Verification and Evaluation of Radiation Doses received by organs at risk in (3D-CRT) and IMRT technique for breast cancer

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Abstract. External beam radiotherapy can be delivered more precisely by using three Dimensional Conformal Radiotherapy (3D-CRT) technique, which is a traditional method used for whole breast radiotherapy. 3D-CRT includes standard wedged tangents (two opposed wedged tangential photon beams), which is based on three Dimensional images (3D) from a special computed tomography (CT scan). Overseas notification form advent of CT scans and more powerful computers have improved dose calculation algorithms and Multi-leaf Collimators (MLCs). Consequently, 3D-CRT is able to shape the Radiotherapy Beam (RTB) closely to match the target shape and volume. Intensity Modulated Radiation Therapy (IMRT) technique has the ability to improve sparing of normal tissues and treatment results of radiotherapy (RT). RT is a standard adjuvant therapy in conservative treatment of breast cancer (BC). The IMRT technique is used for many treatment sites, allowing for improved normal tissue sparing, more conformal dose distributions and prevention of secondary cancer. The purpose of this study is to verify and evaluate between the outcome of Radiation Treatment Plans (RTP) of left-sided whole breast irradiation of IMRT technique, and 3D-CRT technique to organs at risk (OAR) that are proximal to the target volume during breast radiotherapy. These include left lung, right lung, heart, and spinal cord by different numbers of beam in left sided breast at Zhianawa cancer center (ZCC) – Sulaimany-KR-Iraq. A second aim is to establish a guideline for breast cancer radiotherapy planning at ZCC. Thirteen patients with left-sided, breast carcinoma who had received radiotherapy were selected for this study. The dose prescriptions for the patients were different according to each patient’s cancer stage, using 6, 18 MV photons. The clinical target volume [CTV] was contoured as a target volume and the contralateral breast, left lung, right lung, heart, and spinal cord tissues as OAR. The two different planning techniques were analyzed for 13 patients with left-sided breast conserving surgery. Plans were compared on the basis of planning target volume (PTV) dose conformity index (CI), homogeneity index (HI) and the volumes of normal tissues treated based on dose-volume histograms (DVHs). DVHs were calculated for the PTV, heart, left lung, right lung, spinal cord and soft tissue surrounding the breast PTV (VOB) volume. IMRT techniques slightly improved homogeneity (HI) than 3D (0.16.04 vs. 0.22, p<0.068). However, there was no significant difference between IMRT and 3D-CRT plans regarding CI. No significant difference was noted in CI by 3D and IMRT as both showed similarity, p< 0.190). IMRT technique benefited patients more than 3D-CRT by reducing the high-dose (40.05 Gy) volume for the heart. The heart’s mean dose was significantly lower in 3D compared to IMRT (3.58 Gy vs. 10.07Gy, respectively; p < 0.0001). Both the mean dose of the...
left lung and right lung, were significantly lower for 3D compared to IMRT (10.18Gy vs. 14.26Gy and 0.34 vs. 4.17 respectively; \( p < 0.001 \)), and \( p < 0.0001 \). Cord Max. Cord Max dose was significantly lower in 3D compared to IMRT (6.83Gy % vs. 20.89 Gy%, \( p < 0.0001 \)). IMRT plans improved by increasing low-dose volume (Lift lung, and Spinal cord soft tissue surrounding the breast) compared with 3D-CRT plans (\( P<0.0001 \)) but with Right lung \( P<0.575 \).

However, 3D-CRT plans were improved by increasing low-dose volume (heart) compared with IMRT plans (\( P<0.230 \)).

**Keywords:** radiotherapy, breast, cancer, dose

1. **Introduction**

Patients with breast cancer (BC) are often recipients of breast conservation surgery after which External Beam Radiation Therapy (EBRT) is conducted to the entire breast.

EBRT also called Teletherapy consists of directing a high-energy beam of radiation from outside the body (external beam) toward an internal tumor. EBRT is produced by a radiotherapy machine, such as linear accelerators (LINAC) or using radioactive material (\(^{60}\)Co) such as gamma ray (1, 2).

Intensity Modulated Radiotherapy (IMRT) is an advanced form of 3D-CRT that can be used to treat any part of the body, and provides improved, produced uniformity dose distribution the tumor and health tissue sparing - Organs At Risk (OAR) (3,4).

IMRT technique is based on meticulously adjusting collimation leaves according to a tumor’s size, shape and location. Multiple radiation beams are used in IMRT (see Fig. 1) as a way of optimising radiation dosage on tumors. Concomitantly, healthy tissue surrounding the tumor is irradiated with a smaller dose.

