Integrated scoring approach to assess radiotherapy plan quality for breast cancer treatment

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ABSTRACT

Background: Proposal of an integrated scoring approach assessing the quality of different treatment techniques in a radiotherapy planning comparison. This scoring method incorporates all dosimetric indices of planning target volumes (PTVs) as well as organs at risk (OARs) and provides a single quantitative measure to select an ideal plan.

Materials and methods: The radiotherapy planning techniques compared were field-in-field (FinF), intensity modulated radiation therapy (IMRT), volumetric modulated arc therapy (VMAT), hybrid IMRT (H-IMRT), and hybrid VMAT (H-VMAT). These plans were generated for twenty-five locally advanced left-sided breast cancer patients. The PTVs were prescribed a hypofractionation dose of 40.5 Gy in 15 fractions. The integrated score for each planning technique was calculated using the proposed formula.

Results: An integrated score value that is close to zero indicates a superior plan. The integrated score that incorporates all dosimetric indices (PTVs and OARs) were 1.37, 1.64, 1.72, 1.18, and 1.24 for FinF, IMRT, VMAT, H-IMRT, and H-VMAT plans, respectively.

Conclusion: The proposed integrated scoring approach is scientific to select a better plan and flexible to incorporate the patient-specific clinical demands. This simple tool is useful to quantify the treatment techniques and able to differentiate the acceptable and unacceptable plans.

Key words: integrated score; dosimetric index; IMRT; VMAT; breast cancer

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Introduction

Radiotherapy (RT) is one of the multi-modal treatment procedures for cancer patients before or after surgery and systemic therapies. The basis of the RT for any type of cancer is to improve the therapeutic ratio between tumor control probability (TCP) and normal tissue complication probability (NTCP). The RT has different planning techniques from conventional to advanced computer-controlled techniques. Each technique shows its own merits and demerits for a particular cancer site. Further, the availability of various RT facilities also raises the issue of the ideal choice. The selection of an ideal RT planning technique is a difficult task due to the uniqueness of patient’s clinical scenario.
In a linear accelerator setting, three-dimensional conformal radiotherapy (3DCRT) or field-in-field (FinF) is a standard treatment technique for post-mastectomy chest wall (CW) and nodal stations RT which provides a reduced dose to organs at risk (OARs). However, the 3DCRT technique required greater care at planning target volumes (PTVs) dosimetric parameters. Advanced computer controlled treatment techniques like intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) provides conformal and homogeneous doses to PTVs. Both IMRT and VMAT techniques reduce the high dose levels and escalate the low dose levels to normal tissues (NT). Published articles explored dosimetric comparisons of various RT techniques for breast cancer. Nevertheless, the recommended technique is varied as evident in these articles [1].

The plan evaluation process includes various dosimetric indices for PTVs, dose-volume constraints for OARs, treatment delivery parameters, and clinical justifications like patient comfort, propensity to early side effects, and impact of setup errors. The selection of an ideal plan might be a difficult task due a large number of dosimetric indices as well as different indices favors different treatment techniques [2, 3]. In the published literature, most authors did not conclude in favor of a single technique and the choice of optimal plan is based on clinical justifications. Besides providing a clinical justification for selecting a good plan, a scientific scoring approach should be important to show how far a better plan differs from others.

In this context, few authors proposed a unified dosimetric index (UDI) method which combines all dosimetric indices assigning a score to each plan [4, 5]. However, this UDI method only includes PTVs dosimetric indices. None of the authors included the OARs dosimetric parameters in the UDI method. Indeed, with a larger number, the dose parameters of OARs are the game-changers. Some other articles used a simple ranking method to score a treatment plan [6–8] not presenting dosimetric indices that show unacceptable results. Few publications proposed a complex scoring approach that required appropriate software to calculate treatment plan scores [9–12]. The aim of this study is to propose a simple formula that integrates the dosimetric indices of both PTVs and OARs for the appraisal of treatment plans. With this intend, the present study quantified five treatment plans created with different treatment techniques (FinF, IMRT, VMAT, H-IMRT, and H-VMAT), for left-sided CW and nodal stations RT.

