Dosimetric comparison of 3DCRT versus RapidArc in terms of iso-dose distribution, dose volume histogram (DVH) and dosimetric results for the PTV and critical organs for breast cancer

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Abstract **Purpose:** The Aim of this study is to compare (3D-CRT) to RapidArc planning using (LNAC of 6 MV, 15 MV and 18 MV) in terms of dosimetric outcomes of iso-dose distribution, dose volume histogram (DVH), PTV and at risk organs in 11 patients with glioblastoma (GBM). **Methods**: Plans were created for 6 patients with breast cancer who had received radical RapidArc treatment from 2012 to 2014 at KAMC (King Abdullah Medical City). Dosimetric evaluation metrics were used to compare the two plans in terms of mean, maximum and minimum doses to PTV, Homogeneity Index (HI), Conformity Index (CI), Target Coverage Index (TCI) and mean and maximum doses to critical organs and normal tissue. Dose to 95% of the PTV (D95%) was used to quantify PTV coverage. **Results:** Table (3.15) and (3.16), showing the mean value of the PTV which was (51.38 ± 2.172) in RapidArc compared to(52.21 ± 1.963) in 3D-CRT , which means that RapidArc plan achieved lower mean and maximum doses to the PTV. The maximum dose to the PTV in RapidArc was higher compared to 3D-CRT with lower maximum dose to the PTV, (p = 0.011). This results explain the statistical advantage in PTV coverage metrics in RapidArc modality. PTV dose coverage, as measured by the minimum dose and the dose to 95% of the volume, was higher in the RapidArc plan. RapidArc plan also showed a more homogeneous dose distribution in PTV, achieving an HI of 1.262 ± 0.037 compared with 1.271 ± 0.024 in the 3D-CRT plan. However, RapidArc and 3D-CRT achieved similar CI values and improvement in target coverage index (TCI) in which (TCI) in RapidArc was (0.006 ± 0.003) and (0.008 ± 0.006) in 3D-CRT, (P = 0.202). **Conclusions**: (VMAT) is superior to 3D-CRT in term of PTV, conformity and homogeneity and accepting the VMAT class solution over 3D-CRT treatment was preferred to be determined on a case by case basis for breast cancer.

Keywords *Planning Tumor Volume; Organs at Risk; Conformity Index; Heterogeneity Index; Breast cancer,*

1. Introduction

1.1. Management of Patients with Cancer

The optimal care of patients with malignant tumors is a multidisciplinary effort that combines classic modalities, surgery, radiation therapy, and chemotherapy. The role of the radiation oncologist is to assess all conditions relative to the patient and tumor, to systematically review the need for diagnostic and staging procedures, and, in consultation with other oncologists, determine the best therapeutic strategy. Radiation oncology includes the clinical and scientific discipline devoted to management of patients with cancer (and other diseases) with ionizing radiation (alone or combined with other modalities), investigation of the biologic and physical basis of radiation therapy, and training of professionals in the field. The aim of radiation therapy is to deliver a precisely measured dose of irradiation to a defined tumor volume with minimal damage to surrounding healthy tissue. This results in eradication of the tumor, increased quality of life, and prolongation of survival at a competitive cost, and allows for effective palliation or prevention of symptoms of cancer, including pain,

restoring luminal patency, skeletal integrity, and organ function, with minimal morbidity [1,2].

1.2. Process of Radiation Therapy

The goal of therapy should be defined at the onset of therapeutic intervention: • Curative: There is a probability of long-term survival after adequate therapy. Some side effects of therapy, although undesirable, may be acceptable. • Palliative: There is no hope of survival for extended periods. Symptoms producing discomfort or an impending condition that may impair comfort or self-sufficiency require treatment. No major iatrogenic conditions should be observed. Relatively high doses of irradiation (sometimes 75% to 80% of the curative dose) are required to control the tumor for the survival period of the patient [3].

1.*3. Basis for Prescription of Irradiation*

The basis for Prescription of Irradiation includes Evaluation of the extent of the tumor (staging), including diagnostic studies, knowledge of pathologic characteristics of the disease, definition of the goal of therapy (cure or palliation), selection of appropriate treatment modalities (irradiation alone or combined with surgery, chemotherapy, or both), determination of the optimal dose of irradiation and volume to be treated, according to anatomic location, histologic type, stage, potential regional nodal involvement (and other tumor characteristics), and normal structures in the region. It also includes evaluation of the patient's general condition, plus periodic assessment of tolerance to treatment, tumor response, and status of normal tissues treated and Ultimate responsibility for treatment decisions, technical execution of therapy, and consequences of therapy always rests with the radiation oncologist [1,4].