This means that IMRT can deliver the same radiation dose to the tumor with fewer side effects as compared to the 3D-CRT or much higher dose to the tumor with the same dose to healthy tissues. This is particularly effective when dealing with tumors that are located close to vital organs or structures within the breast, skull and neck(5).

![Figure 1: The used beams for IMRT technique (6).](image)

The (3D-CRT) technique, is a traditional method used for treatment of whole breast. External beam radiotherapy can be delivered more precisely by using 3D-CRT technique, which is based on 3D images from a special computed tomography (CT scan), or by MRI, or Ultrasound. However, CT scan is used to improve dose calculation algorithms and Multi-leaf Collimators (MLCs). 3D-CRT technique is capable of adjusting a Radiotherapy Beam (RTB) according to a tumor’s physical properties. This
includes three dimensional viewing of a tumor and the neighbouring tissue. During 3D-CRT irregular and consistent intensity radiation is delivered, and is informed by a tumor’s form from various directions. (Fig. 2) (4).

Figure 2: Different beams used in 3D-CRT technique(4).

Two opposed wedged tangential photon beams are delivered to the breast tumor. Caution is recommended in order to minimise radiation exposure to the spinal cord and lung and heart tissue which are proximal to the treatment regions.

In clinical practice, the determining of breast thickness variance often requires the use of wedges. Also, there is strategic employment of static leaf collimators (MLCs) or blocks to excessive radiation exposure to the heart, spinal cord, and lungs. The use of conventional 3D=CRT has been found to enhance local control (7).

Whole breast radiotherapy (WBR) treatment consists of external beam radiotherapy to the entire breast (40.05 50 Gy) for 5 weeks which is divided into 20-25 fractions. This is continued with a further 7-10 fractions of external beam radiotherapy to the target bed.

Conventional targeted techniques (CTT) are employed in a majority of centers. These are referred to as two opposing wedged photon fields during WBR. Whole breast radiotherapy is posited on treating the entire breast using two divergent wedged beams. Wedge usage intensifies dosage uniformity and consistency (8).

Most centers use conventional tangential techniques (CTT) known as two opposite wedged photon fields for WBR. Conventionally, WBR is planned to a crude planning target volume consisting of the whole breast and treated by two tangential wedged beams. The usage of wedge increases the dose homogeneity and uniformity of dose (8). IMRT techniques have also been used in post breast conservation surgery.

IMRT has been successful in distributing uniformity and consistency dose delivery to tumor while decreasing high volume exposure to structures at risk (ie. spinal cord, heart and lung tissue), when compared to 2DRT and CTTI (4,8).

Even so, IMRT has limitations. Firstly, IMRT can lead to higher scatter dose to healthy tissue. Second, major organs at risk may be susceptible to low dose exposure size using IMRT, due to its unique uniformity and distribution properties. Alternatively, IMRT can lead to reduced toxicity to healthy tissue when compared to conventional tangential technique. However, a possible disadvantage of using IMRT is the likelihood of raised scatter dose to healthy tissue (9,10). This study’s objective
was to evaluate and verify RTP outcomes of left-sided whole breast irradiation of IMRT, and 3D-CRT technique to organs at risk (OAR) that are proximal to the target volume during breast radiotherapy. These include left lung, right lung, heart, and spinal cord according to dissimilar beam numbers in the left-sided breast. The study was conducted at the Zhianawa cancer center (ZCC) – Sulaimany-KR-Iraq

2. Materials and Methods

2.1. Patients
For this study, 13 patients who had undergone radiotherapy for left-sided breast carcinoma were chosen. Each patient received different dose prescriptions depending on their stage of cancer, using 6, 18 MV photons.

2.2. Optima CT scanner
Optima CT 580 RT (general electric Healthcare -USA) 80cm big bore CT-Scanner used for radiotherapy with flat RT couch. Optima 580 is a 16 slice scanner (it takes 16 slices in one gantry rotation) that can scan with (0.625, 1.25, 2.5, 5, and 10mm) slice thickness and able to scan 4D-CT images. Both helical and axial scans can be carried out by this scanner. The scanner is equipped with an injection system for contrast and laser system for accurate setup and verification patient position (Fig. 3) (11, 12).

2.3. Monaco planning system
The Elektra company has produced the treatment planning system (TPS) radiotherapy software – Monaco.

Monaco can calculate 3D, IMRT, VMAT, SRS, and Brachytherapy, providing Monte Carlos algorithm with precision accuracy. Monaco can also duplicate QA plans from an initial blueprint in order to check IMRT quality and VMAT plans.

