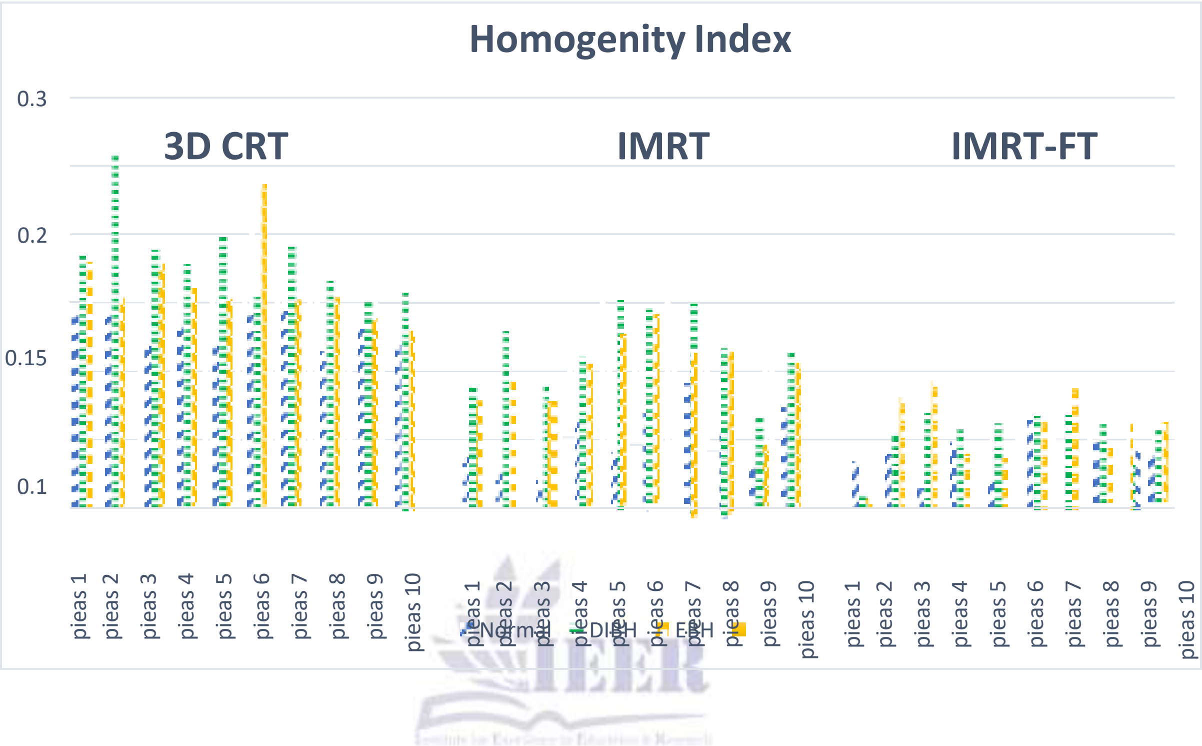

Figure 4-1 Homogeneity index of three modalities (3D CRT, IMRT and IMRT-FT).

Figure 4-1 Homogeneity index of three modalities (3D CRT, IMRT and IMRT-FT).

Conformity Index

The results of the Conformity Index (HI) are presented in Figure 4-2.

Mean value of CI (ideal value = 1) for the three modalities of 3D CRT, IMRT and IMRT- FT of figure 4-2 are 2.082, 1.285 and 1.254 respectively (up to three significant figure). CI for 3D-CRT in figure 4-2 is on higher side ideal value. This is due to limited number of gantry angle increases the volume of reference iso-dose curve compared to volume of PTV,results in higher the value of CI.

Also from figure 4-2, IMRT and IMRT-FT gives improved results of CI due to increased number of gantry angles which results in very conform reference iso-dose curve around the PTV. Hence gives improved results of CI for IMRT and IMRT-FT as comparedto 3D-CRT. Similarly CI in case IMRT and IMRT-FT is as compared to 3D-CRT.