### Materials and methods

#### Patient preparation

Twenty-five left-sided locally advanced breast cancer patients were retrospectively selected for this study. All patients underwent planning computed tomography (CT) scans with proper immobilization devices. The CT images of these patients were used for this dosimetric comparison study. The informed consent has been waived off by the ethics board of the institute considering this as a retrospective dosimetric comparison study with no humans involved. PTVs for CW (PTVCW), supraclavicular node (PTV SCL), and internal mammary node (PTV Dam) were delineated in CT images. OARs delineated were the heart, left anterior descending coronary artery (LAD), right coronary artery (RCA), ipsilateral lung (IL), contralateral lung (CL), contralateral breast (CB), esophagus, trachea, thyroid, humeral head, coeliac plexus and gastroesophageal junction (GEJCP), spinal cord (SC), and normal tissues (NT), defined as external body volume minus the PTVs. Table 1 presents the radiation dose limits for these OARs.

#### Planning techniques

The RT planning techniques included FinF, IMRT, VMAT, H-IMRT, and H-VMAT were generated for each patient in Eclipse™ version 13.7 treatment planning system (TPS) using 6, 10, and 15 MV x-ray photon beams of Truebeam linear accelerator (Varian Medical Systems, Palo Alto, CA, USA). The PTVs were prescribed to a hypofractionated dose prescription of 40.5 Gy (2.7 Gy per fraction) in 15 fractions and normalized to deliver the PTVs mean dose equal to the prescription dose. Photon optimizers (PO) algorithm for IMRT and VMAT plan optimizations, and Analytical Anisotropic Algorithm (AAA) for dose computation were used in the Eclipse™ TPS. The planning details of each RT technique are described below.

For all plans, an isocenter was placed at the junction of PTV CW and PTV SCL in cranio-caudal direction and axially at CW and IL interface. The FinF plan consisted of two tangential half beam blocked...
fields for the PTV$_{CNS}$, PTV$_{OAR}$ and one anterior oblique, one posterior oblique, half beam blocked field for the PTV$_{SCC}$. The x-ray photon energies for these fields were iteratively varied depending on the patient separation along the field direction. After dose calculation, sub-fields were then created from the main fields by modifying the multileaf collimators (MLC) shape. The field weights and shapes of these sub-fields were iteratively changed to homogenize the hot and cold dose regions.

The IMRT plans consisted of 7 fixed fields with gantry angles of 300°, 320°, 340°, 40°, 100°, 130°, and 160°. The collimator angles were set at ±5° for each field. The 6 MV photon beams were employed with a set dose rate of 400 MU/minute. These fields were calculated to deliver in a dynamic MLC mode. The VMAT plans used two partial arcs running from 300° to 160° and two tangential arcs of length 50° ranges from 300° to 350° and 160° to 110°. The collimator angles were set at ±15° for each arc. The 6 MV photon beams were employed with a set dose rate of 600 MU/minute.

For the hybrid techniques, the base 3DCRT plans were generated with 1.9 Gy (70% of prescription dose). The beam arrangements were similar to FinF main fields without any sub-fields. For the IMRT and VMAT components, the field arrangements were similar as explained above. These plans were created with the remaining prescription dose of 0.8 Gy (30% of prescription dose). While performing the IMRT and VMAT optimization, the 3DCRT plan was kept as a base-dose plan. Optimization dose constraints and priorities were almost similar for all plans. The PTVs priority weights were adjusted when required to make adequate dose coverage. After normalization, plan sum of 3DCRT+IMRT, 3DCRT+VMAT were created for H-IMRT and H-VMAT, respectively.