Another function of Monaco is Segment Shape Optimisation. This allows for assembling and arranging segments for enhancing beam shapes and wedges, with improved plan quality.

Figure 3 shows a screenshot of Monaco TPS(13). The Monaco TPS in (ZCC) is version 5.00.02.

2.4. Xio treatment planning system
CMS-Elektra has also designed a unique radiotherapy software system called Xio which enables 3D-CRT plan evaluation. Xio is also able to calculate 3D dose distribution and correction in homogeneity.
Xio is a versatile software system which can utilise algorithms, super position, pencil beams and convolutions (14).

The Xio in Zhianawa Cancer Center (ZCC) is version 5.00.02, and uses three high performance computers that connect to the center’s main network.

2.5. Elekta Synergy Linac
Elekta Synergy Linac (2013, UK) uses three photon energies (6, 10 and 18MV) and 8 electron energies (4, 6, 8, 10, 12, 15, 18 and 22MeV) as shown in Fig. (4). Maximum does rate is 60-0MU/min, 60° motorized wedge, MLCi2 80 leaf (40 pair). The size of each leaf is 1 cm in width and is exposed to a maximum field size of 40x40 cm at SSD 100cm. Synergy Linac also has a digital portal imager and cone beam CT system (CBCT) for verifying treatment position.

![Elekta Synergy Linac](image)

**Figure 4;** The Elekta Synergy Linac used in the treatment of patients was included in this study

2.6. Methods
IMRT and 3D-CRT techniques for treating patients were included in this study. Several equipment and parameters were used to evaluate and compare these plans.

- Three dimensional plans 3D-CRT were created on XIO planning system for all eight patients.
- dose Monte Carlo dose calculation algorithm was employed for IMRT based dose calculation.

2.7. Methodology
All patients were treated at the Zhianawa cancer center (ZCC) – Sulaimany-KR-Iraq. Treatment employed these following procedures:
1. Patient appraisal before radiotherapy treatment.
2. Diagnosing the type of tumor, size and staging.
3. Determining OAR (left lung, right lung, heart, and spinal cord tissues) and their proximity to the target (Figure 3).

1. Fractioning, contouring, dose prescription and C.T. simulation.
2. Planning procedure
3. QA for correct delivery procedure.
4. Mode for implementing approved delivery
5. Patient assessment and prescribed follow ups during and post radiotherapy treatment.
6. Identifying and assessing benefits/side effects of short or long term radiation exposure.

2.8. Plan evaluation

Current radiation therapy treatments provide a range of DVHs for using quantitative evaluation tools and evaluation. Furthermore, modern radiation therapy treatments use isodose distribution chart and physical dose indices. Included here are 3D-CRT and IMRT, as well as, maximum dose (CI), (HI), OAR dose and coverage of target volume.

2.9. Conformity index (CI)

Conformity index (CT) is a evaluated ratio between PTV and specified dosage volumes. Our study noted that CI values (Eq.:1) were calculated according to volumes comprising 95% of fixed doses. CI value is identified as the degree of consistency of a design. Therefore, according to this definition where CI is found to be less than one, this indicates that the PTV is under coverage. Alternately, where CI is greater than 1 is indicative of high dose levels delivered to normal tissue. Lastly, where C1 is equivalent to 1 denotes that the recommended dose follows the PTV outline (15).

\[ CI = \frac{\text{volume covered by 95\% of prescribed dose}}{\text{volume of PTV}} \quad .......... \quad 1 \]

2.10. Homogeneity index (HI)

Homogeneity Index (HI) evaluates the level of consistency of dose allocation in a target volume. PTV values of D2% and D98% were acquired from DVH. D2% constitutes the highest dose directed to 2% of the PTV. Dp is defined as the recommended PTV dose, while D98% is defined as the lowest prescribed dose determined for 98% of the PTV. The aforementioned parameters were employed to determine the HI by applying the Eq 2.

\[ HI = \frac{D_{(2\%)} - D_{(98\%)}}{D_p} \quad ........................................ \quad 2 \]

Our study found that a lower HI provided a more optimal dose distribution within the target (15).