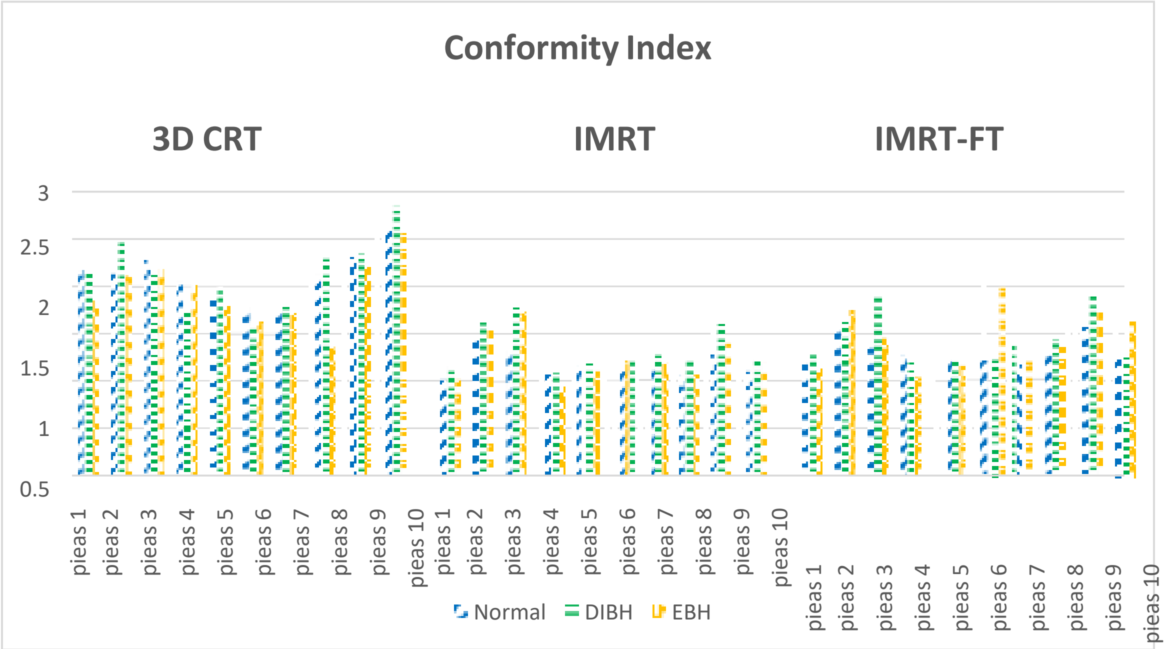

Figure 4-2 Conformity index of three modalities (3D CRT, IMRT and IMRT-FT).

Coverage Factor

The results of the Coverage Factor (CF) are presented in Figure 4-3.Mean value of CF (ideal value = 1) for the three modalities of 3D CRT, IMRT and IMRT-FT of figure 4-3 are 0.997, 0.934 and 0.980 respectively (up to three significant figures). Figure 4-3 represents that 3D-CRT show good target coverage irrespective of the breathingcycle. This is due to the large field opening in air compensates breathing related issues. Figure 4-3 also depicts that's coverage factor for IMRT gets poorer as compared tothat for 3D-CRT. This is due to tight packing of MLCs around the target as a consequencetarget is being missed for case of DIBH and EBH. Hence for IMRT without using flash tools, over all mean value for coverage factor becomes poorer as compared to 3D-CRT.

The mean values of HI, CI and CF of 3D-CRT modality, recorded only for normalbreathing scans are 0.131, 2.113 and 0.971 respectively. Similarly these values of normal scans for IMRT without flash tools are 0.053, 1.167 and 0.970 respectively. Comparing the results of evaluating parameters for both modalities shows IMRT is better option of breastradiotherapy for normal breathing technique. The mean values of HI and CI are calculated 1.12 and 0.33 for 3D-CRT and 1.10 and 0.77 for IMRT in paper (39). Results of HI for ourwork are better but for CI are slight poorer than (40).