1.4. Radiation Treatment Planning

Different irradiation doses are required for various probabilities of tumor control, depending on the tumor type and the initial number of clonogenic cells present. Various radiation doses can be delivered to specific portions of the tumor periphery versus central portion) or to the tumor bed in cases in which the entire gross tumor has been surgically removed. The International Commission on Radiation Units and Measurements Reports Nos. 50 and 62 define the following treatment planning volumes [5,6]: Gross tumor volume (GTV): all known gross disease, including abnormally enlarged regional lymph nodes. To determine GTV, appropriate computed tomography (CT) window and level settings that give the maximum dimension of what is considered potential gross disease must be used. Clinical target volume (CTV): Encompasses GTV plus regions considered to harbor potential microscopic disease. Planning target volume (PTV): provides margin around CTV to allow for internal target motion, other anatomic motion during treatment (e.g., respiration), and variations in treatment setup. PTV does not account for treatment machine beam characteristics [7]. Treatment portals must adequately cover all treatment volumes plus a margin to account for beam physical characteristics, such as penumbra. Simulation is used to accurately identify target volumes and sensitive structures and to document configuration of portals and the target volume to be irradiated. Treatment aids (e.g., shielding blocks, molds, masks, immobilization devices, compensators) are extremely important in treatment planning and delivery of optimal dose distribution. Repositioning and immobilization devices are critical because the only effective irradiation is that which strikes the clonogenic tumor cells [8]. Simpler treatment techniques that yield an acceptable dose distribution are preferred over more costly and complex ones, which may have a greater margin of error in day-to-day treatments. Accuracy is periodically assessed with portal (localization) films or on-line (electronic portal) imaging verification devices. Portal localization errors may be systematic or may occur at random [7].

1.5 *Three-Dimensional Treatment Planning*

CT simulation allows for a more accurate definition of target volume and anatomy of critical normal structures, three-dimensional (3-D) treatment planning to optimize dose distribution, and radiographic verification of the treated volume [9]. Advances in computer technology have augmented accurate and timely computation, display of 3-D radiation dose distributions, and dose-volume histograms that yield relevant information for the evaluation of tumor extent, definition of target volume, delineation of normal tissues, virtual simulation of therapy, generation of digitally reconstructed radiographs, design of treatment portals and aids, calculation of 3-D dose distributions and dose optimization, and critical evaluation of the treatment plan [10]. Dose-volume histograms are useful in assessing several treatment plan dose distributions and providing a complete summary of the entire 3-D dose matrix, and showing the amount of target volume or critical structure receiving more than the specified dose. They do not provide spatial dose information and cannot replace other methods of dose display [11]. 3-D treatment planning systems play an important role in treatment verification. Digitally reconstructed radiographs based on sequential CT slice data generate a simulation film that can be used in portal localization and for comparison with the treatment portal film for verifying treatment geometry [12]. Increased sophistication in treatment planning requires parallel precision in patient repositioning and immobilization, as well as in portal verification techniques. Several real-time, on-line verification systems allow monitoring of the position of the area to be treated during radiation exposure. Computer-aided integration of data generated by 3-D radiation treatment planning with parameters used on the treatment machine, including gantry and couch position, may decrease localization errors and enhance the

precision and efficiency of irradiation [13].

1.6 *Intensity-Modulated Radiation Therapy*

Intensity-modulated radiation therapy (IMRT), a new approach to 3-D treatment planning and conformal therapy, optimizes delivery of irradiation to irregularly shaped volumes through complex forward or inverse treatment planning and dynamic delivery of irradiation that results in modulated fluency of multiple photon beam profiles. Inverse planning starts with an ideal dose distribution and identifies, through trial and error or multiple iterations (simulated annealing), the beam characteristics (fluence profiles). It then produces the best approximation of the ideal dose defined in a 3-D array of dose voxels organized in a stack of two-dimensional arrays [12]. Other approaches to achieve IMRT include the step-and-shoot method, with a linear accelerator and multileaf collimation (MLC), which uses a variety of portals at various angles. The MLC determines photon-modulated fluency and portal shape by the dynamic computer-controlled IMRT being delivered when the configuration of the portals with the MLC changes at the same time that the gantry or accelerator changes positions around the patient.. In helical tomotherapy, a photon fan beam continually rotates around the patient as the couch transports the patient longitudinally through a ring gantry. The robotic arm IMRT system (Cyberknife) consists of a miniaturized MV photon linear accelerator mounted on a highly mobile arm and a set of ceiling-mounted x-ray cameras to provide near real time information on the patient's position and target exposure during treatment [14]. The majority of IMRT systems use 6 MV x-rays, but energies of 8 to 10 MV may be more desirable in some anatomic sites to decrease skin and superficial subcutaneous tissue dose [15].

1.*7 Quality Assurance*

A comprehensive quality assurance (QA) program is critical to ensure the best treatment for each patient and to establish and document all operating policies and procedures. QA procedures in radiation therapy vary, depending on whether standard treatment or a clinical trial is carried out, and if such treatments and trials occur at single or multiple institutions. In multi-institutional studies, it is important to provide all participants with clear instructions and standardized parameters in dosimetry procedures, treatment techniques, and treatment [16].

1.8 Principles of IMRT:

The concept of IMRT was not applied until the 1990s. The software and hardware were not available before that time [17]. IMRT is a more advanced mode of conformal radiotherapy and an extension of 3-dimensional conformal radiation therapy (3D-CRT) that includes the use a larger number of x-ray beam compared to 3D-CRT. Therefore, large volumes of healthy tissue are exposed to low levels of radiation [18,19]. IMRT allows for appropriate conforming of the high and low doses to the target and healthy tissue, by creating non-uniform radiation beam intensities across the irradiation field. This creation can be performed in two ways: step and shoot (static technique) or sliding window (dynamic technique) [14,19,20]. Intensity modulated arc therapy (IMAT) is the next step in IMRT radiation delivery, whereby the gantry rotates around the patient and the radiation dose is delivered continuously in an arc [14]. It is possible to summarize the advantages of IMRT in good sparing to critical structures and fairly quick planning. However, the disadvantages include complex QA and longer treatment time.