3. Result and Discussion

Table 1: Dose characteristics of the PTV (breast) associated with both IMRT and 3D plans including dose homogeneity (HI), and Conformity Index (CI), in 13 patients.

| No. | Code of patient | HI by 3D technique | HI by IMRT technique | CI by 3D | CI by IMRT |
|-----|-----------------|-------------------|---------------------|---------|-----------|
| 1   | 170629          | 0.20749           | 0.222694            | 0.905485| 0.882556  |
| 2   | 170598          | 0.166821          | 0.194632            | 0.949103| 0.94215   |
| 3   | 7016            | 0.208388          | 0.225565            | 0.936251| 0.916207  |
| 4   | 7048            | 0.179553          | 0.169991            | 0.51584 | 0.886646  |
| 5   | 170640          | 0.179903          | 0.135339            | 0.919338| 0.97985   |
| 6   | 7034            | 0.21825           | 0.165597            | 1.339031| 1.384275  |
| 7   | 7043            | 0.187193          | 0.162152            | 0.945477| 0.953388  |
| 8   | 170607          | 0.167095          | 0.128149            | 0.949424| 0.984695  |
| 9   | 170654          | 0.374485          | 0.105655            | 0.976303| 0.995687  |
| 10  | 170619          | 0.453851          | 0.123705            | 0.913427| 0.988781  |
| 11  | 7052            | 0.196954          | 0.157009            | 0.516054| 0.80897   |
| 12  | 170307          | 0.200499          | 0.189614            | 0.754823| 0.576214  |
| 13  | 171042          | 0.175484          | 0.143478            | 0.950828| 0.968934  |
Table 2: Conformity Index (CI) value, and Dose homogeneity (HI) value, in 13 patients with IMRT and 3D plans.

| CI in 3D-CRT | No risk (<1) | % |
|--------------|--------------|---|
| High risk (>1) | 1 | 7.7 |
| Perfect (=1) | - | - |

| CI in IMRT | No risk (<1) | % |
|------------|--------------|---|
| High risk (>1) | 1 | 7.7 |
| Perfect (=1) | 1 | 7.7 |

Table 3: Mean of dose HICI, and Mean dose to CB calculated by diverse left sided beam quantities using the linear model for the 13 patients using both IMRT and 3D techniques. The mean CB dose was used to predict the risk for radiation induced malignancy in CB using a linear model.

| 3D technique | IRMT technique | P value |
|--------------|----------------|---------|
| HI | 0.22±0.09 (0.17-0.45) | 0.16±0.04 (0.11-0.23) | 0.068 |
| Cl | 0.89±0.21 (0.52-1.34) | 0.94±0.17 (0.58-1.38) | 0.190 |
| Mean dose Gy for PVT | 40.61±0.32 (39.87-41.04) | 41.2±0.34 (40.47-41.73) | 0.001* |
| Mean dose Gy for Lt- lung | 10.18±2.77 (4.84-13.92) | 14.26±0.98 (11.48-15.41) | 0.0001* |
| Mean dose Gy for Rt-lung | 0.34±0.28 (0.16-1.23) | 4.17±0.77 (3.23-5.64) | 0.0001* |
| Mean dose Gy for Heart | 3.58±1.65 (1.91-7.59) | 10.07±1.33 (7.51-11.96) | 0.0001* |
| Max dose Gy | 6.83±4.63 (0.22-14.56) | 20.89±8.21 (5.51-31.19) | 0.0001* |
| Lt-Lung <30Gy | 21.36±6.64 (9.81-30.35) | 29.36±3.62 (20.25-33.27) | 0.0001* |
| RT-Lung <30Gy | 0.20±0.62 (0-2.25) | 0.38±0.82 (0-3.02) | 0.575 |
| Haert <20Gy | 2.35±2.69 (0-2.25) | 1.43±0.59 (0-2.23) | 0.230 |
| Cord max dose <45Gy | 6.83±4.63 (0.22-14.56) | 20.89±8.21 (5.51-31.19) | 0.0001* |

* Substantial variance between two dependent means employing Paired-t-test at 0.05 level.
-Data were presented as Mean±SD (Range)
According to table 3 results, HI showed slight improvement when IMRT was employed than 3D (0.16.04 vs. 0.22, p<0.068). However, no significant difference was noted in CI by 3D and IMRT (0.89±0.21 vs. 0.94±0.17) as of both of them < 1.

The majority of the plans of our study employed PTV 95% coverage values which were greater than 95% of the recommended dose, with the exception of patient No. 6.

The present study concurs with Li W. (2016) who suggested that IMRT did not make any significant improvement to HI (0.16 vs. 0.22) nor CT (0.89 vs. 0.94, p = 0.190). However, this did not include patient No. 6. Interestingly, Beckham (2007)(16) does not mention our findings.

Both the mean dose of left-lung and right lung were significantly lower when using 3D compared to IMRT (10.18Gy vs. 14.26Gy and 0.34 vs. 4.17 respectively; p < 0.001), and p< 0.0001. The dose for the two planning methods was 40.050Gy.