Dosimetric evaluation and scoring method

Dose-volume histogram (DVH) analysis was performed to assess the PTVs and OARs dosimetric parameters for all plans. For the PTVs, dosimetric indices coverage index (COI), uniformity index (UI), conformity index (CI) and gradient index (GI) were calculated as stated in Table 2. Dose-volume parameters presented in Table 1 were considered for the OARs comparison. In addition, monitor units (MU) and treatment time (TT) were assessed for delivery efficiency of the plans.

A single scoring method was then used to calculate an integrated score that incorporates all dosimetric indices of the PTVs, OARs and the delivery parameters like MU and TT. The integrated score was calculated as:

\[
\text{Integrated score} = \sum_{i} \left( \text{COI}_i \times \text{UI}_i \times \text{CI}_i \times \text{GI}_i \right) + \sum_{j} \left( \text{MU}_j \times \text{TT}_j \right)
\]
The desired values for the OARs were taken from published literature [13–22]. For the MU and TT delivery parameters, their average values from all plans were taken as the desired values. A plan which shows an integrated score of close to 0 will be chosen as a superior plan. For example, if the desired value for the mean dose to the heart is 5 Gy and the achieved value is 3 Gy then the individual score \( A/D_h \) would be 0.6. In contrast, if the achieved value is 8 Gy then the individual score without the penalty would be 1.6 and with the penalty, 3.2 (double the score).

In addition, to demonstrate a case of two plans comparison, the top two scored plans among five studied techniques were selected. Further, these top two plans were statistically analyzed to account for the statistical significance in the score calculation. If the difference between any dosimetric parameter values of two plans was statistically significant, then the poor plan was given a penalty in score calculation, which doubles the score again. The statistical analysis was performed using a non-parametric Wilcoxon signed-rank test for a paired group of plan comparisons. The statistical test was two-tailed and the threshold value of \( p < 0.05 \) pointed out that the difference between the plans was statistically significant.

Further, to find the impact of the individual dosimetric index scores on the integrated scores, the correlation coefficients \( r \) between the individual dosimetric index scores and the integrated

### Table 2. Planning target volume dosimetric indices and limits

| Parameter description                                      | Ideal value | Desired value |
|-----------------------------------------------------------|-------------|---------------|
| COI = \( \frac{D_P}{D_{95\%}} \)                         | 1.00        | \( \leq 1.05 \) |
| \( D_P \) is the prescription dose and \( D_{95\%} \) is the dose received by 95% of the PTV |             |               |
| UI = \( \frac{D_{2\%}}{D_{98\%}} \)                      | 1.00        | \( \leq 1.15 \) |
| \( D_{2\%}, D_{98\%} \) are the doses received by 2%, 98% of the PTV |             |               |
| CI = \( \frac{V_{PTV}}{V_{PTVref}} \times \frac{V_{ref}}{V_{PTVref}} \) | 1.00        | \( \leq 1.25 \) |
| \( V_{PTV}, V_{ref}, V_{PTVref} \) are the volumes of PTV, reference isodose (95%) within the PTV and reference isodose (95%) |             |               |
| GI = \( \frac{V_{50\%}}{V_{PTV}} \)                      | 1.00        | \( \leq 3.50 \) |
| \( V_{50\%}, V_{PTV} \) are the volumes of 50% isodose and PTV |             |               |

COI — coverage index; PTV — planning target volume; UI — uniformity index; CI — conformity index; GI — gradient index

\[
\text{Integrated Score} = \frac{\sum_{i=1}^{n} \text{Individual Score}_i}{n}
\]

\[
\text{Individual Score}_i = \left( \frac{A_i}{D_i} \right) \times P_i \times W_i
\]