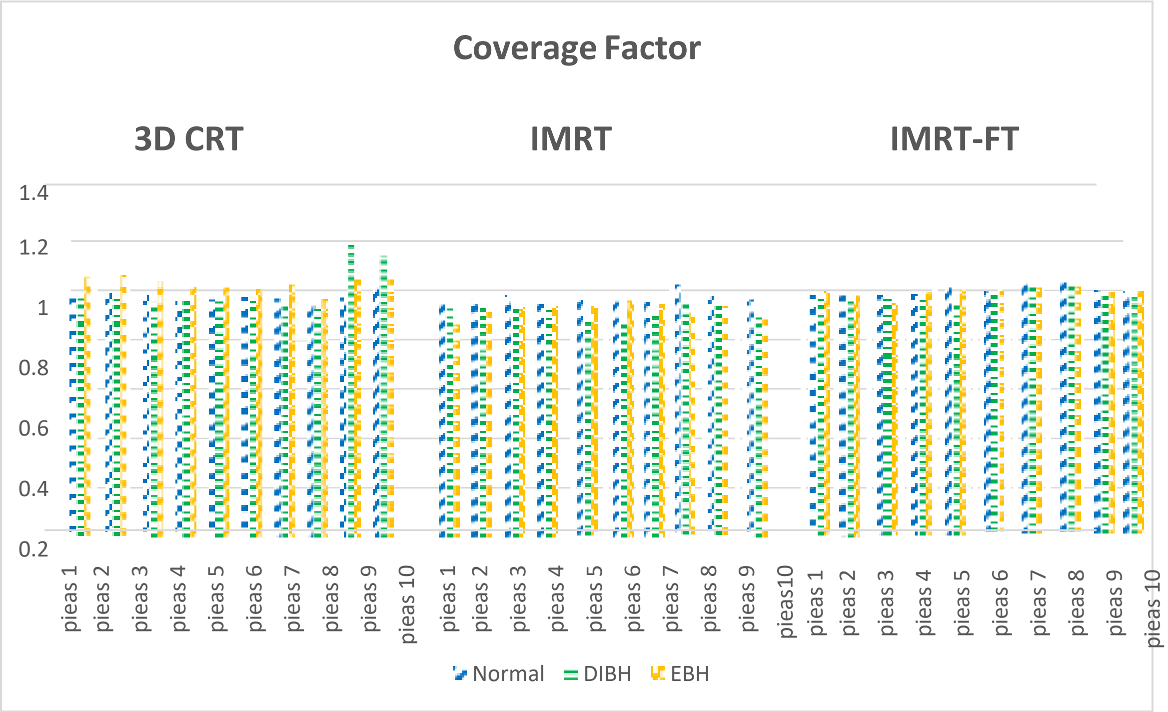

Figure 4-3 Coverage factor of three modalities (3D CRT, IMRT and IMRT-FT).

CF for IMRT-FT shows very improved result (figure 4-3) as compared to IMRT without flash tools. The reason is using flash skin tools i.e. using this tool, provides desired margins between PTV and MLCs which compensates for the target missing in case of DIBH and EBH.

Doses of OARs

Table 4.1 presents the mean doses to OARs for the three breathing scenarios amongst the various modalities.

Table 4.1 OARs means values of doses in gray of different Modalities

Breathing Technique	Normal	DIBH	EBH
Ipsilateral Lung (V30%)			
3D CRT	14.876	18.406	16.34
IMRT	17.56	18.32	18.04
IMRT-FT	17.93	18.74	18.22
Spinal Cord (Dmax)			
3D CRT	12.6005	10.6332	10.6565
IMRT	12.4614	11.7532	11.6065
IMRT-FT	13.5243	14.7648	14.6754
Heart (DMean)			
3D CRT	4.9234	4.0885	3.8253
IMRT	4.6432	5.3241	5.1023
IMRT-FT	5.4324	5.6874	5.7546

Table 4.1 shows no major changes in the doses of OARs of the three different breathing techniques (normal breathing, DIBH and EBH) for the three modalities. The doses to OARsfor IMRT and IMRT-FT can be further reduced as compared to that of 3D-CRT with betterplanning expertise. Doses to OARs recorded in (41) are V30% = 28.14Gy of Ipsilateral lung, D_{mean} = 8.815Gy of heart and D_{max} = 8.079Gy of spinal cord for 3D-CRT. Similarly, V30% = 15.95Gy of Ipsilateral lung, D_{mean} = 13.024Gy of heart and D_{max} = 19.90Gy of spinal cordfor IMRT without skin flash tools. Comparing the results of OARs with (42), the present results are within limits for constrains except for spinal cord in case of 3D-CRT.

Comparison of DVHs of PTV and OARs

Figure 4-4 presents Dose Volume Histograms (DVH) for PTV and OARs are copied fromeclipse planning system. These values are plotted on mat lab as shown below. IMRT with flash tools gives smallertail than IMRT without flash tools and thus more homogenous dose to tumor as depicted from figure 4.4. This is because of 1 cm margin to MLCs in case of IMRT with flash tools. Dose to PTV is more homogenous in case of IMRT with or without flash tools than 3D CRT.