1.9 *Volumetric modulated arc therapy (VMAT):*

Volumetric modulated arc therapy (VMAT) is a novel from of IMRT that allows the radiation to be delivered to the patient in a single 360◦ of gantry rotation that is accurately and efficiently with varying velocities and positions of the MLC, dose rate and gantry speed. This leads VMAT being an intensity-modulated dose distribution [21]. RapidArc (Varain medical system) is a form of VMAT [22]. RapidArc (RA) is intended to protect healthy tissue more than other techniques and to improve target coverage distribution and treatment time, and attain accurate dosimetric delivery to have the ideal dose distribution. VMAT has many different advantages over conventional modality 3D-CRT [20]. The fundamental feature is treatment time. VMAT treatment time was 1.3 minutes, IMRT treatment time was 8 minutes and 3D-CRT was 3 minutes [23,].Other studies have demonstrated a similar decline in treatment time between VMAT and 3D-CRT. Depending on decreased treatment time in the machine, patient comfort, compliance and throughput increased. The main disadvantage of VMAT is the increased optimization time compared to 3D-CRT. Shannon M. MacDonald et al. [24] compared 3D-CRT with IMRT for 20 patients treated for high – grade glioma. The prescribed dose was 59.4 Gy. The authors showed that IMRT was superior in target coverage compared with 3D-CRT plans, and effectively reduced radiation dose to the brain, brain stem and optic chiasm. David Palam et al. [21] compared three techniques: VMAT, IMRT and 3D-CRT for 10 patients with prostate cancer. The comparison showed lower doses to normal critical structure and achieved highly conformal treatment plans in VMAT and IMRT over 3D-CRT plans. Luca Cozzi et al. [25] used a treatment planning system to compare Volumetric Arc Modulation with RapidArc and IMRT for cervix uteri of 8 patients. Both RA and IMRT showed equivalent target coverage. RA improved CI, HI and OARs sparing. Wilko F.A.R Verbakel et al. [26] compared VMAT with conventional IMRT in 12 patients for head and neck cancer. The comparison showed that double arc plans provided at least similar sparing of OAR and better PTV dose homogeneity than single arc or IMRT. Bao–min Zheng et al. [27] compared VMAT with RA and fixed filed dynamic IMRT for 20 patients with nasopharyngeal

carcinoma. The prescribed dose was 70 Gy. For both RA and IMRT, the target volume coverage was similar. Peszynska–piorun et al. [28] compared IMRT with 3D-CRT for 25 patients with head and neck cancer. IMRT delivered comparable or greater doses to OARs, while 3D-CRT was found to better spare the organs. Andrea Holt et al. [29] compared VMAT with IMRT in 5 oropharyngeal cancer patients from five institutes. VMAT showed significantly better sparing of OARs and improvement in CI. Kham Nguyen et al. [30] compare VMAT versus IMRT in 10 nasal cavity patients and found that VMAT achieved similar or better target coverage in comparison to IMRT. VMAT plans better spared critical structure and nearly normal tissue from higher dose volumes. IMRT plans were favored in minimizing the volume of low dose received to normal tissue and critical structures. Nima Nabavizadeh et al. [31] compared VMAT with 3D-CRT and IMRT in 20 patients with pancreatic cancer. VMAT and IMRT were shown to be superior over 3D-CRT in planning target volume (PTV) coverage and sparing OARs.

2. material and methods

2.1. Equipment Used

2.1.1. Linear Accelerator

The linear accelerator utilized for treatment planning was the Trilogy equipped with the Millennium Multi leaf Collimator by Varian Medical Systems. It is able to deliver beams of electrons and photons. Only the photon beam is used in this study for all cases with energies of 6 MV, 15 MV and 18 MV. There are 120 leaves total with 40 leaf pairs in the center and 10 pairs on each side. The center leaf width is 5 mm projected at isocenter, while the outer leaves are larger at 10 mm. The maximum leaf speed is 2.5 cm/s. The treatment planning system was the external beam planning system of Eclipse (Version 10.0.28.2, Varian Medical System) and the volume calculation used was the Anisotropic Analytical Algorithm (AAA, version 10.0.28.2). The Progressive Resolution Optimizer (PRO) utilized in the RapidArc optimization was Version 10.0.28.2. Varian's Leaf Motion Calculator (version 10.0.28.2) was enabled for the IMRT leaf sequence generation (see figure 2.1).