Similarly, the mean dose for the heart was significantly lower when using 3D compared to IMRT (3.58 Gy vs. 10.07Gy, respectively; p < 0.0001). The present study indicated that in both techniques the heart was exposed to doses <30 Gy. Our study results have been confirmed by Gagliardi (2010)(17) who commented on the significant reduction of coronary heart disease when minimal Gy was used. It has been shown that 3D CRT not only decreases high and mean dose volumes in specific anatomical structures such as the spinal cord and ipsilateral left lung when related to IMRT, but also considerably improves plan compliance.

It should be noted that the primary objective of RT plans was to decrease exposure size of lung and heart tissue, during treatment with a high RT dose. Comparative parameters for ipsilateral lung (V30) and heart (V20) were chosen.

The present study, a small dose size (<30 Gy) given to the left lung showed unequivocally higher IMRT than when compared to 3DCRT (29.36% vs. 21.36 %, p < 0.0001). In contrast, in relation to the right lung the low size dose (<30Gy) was not considerably larger for for IMRT when compared to 3DCRT (0.38% vs. 0.20%, p < 0.575). Our results concur with Beckham (2007) Beckham (2007) found similar findings in relation to IMRT where it had increased normal tissue size when exposed to exposed to small RT dose. Beckam (2007) found that when employing IMRT, the mean dose used for the heart was markedly smaller when compared to 3DCRT (1.43% vs. 2.35%, p < 0.230). In his conclusion Beckham states that the use of IMRT was beneficial in decreasing heart volume during exposure of > 30 Gy.

Cord Max. Cord max dose was significantly lower in 3D compared to IMRT (6.83Gy % vs. 20.89 Gy%, p < 0.0001). Additionally, our use of maximum dose for the spinal cord (<45Gy) correlates in a study by Majumder (2014) (18).

The employment of the two procedures to all the patients (N=13) exhibited the PTV 95% coverage values of >95% of the recommended dose. This result corresponds with Abo-Madayan (2008) (19).
Figure 6: It shows that the mean dose of left lung, and right lung were significantly lower for 3D compared to IMRT. This result varies from Rudat (2011) (20) who notes that when given a tangential beam IMRT showed a marked decrease on the mean dose of the ipsilateral lung.

Figure 7: Indicates that the mean dose for the heart was significantly lower in 3D compared to IMRT. In both techniques the heart are exposed to doses <30 Gy. However, we realised that there was no achievable safe dose. Our finding Our conclusion is also noted by Taylor (2009) (21). Taylor’s study identified that when left sided breast cancers were exposed to appurtenant RT showed a small but marked increase in cardiac and cerebrovascular mortality. Similarly, iatrogenic caused heart disease attributed to radiation therapy is evident in partial heart volumes when irradiated with doses greater than 35 Gy.
Figure 8: Indicated that in relation to the spinal cord the maximal dose was significantly lower in 3D compared to IMRT. In both techniques the spinal cord max dose <45 Gy. Our result correlates with Dipanjan Majumder (2014) (18).

4. Conclusion

Based on our findings, we conclude that:

1- Using different planning techniques in radiotherapy can increase radiation dose to tumors while at the same time limiting radiation dose to surrounding health tissue.

2- Homogeneity and uniformity of dose distribution is more effective in IMRT plan compared to 3D-CRT plan. However, no significant difference was noted in CI by 3D-CRT and IMRT.

3- The mean dose of the heart was significantly lower in 3D compared to IMRT, cord max dose. Furthermore the mean dose of right lung and left lung were significantly lower for 3D compared to IMRT.

4- IMRT plans improved by increasing low-dose volume (left lung, spinal cord and soft tissue surrounding the breast) compared to 3D-CRT.

5- Healthy tissue beyond the treatment area received a slightly higher dose when using IMRT than 3D-CRT.

Suggestions

1- Radiotherapy centers like ZCC can only provide a limited amount of treatments, and are characterised by long waiting lists. Furthermore, time to deliver RT plan must be taken into consideration when choosing the treatment technique. This selection should not affect the plan outcome.

2- Refrain from treating patients with radiotherapy without prior completion of QA for the treatment plan.

3- Increasing more complex QA procedures before using Advanced RT techniques such as IMRT.

4- Increase research in the new planning methods and their clinical outcomes.

5- The outcome of RTP that use 3D-CRT or IMRT plans for breast cancer may provide a guideline for selecting a possible treatment technique for breast cancer at Zhianawa cancer center (ZCC) – Sulaimany-KR-Iraq.
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