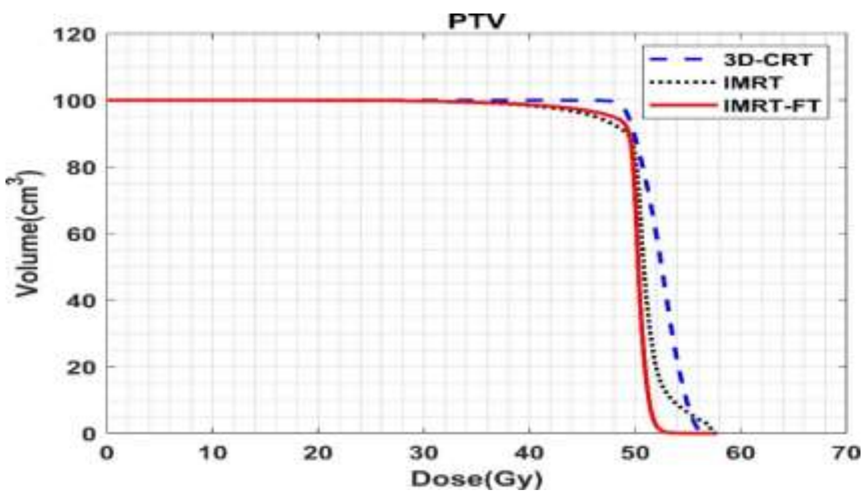

Figure 4-4 DVH of PTV for the three modalities.

Figure 4-5 shows that low dose volume is slightly higher in case IMRT with or without flash tools as compared to 3D CRT but High dose volume for IMRT with or without flash tools is sharply lower than 3D CRT.

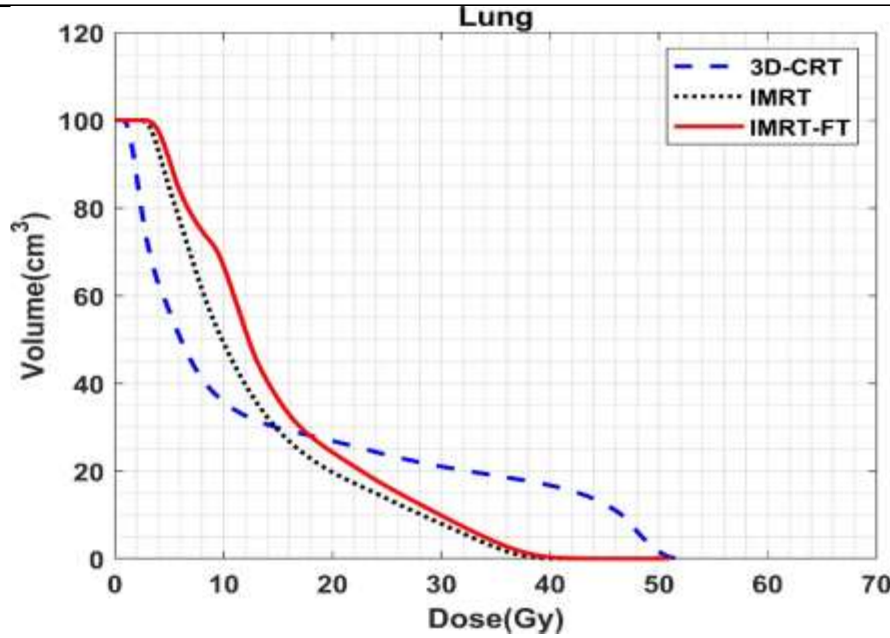

Figure 4-5 DVH of ipsilateral breast for the three Modalities.

Figure 4.6 shows slight higher doses to heart in case of IMRT with or without flash tools than 3D CRT. These doses can be reduced more than 3D CRT with better expertise of treatment planning.

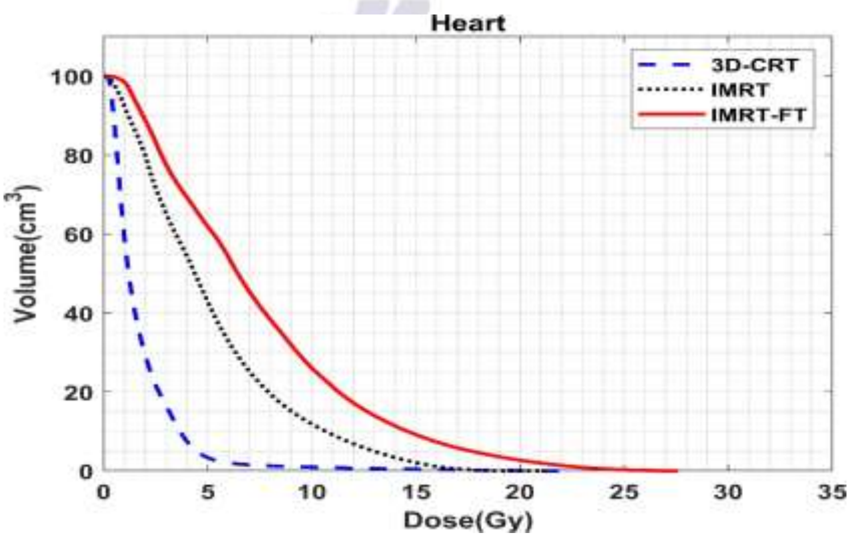

Figure 4-6 DVH of heart for the three Modalities.