Fig 2.1: LINAC machine and MLC

2.1.2. CT simulation

It is necessary for each cancer center to have CT simulator in the radiation therapy department [33]. CT scan should include the part of the body to be treated with radiation. A slice thickness between 3 mm and 5 mm is recommended for CT scanning except for head and neck, which may be between 2 mm and 3 mm [34]. The CT scanner couch should be flat and comfortable for the patient and compatible with the therapy machine couch. The positioning of laser lights in the CT room must be similar to those in the treatment room to ensure exact positioning of the patient (see figure 2.4).In this study, the patients underwent pervious computed tomography simulation (CT-sim) (GE Light Speed 16 Slice CT) for treatment planning. For all patients, plans were designed on CT scans acquired 5 mm slice thickness, except for head and neck cases that acquired 2 mm slice thickness, and included the region of interest. The patients were positioned supine and straight and level.



Fig. 2.4. CT scanner.

2.2. Planning technique

After simulation, the CT images were transferred to the External Beam planning system of Eclipse using 6 MV and 15 MV photon beam data. The Progressive Resolution Optimizer (PRO) was used for the RapidArc plans. The Anisotropic Analytical Algorithm (AAA) was used for photon dose calculation for all cases. For RapidArc, arcs were used clockwise (181˚- 179˚) and anticlockwise (179˚- 181˚), the collimator was rotated 30˚ to 330˚ with the dose rate varied between 0 MU/min and 600 MU/min (upper limit) to reduce the effect due to inter-leaf leakage. The double arc technique was expected to achieve better target dose coverage than the single arc because the independent optimization of two arcs allows each arc to create a completely unrelated sequence of MLC shapes, dose rates and gantry speed combinations. For the 3D-CRT plans, all of the gantry angles and numbers of radiation fields (range,3-4) were manually selected on the basis of the formalism relationship between the PTV and OARs to cover at least 95% of the PTV and spare the OARs. The dose rate of 400 MU/min was used for 3D-CRT. Wedges were used to provide a more homogenous distribution. The optimization constraints for OARs using RapidArc are illustrated in table 2.1.

Table.2.1. The dose constraints of organ at risk

Critical organ at risk	First Criteria: Ideal	Second Criteria: Acceptable
Heart	Mean < 26 Gy V30< 46%	Mean < 35 Gy
Lung	V20≤ 30%	----------

2.3. Compile Patient Database

2.3.1. Patient selection

Institutional Review Board (IRB) approval was obtained before the initiation of this retrospective study. The plans of 6 different malignant tumor patients who had received radical RapidArc treatment from 2012 to 2014 at KAMC were randomly selected and re-planned for 3-dimensional conformal radiation therapy. The sample included both male and female patients and the median age was 54 years old (range, 47 - 57 Years).

2.3.2. Patient Anonymization

Patient names, age, sex, treatment site, treatment modality and codes were collected and recorded in an Excel sheet. Each patient was assigned a research code of 0xx, where xx is a number from 01 to 06. The patient's last name and medical record number were replaced by this research code, and all other personal information was removed. Furthermore, the personal information in the image set header files was removed. Table 2.2 lists the cases used for this study, indicating their age, sex, treatment site and modality.A malignant neoplasm is composed of cells that look less similar to the normal cell of origin or an abnormal mass of tissue arising from an abnormal proliferation of the cells. Malignant neoplasms derived from epithelial cells are called carcinomas, which is a cancer that begins in the skin or in tissue that cover body organs. Those derived from mesenchymal (connective tissue) cells are called sarcomas. Malignant brain neoplasms and neoplasms of the immune system are special categories with complex nomenclature [35].

Table. 2.2. Patient database (Malignant neoplasm)

Code	Sex	Age	Treatment site	Modality
001	F	54	Malignant neoplasm of upper quadrant of female breast	RA – 3DCRT
002	F	60	Malignant neoplasm of specified sites of female breast	RA – 3DCRT
003	F	27	Malignant neoplasm of specified sites of female breast	RA – 3DCRT
004	F	57	Carcinoma in situ of breast	RA – 3DCRT
005	F	39	Malignant neoplasm of specified sites of female breast	RA – 3DCRT
006	F	52	Malignant neoplasm of specified sites of female breast	RA – 3DCRT

2.4. Treatment Plan Evaluation Metrics

2.4.1. Dosimetric Plan Evaluation Metrics

The dosimetric evaluation metrics used to compare the two plans, in terms of mean, maximum and minimum doses to PTV, were dose to 95% of PTV, Homogeneity Index (HI), Conformity Index (CI), Target Coverage Index (TCI) and Mean and maximum doses to critical organs and normal tissue. The dose to 95% of the PTV (D95%) was used to quantify PTV coverage. The homogeneity index (HI) was used to evaluate uniformity (homogeneity) of dose within the PTV and is calculated as

$$\mathbf{HI} = \frac{D_5}{D_{95}} \qquad \mathbf{(1)}$$

Where D_5 and D_{95} represent the dose delivered to 5% and 95% of the PTV, respectively. The smaller and closer the value of HI is to 1, the better the homogeneity of the PTV [36]. The conformity index (CI) was also calculated and can be defined as the degree of conformity of the plans, which is a ratio of the PTV receiving 95% of the prescribed dose divided by the volume of the PTV. A CI value approaching 1 indicates a higher degree of conformity.

$$\mathbf{CI} = \frac{PTV_{95\%\,PD}}{V_{PTV}} \qquad \mathbf{(2)}$$

The target coverage index (TCI) accounts for the exact coverage of PTV in the treatment plan at the prescribed dose as shown below:

$$\mathbf{TCI} = \frac{PTV_{PD}}{PTV} \qquad \mathbf{(3)}$$

Where PTV_{PD} is the PTV coverage at the prescribed dose (PD) and PTV is the volume of PTV. Target conformity index reports target dose coverage as a value between 0 and 1. A value of 1 indicates an ideal plan with target coverage by prescribed dose. However, a TCI value of 0 indicates the whole target volume is not covered by the prescribed dose [37,38, 39].