where \( A_i \) is an achieved value of the \( i^{th} \) dosimetric index of a particular plan and \( D_i \) is the desired value of the \( i^{th} \) dosimetric index and \( n \) is a number of dosimetric indices assessed. The \( P_i \) is a penalty function that can be used to double the score if the achieved value shows an unacceptable result and if the values between two plans were statistically different. The \( W_i \) is a weighting factor (range 0.1 to 1) that can be used to enhance significance to any patient-specific clinical demands. The weighting factor 0.1 is meant for higher clinical demand and 1 for no clinical demand. For instance, in elderly patients early toxicity produced by the high dose irradiation of the lung and heart might need to be reduced. In such event, a lower weighting factor can be applied to high dose (\( V_{35Gy} \)) parameters to OARs based on the clinician’s decision. Similarly, the clinical goal for the younger patient group (age < 45 years) might be minimizing the low dose irradiation for the reduction of secondary cancer risk. In such case, a lower weighting factor can be applied to low dose (\( V_{5Gy} \)) parameters to OARs.

The desired values for the OARs and PTVs dosimetric indices are presented in Tables 1 and 2.
scores for each planning technique were calculated using the Pearson correlation coefficient method. This correlation coefficient provides the details of dosimetric indices that show favorable results from a particular treatment technique. For instance, the ‘r’ value closer to 1 denotes that the individual scores of a particular index were in agreement with the integrated scores of all plans. While the ‘r’ value closer to –1 denotes that the individual scores disagreed with the integrated scores of all plans.

**Results**

The achieved values (mean) and individual scores of the PTVs dosimetric indices for all planning techniques are summarized in Table 3. The H-IMRT and H-VMAT plans achieved expected coverage (COI ≤ 1.05) for PTV_{CW} and PTV_{SCL}, while the pure VMAT plan achieved better COI for PTV_{IMN} as shown in Table 3. The UI of PTV_{CW} was comparable among all plans, while the UI of PTV_{SCL} and PTV_{IMN} were showed unexpected results in the FinF plan. The CI of combined PTV has shown better results with pure IMRT and VMAT plans. The total score for the PTVs has shown that the pure VMAT plan was better than other plans. This is due to the substantial reduction of MU and TT in the pure VMAT plan compared to other plans.

Table 4 presents the OARs dose comparison results (achieved value and individual score) of all plans. The mean dose and V_{5Gy} to the heart, IL, and NT were considerably less in the FinF plan, while the V_{35Gy} of the heart, IL, and LAD were significantly high in the FinF plan. The mean doses to RCA, CL, and CB were considerably less in the FinF plan compared to other plans. The pure IMRT and VMAT provided an unexpected mean dose and V_{5Gy} of the CL and CB. The mean doses to the esophagus and trachea were out of desired value in the pure VMAT plan. The total score for OARs has shown that the H-IMRT plan was better than other plans. This is due to the balanced results between low and high dose levels provided by the H-IMRT plan.

The integrated scores that incorporate all dosimetric indices (PTVs and OARs) were 1.37, 1.64, 1.72, 1.18, and 1.24 for FinF, IMRT, VMAT, H-IMRT, and H-VMAT plans as shown in Figure 1. The correlation coefficient results of all dosimetric indices are shown in Table 5. The wide range of correlation coefficient values revealed that the favorable planning technique for each dosimetric index of the PTVs and OARs was varied.