DISCUSSION

The outcome of this study indicate the impacts of several radiation therapy modalities (3D CRT, IMRT and IMRT-FT) on dosimetric parameters and organ at risks (OARs) in breast cancer treatment. Evaluation measures, such as homogeneity index (HI), conformity index (CI), and coverage factor (CF), provide insights into the quality of treatment plans. The HI results demonstrate that IMRT and IMRT-FT give more homogenous dose distribution than 3D CRT. The mean HI value for IMRT and IMRT-FT are 0.075 and 0.015, respectively, which are much lower than the mean HI value for 3D CRT (0.125). This improvement in HI can be defined to the increase number of gantry angles used during IMRT and IMRT-FT, allowing for more precise dose administration. The CI outcomes indicate that IMRT and IMRT-FT have higher conformity to the plan target volume (PTV) than 3D CRT. The mean CI value for IMRT and IMRT-FT are 1.285 and 1.254, respectively, both lower than the mean CI value for 3D CRT (2.082). This increase in CI can be ascribed to the capacity of IMRT and IMRT-FT to achieve a more conformal dose distribution around the PTV. The CF conclusions show that 3D CRT provide strongly target coverage, with an average CF value of 0.997. However, without flash tools, IMRT provide lower target coverage, with a mean CF value of 0.934. This is due to tight packing of multi-leaf collimators (MLSs) around the target, which can be cause target lose during deep inspiration breath-hold (DIBH) and end-expiration breath hold (EBH). The employment of flash tools in IMRT-FT increases target coverage, with an average CF value of 0.980. The results demonstrate no significant variation in doses to OARs (ipsilateral lungs, spinal cord, and heart) to the three breathing techniques (normal breathing, DIBH, and EBH) for three modalities. However, OARs doses can be further reduced with better planning expertise, notably for IMRT and IMRT-FT. The results of this study correspond with those published in the literature. The HI and CI values for IMRT and IMRT-FT are consistent with prior studies, providing these modalities' advantage in producing homogenous and conformal dose distribution. The dosage for OARs similarly within the limits stated in the literature. The major findings of this study have significant therapeutic relevance for breast cancer therapy. The use of IMRT and IMRT-FT can enhance dose distribution and minimize dose to OARs, perhaps leading to better treatment results and less toxicity. Using flash tools in IMRT-FT can increase target coverage and lessen the probability of target misses. Finally, this study demonstrate that IMRT and IMRT-FT outperform 3D CRT in terms of providing homogenous and conformal dose distribution for breast cancer therapy. The employment of flash tools in IMRT-FT can increase target coverage while reducing the probability of target misses. With improved planning skills, OAR doses can be reduced even more. The findings have significant clinical implications for breast cancer treatment, indicating the need for more research to validate them.

CONCLUSION

Comparing the results of 3D-CRT with that of IMRT shows that homogeneity index and conformity index are improved for IMRT than 3D-CRT. This is due to large number of gantry angle for an IMRT plan. But coverage factor for 3D-CRT (mean value 0.997) shows improved result as compared to IMRT (mean value 0.934). The reason for poor result in case of IMRT is due to missing of PTV in case of DIBH and EBH for to tight packing of MLCs around PTV. Comparing the results of 3D-CRT with that of IMRT-FT shows better result of homogeneity index and conformity index for IMRT-FT as compared 3D-CRT due to samereason of large number of gantry angles. Similarly coverage factor results are almost same for 3D-CRT (mean value 0.997) and IMRT-FT (mean value 0.980). The reason is flash tools provides 1 cm margins for MLCs around PTV to compensates for DIBH and EBH. Doses to organ at risks shows not any significant changes for the three treatment techniques. Even the doses to OARS can be reduced for IMRT and IMRT-FT as comparedto 3D-CRT with better treatment expertise. Final conclusion is IMRT with skin flash tools (IMRT-FT) is best modalitycompared to other two modalities (3D-CRT and IMRT without skin flash tools) for case of the three different breathing techniques i.e. Normal Breathing, deep inspiratory breath hold (DIBH) and expiratory breath hold (EBH).

Future Recommendations

IMRT with skin Flash tools need patient repositioning with high accuracy. Three reference points as in 3D CRT are insufficient for highly conformed target IMRT Radiotherapy thatis why we need infrared surface scan cameras for high accuracy repositioning. For this purpose recently a new surface-based monitoring techniques has been developed with thebenefit to setup the patient in 3D without the use of ionizing radiations (Infrared cameras).Before delivering each fraction an image of breast is acquired and is than compared with the reference surface model. This type of treatment is delivered globally.

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