4.2.1. Breast cancer

The most common type of breast cancer that forms in tissue of the breast is ductal carcinoma, which begins in the lining of the milk ducts (thin tubes that carry milk from the lobules of the breast to the nipple). Another type of breast cancer is lobular carcinoma, which begins in the lobules (milk glands) of the breast. Invasive breast cancer is breast cancer that can be spread from where it

began in the breast ducts or lobules to surrounding normal tissue. Breast cancer occurs in both men and women, although male breast cancer is rare [40]. Six patients of breast cancer whose received 60 Gy in 30 fraction were discussed in this study. The median age was 48 years with rang from 27 to 60 years. CT Scans with 0.5 cm slice thickness obtained extending from the hyoid bone to the upper abdomen, including both breast, bilateral lungs and the heart. After CT scan, the images transferred to planning system (TPS). 3D-CRT plan was used two parallel opposing tangential, which allows acceptable coverage of the breast tissue while minimizing the dose to the adjacent critical structures, physical or dynamic wedges are usually added to these tangential beams in order to compensate for the rapid changes in external contours and to improve the dose uniformity to the entire breast [41], using 6 MV photon and dose rate 400 MU/min see figure (2.11).

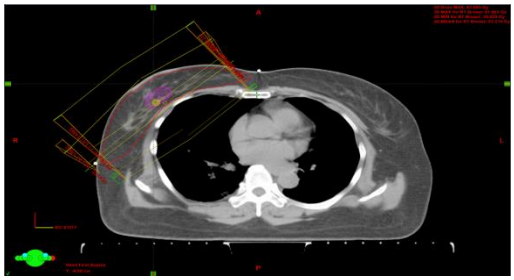


Figure (2.11): 3D-CRT plan setup for breast cancer using two fields.

RapidArc plan was used two arcs clockwise (181˚- 65˚), the collimator was rotated 30˚ to 330˚, using 6 MV photon and dose rate 600 MU/min see figure (2.12).

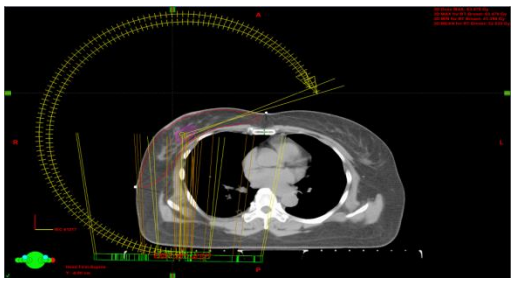


Figure (2.12): RapidArc plan setup for breast cancer using two arcs and gantry angles range from (181˚- 65˚).

3. Results

Differences were recorded between those patients who planned with 3D-CRT and those who planned with RapidArc. Thus one patient was selected to represent all other patients in this site for isodose distribution comparison, dose volume histogram (DVH) comparison, dosimetric results for the PTV and dosimetric results for the critical organs. DVHs figures include the PTV and critical organs for each modality and show the percentage of the total volume (y-axis) of each ROI receiving a specified dose (x-axis) in units of Gy. RA and 3D-CRT details for each patient as prescribed dose, number of fractions, dose per fractions, PTV volumes and number of fields or arcs are given in table (2.9). and dose constraints adopted by the physician for the organs at risk are given in Table 2.4.

Table.2.3. Representation of patients' prescription doses, PTV volume, and number of fields for both 3D-CRT and RA. Pc(patient code), No of F(No of fraction), D/F(dose per fraction), No of F/A (No of field/Arcs)

Pc	PD(Gy)	No of F	D/F	PTV(cm^3)	No of F/A	
					RA	**3D-CRT**
001	60	52.56	30	1.8	1052.2	2 fields
002	60	60	30	2	838	2 fields
003	60	60	30	2	884.9	2 fields
004	60	60	30	2	985	2 fields
005	60	60	30	2	750.5	2 fields
006	60	60	30	2	984.5	2 fields

Table.2.4. Dose constrains for OARs.

Organs	**Per protocol**	**Acceptable variation**
Lung	V20 $\leq$ 30 %	----------
Heart	Mean $<$ 26 Gy V30 $<$ 46%	Mean $<$ 35 Gy

Lungs had dose constrains corresponding to the V20Gy, V10Gy and V5Gy. The upper and lower limits on the PTV were set to 107% and 95% of the prescribed dose respectively.

3.1. Breast cancer

Table (3.1) shows the mean, max and minimum dose that covered 95% of the target and p-value of the target (PTV) for both modalities. The prescribed dose was 60 Gy.

Table.3.1: Evaluation metrics for PTV in terms of .D_{MEAN} , D_{max} and D_{min} covered 95% of the target

Pc	D_{mean}(Gy)		D_{max}(Gy)		D_{min}(Gy)		$D_{95\%}$(Gy)	
	RA	3DCRT	RA	3DCRT	RA	3DCRT	RA	3DCRT
001	47.1	48.3	57.5	54.9	30.7	5.3	42.1	41.7

002	52.6	53.2	63.4	61.8	40.5	38.0	48.6	48.5
003	52.7	53.4	62.9	62.5	33.0	19.0	47.9	47.4
004	52.1	53.1	64.7	62.4	36.5	34.1	46.7	47.0
005	51.2	52.2	65.8	61.3	29.9	26.3	44.9	45.7
006	52.6	53.1	63.1	61.3	35.6	40.2	48.8	47.8
Mean	51.38 ± 2.172	52.21 ± 1.963	62.9 ± 2.867	60.70 ± 2.887	34.33 ± 3.973	27.15 ± 13.273	46.50 ± 2.593	46.35 ± 2.461
P-value	**P < 0.001**		**P < 0.011**		**P < 0.160**		**P < 0.588**	

Table.3.2. Evaluation metrics for the PTV in terms of CI, HI and TCI.

Pc	**CI = $\frac{PTV_{95\%\,PD}}{V_{PTV}}$**		**HI = $\frac{D_5}{D_{95}}$**		**TCI = $\frac{PTV_{PD}}{PTV}$**	
	RA	**3DCRT**	**RA**	**3DCRT**	**RA**	**3DCRT**
001	0.0239	0.0467	1.2808	1.2840	0.0124	0.0185
002	0.0160	0.0300	1.2344	1.2466	0.0064	0.0102
003	0.0132	0.0258	1.2477	1.2749	0.0047	0.0093
004	0.0115	0.0266	1.2887	1.2882	0.0057	0.0083
005	0.0097	0.0261	1.3131	1.2980	0.0054	0.0017
006	0.0108	0.0237	1.2120	1.2366	0.0029	0.0025
Mean	0.014 ± 0.005	0.029 ± 0.008	1.262 ± 0.037	1.271 ± 0.024	0.006 ± 0.003	0.008 ± 0.006
P-value	**P < 0.000**		**P < 0.246**		**P < 0.202**	

3.4.1. PTV

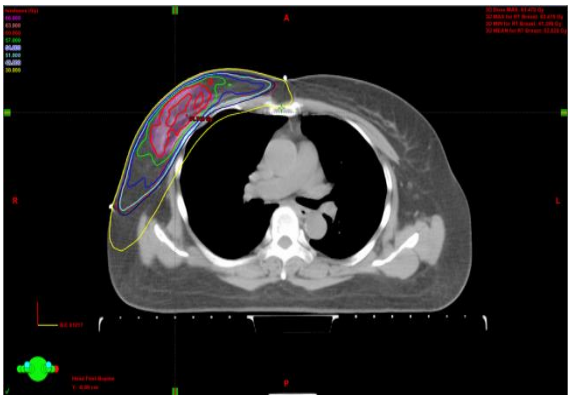
From table (3.15) and (3.16), the mean value of the PTV was (51.38 ± 2.172) in RapidArc and (52.21 ± 1.963) in 3D-CRT. The maximum dose to the PTV in RapidArc (62.90 ± 2.867) and in 3D-CRT (60.70 ± 2.887) with lower maximum dose to the PTV, (p = 0.011). This results explain the statistical advantage in PTV coverage metrics in RapidArc modality. The average minimum dose in RapidArc was (34.33 ± 3.973) compared to (27.15 ± 13.273) in 3D-CRT, (p = 0.160). The dose to 95% of the PTV was (46.50 ± 2.593) in RapidArc to (46.35 ± 2.46) in 3D-CRT, (p = 0.588). Conformity index (CI) the difference is simple between the two modalities with average value of (0.014 ± 0.005) in RapidArc compared to (0.029 ± 0.008) in 3D-CRT, (p = 0.000). The average in homogeneity index (HI) in RapidArc was (1.262 ± 0.037) to (1.271 ± 0.024) in 3D-CRT, (p = 0.246). Target coverage index (TCI) was (0.006 ± 0.003) in RapidArc and (0.008 ± 0.006) in 3D-CRT, (P = 0.202).

3.4.2. Patient-002

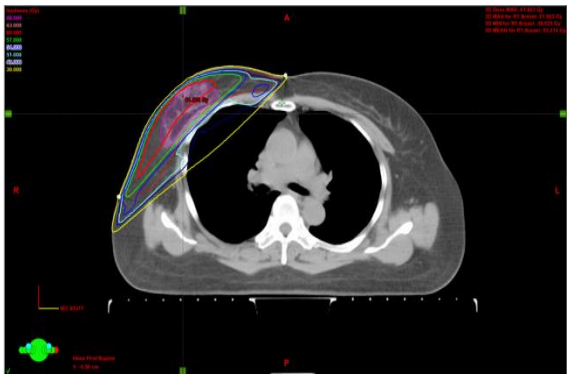
Patient-002 was a 60-year-old woman diagnosed with malignant neoplasm of other specified sites of female right breast. After receiving curative dose by RapidArc, 3D-CRT plan was done for the comparison.

3.4.3. Isodose Distribution Comparison

Isodose distributions for the RapidArc figure (3.7.a) and 3D-CRT figure (4.7.b) plans were shown below. The 3D-CRT plan contained the PTV receiving greater than 103% of the prescription dose, 61.8 Gy, RapidArc plan the PTV receiving greater than 106% of prescription dose, 63.6 Gy. The dose distribution within the PTV was homogeneous in the both modalities. There were hot area (doses greater than 61 Gy) in the medial portion of the PTV in the 3D-CRT plan and the RapidArc plan. The distributions showed comparable PTV dose coverage between the two modalities.



A



B

Figure (3.7): Isodose distributions for patient-002 showing (a) RapidArc and (b) 3D-CRT.

PTV conformity in the 3D-CRT plan was better than in the RapidArc. There was a small region of the PTV in the RapidArc plan receiving 63 Gy or greater, resulting in what appeared to be greater PTV dose conformity in the 3D-CRT plan.

3.4.4. DVH Comparison

Figure (3.8) contains a DVH for the RapidArc and 3D-

CRT plans for patient-002.The RapidArc and 3D-CRT plans contained a slight difference in the PTV coverage, which indicates higher dose coverage compared with RapidArc. The dose homogeneity within the PTV as seen in the isodose distributions was high in 3D-CRT.

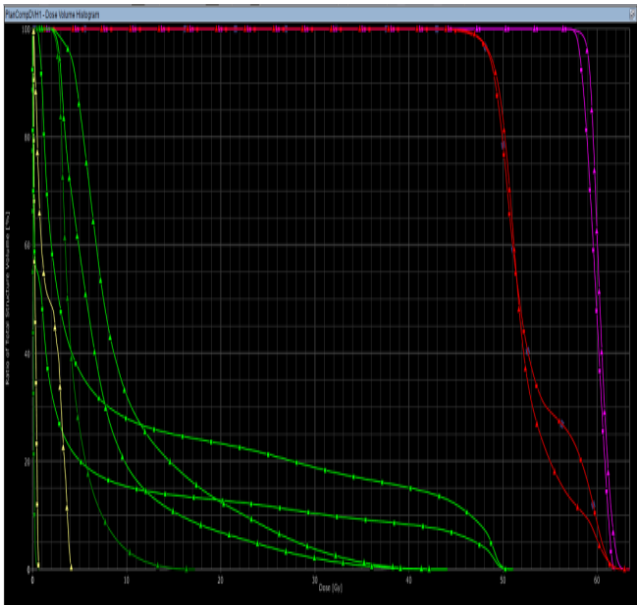


Figure (3.8): Comparison of DVHs between RA (triangles) and 3D-CRT (squares). The PTV in red, kidneys in green, liver in dark green and spinal cord in yellow

3.4.5. PTV-002

Results for the PTV are shown in table (3.17). The RapidArc plan showed better dosimetric results in the PTV in almost every metric for patient-026. The RapidArc plan achieved lower mean dose to the PTV and higher maximum dose. PTV dose coverage, as measured by the minimum dose and the dose to 95% of the volume, was higher in the RapidArc plan. There was very little difference in the homogeneous dose distribution in the PTV between RapidArc and 3D-CRT, achieving a HI of 1.23 in RapidArc plan and 1.24 in the 3D-CRT plan. However, the RapidArc plan was slightly lower CI and TCI than 3D-CRT.

Table (3.17): Evaluation metrics for the PTV – patient-002**.**

Parameter	Objective	RA	3D-CRT
Mean (Gy)	60	52.6	53.2
Dmax (Gy)	64.2	63.4	61.8
Dmin (Gy)	54	40.5	38.0
D95%	57	48.6	48.5
Conformity Index (CI)	1	0.016	0.030
Homogeneity Index (HI)	1	1.234	1.246
Target Conformity Index (TCI)	1	0.0064	0.0102

3.4.6. Organs at risk (OARs)

Table (3.18) shows the results for the right lung. The mean and maximum dose was lower in RapidArc. The maximum dose and V20Gy in the lungs were lower in the RapidArc plan. 85.4% of the lungs received at least 5 Gy in the RapidArc plan, while only 36.6% received this dose in the 3D-CRT plan. Similarly, 32.1% of the lungs received greater than 10 Gy in RapidArc, while only 27.9% received this dose in 3D-CRT.

Table (3.18): Evaluation metrics for the OARs – patient-002

RT. lung	Mean (Gy)	< 26	10.4	12.0
	V5Gy	Minimize	85.43	36.66
	V15Gy	No more than 50% of the lung for right-sided cancer	32.12	27.91
	V30Gy	No more than 35% of the lung for right-sided cancer	12.45	23.26

Dissection:-

Many studies on comparison of dose distribution for breast cancer radiotherapy techniques have been reported [42,43]. In the current study, we reported a dosimetric comparison between the two techniques of right-sided breast cancer. The present study demonstrates that 3D-CRT technique provide improved target volume coverage. There is no significant difference between HI and TCI and high significant in CI. 3D-CRT was better conformity than VMAT as seen in figure (4.10).

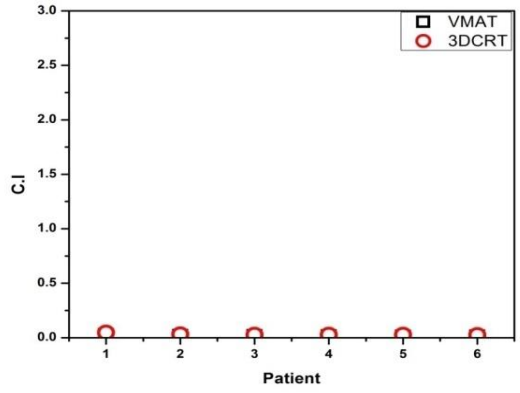


Figure (4.10): A histogram plot of (CI) for 6 breast cases.

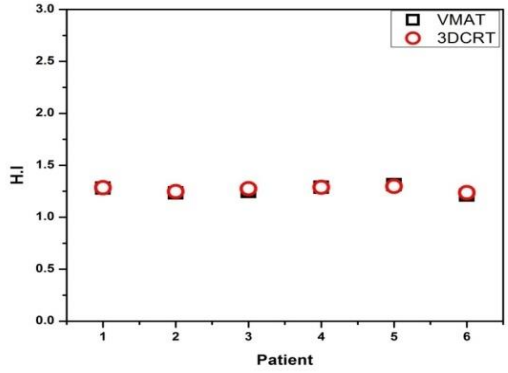


Figure (4.11): A histogram plot of (HI) for 6 breast cases.

Homogeneity index (HI) in figure (4.11) showed there is no significant difference between the values with the approach the values of VMAT to 1

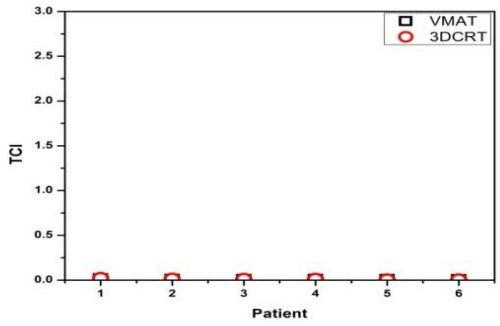


Figure (4.12): A histogram plot of (TCI) for 6 breast cases.

Figure (4.12) showed that TCI in 3D-CRT better than VMAT but both were far from the ideal value which is 1. From pervious study, VMAT improved the plan conformity compared to 3D-CRT [74] and this study demonstrated VMAT lowered the mean dose to the right lung over 3D-CRT by almost 7 Gy while reducing the V20Gy over the same by close to 19%. The low doses < 10 Gy were also reduced by 21.9% compared to 3D-CRT, and the V5Gy was lowered with VMAT by almost 6%. Our study has not fully agreed with this result, the mean dose was lower in VMAT by 2 Gy while reducing the V20Gy over the same by close to
11 Gy while V5Gy and V10Gy was lowered with 3D-CRT by 49 Gy, 5 Gy respectively.

One study observe that VMAT has been revealed to deliver lower doses to the ipsilateral breast and lung and offer better dose conformity than 3D-CRT technique for partial breast irradiation patients [75] and another study demonstrated the 3D-CRT technique reduces the values for lung dose volume, heart dose volume, dose to contralateral breast and dose to both lungs than IMRT technique without compromising the target coverage [44] this result is somewhat agree the results of our study. Until now we found that the used of 3D-CRT in breast cancer achieve better results and spare the healthy tissue more than VMAT.

Conclusion:-

Different sites of tumor was treated with three dimensional conformal radiation therapy. 3D-CRT resulting in some cases poor dose conformity to the target and high doses to critical organs. Volumetric modulated arc therapy is a relatively new treatment technology that providing better conformity to the tumor, sparing healthy structures and better low-dose OAR sparing in the lungs and heart. This study has also shown that the VMAT is superior to 3D-CRT in term of PTV, conformity and homogeneity but not in term of doses to critical organs in some cases. Clinical preference for accepting the VMAT class solution over 3D-CRT treatment was preferred to be determined on a case by case basis. VMAT will be the treatment choice for tumor requiring PTV conformity and homogeneity that VMAT provides. This study suggests that VMAT class solution is the superior treatment option. The major advantage of VMAT over 3D-CRT is the shorter treatment time. In conclusion, due to the ability of VMAT to generate highly conformal and efficient treatment plans that are clinically comparable to 3D-CRT, this study recommends VMAT be considered as a viable option for treatment different site of tumors.

competing interests

"The authors declare that they have no competing interests."

Authors' Contributions

Allehyani S carried out the dosimetric evaluation metrics and participated in comparing the two plans in terms of mean, maximum and minimum doses to PTV, Homogeneity Index (HI), Conformity Index (CI), Target Coverage Index (TCI) and mean and maximum doses to critical organs and normal tissue and drafted the

manuscript.. Aida R carried out measurements of the dose to 95% of the PTV (D95%) to quantify PTV coverage and the homogeneity index (HI) to evaluate uniformity (homogeneity) of the dose within the PTV and participated in drafted the manuscript. Huda A participated in the design of the study and performed the statistical analysis and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript".

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