| Parameter | Mean achieved value (Individual Score) |
|-----------|----------------------------------------|
|           | FinF | IMRT | VMAT | H-IMRT | H-VMAT |
| PTV_{CW}  |      |      |      |        |        |
| COI       | 1.051 (2.00) | 1.039 (0.99) | 1.051 (2.00) | 1.030 (0.98) | 1.037 (0.99) |
| UI        | 1.133 (0.99) | 1.103 (0.96) | 1.113 (0.97) | 1.083 (0.94) | 1.086 (0.94) |
| PTV_{SCL} |      |      |      |        |        |
| COI       | 1.069 (2.04) | 1.055 (2.01) | 1.056 (2.01) | 1.040 (0.99) | 1.046 (1.00) |
| UI        | 1.153 (2.01) | 1.122 (0.98) | 1.124 (0.98) | 1.086 (0.94) | 1.094 (0.95) |
| PTV_{IMN} |      |      |      |        |        |
| COI       | 1.169 (2.23) | 1.088 (2.07) | 1.049 (1.00) | 1.088 (2.07) | 1.111 (2.12) |
| UI        | 1.260 (2.19) | 1.166 (2.03) | 1.100 (0.96) | 1.136 (0.99) | 1.141 (0.99) |
| All PTVs  |      |      |      |        |        |
| CI        | 1.808 (2.89) | 1.222 (0.98) | 1.229 (0.98) | 1.275 (2.04) | 1.290 (2.06) |
| GI        | 3.417 (0.98) | 3.130 (0.89) | 3.190 (0.91) | 3.297 (0.94) | 3.321 (0.95) |
| MU        | 569.41 (0.71) | 1186.26 (2.98) | 491.27 (0.62) | 1162.55 (2.92) | 574.38 (0.72) |
| TT [min]  | 2.07 (0.64) | 3.67 (2.26) | 1.54 (0.48) | 5.31 (3.28) | 3.61 (2.23) |
| PTVs Total Score | 1.67 | 1.61 | 1.09 | 1.61 | 1.30 |

PTV_{CW} — chest wall planning target volume; PTV_{SCL} — supraclavicular node planning target volume; PTV_{IMN} — internal mammary node planning target volume; COI — coverage index; UI — uniformity index; CI — conformity index; GI — gradient index; MU — Monitor units; TT — treatment time; min — minute
In addition, for a case of two plans comparison, the H-IMRT and H-VMAT plans that secure the top two scores among the five studied techniques were analyzed statistically. The PTVs dosimetric parameters scores that comprise penalty for statistical significance were 2.23 and 1.50 for

| Parameter | Mean achieved value (Individual Score) |
|-----------|--------------------------------------|
|           | FinF | IMRT | VMAT | H-IMRT | H-VMAT |
| **Heart** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 4.65 (0.93) | 6.46 (2.58) | 8.20 (3.28) | 5.90 (2.36) | 6.27 (2.51) |
| $V_{5\text{Gy}}$ (%) | 15.40 (0.39) | 40.69 (2.03) | 53.02 (2.65) | 27.25 (0.68) | 29.56 (0.74) |
| $V_{25\text{Gy}}$ (%) | 7.36 (0.74) | 3.23 (0.32) | 6.42 (0.64) | 6.68 (0.67) | 7.09 (0.71) |
| $V_{35\text{Gy}}$ (%) | 4.53 (0.91) | 0.50 (0.10) | 1.48 (0.30) | 0.68 (0.14) | 2.23 (0.45) |
| **LAD** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 25.11 (2.51) | 17.94 (0.90) | 23.32 (2.33) | 21.42 (2.14) | 23.48 (2.35) |
| $V_{35\text{Gy}}$ (%) | 44.64 (8.93) | 1.98 (0.20) | 10.23 (2.05) | 2.40 (0.24) | 20.90 (4.18) |
| **RCA** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 1.34 (0.34) | 4.36 (2.18) | 4.45 (2.22) | 3.89 (0.97) | 2.85 (0.71) |
| **IL** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 11.18 (0.93) | 12.04 (2.01) | 13.98 (2.33) | 12.00 (1.00) | 12.71 (2.12) |
| $V_{5\text{Gy}}$ (%) | 40.19 (0.67) | 66.95 (2.23) | 71.80 (2.39) | 55.23 (0.92) | 56.65 (0.94) |
| $V_{25\text{Gy}}$ (%) | 25.60 (0.85) | 21.63 (0.72) | 27.37 (0.91) | 25.70 (0.86) | 26.71 (0.89) |
| $V_{35\text{Gy}}$ (%) | 14.35 (5.74) | 5.10 (2.04) | 8.78 (3.51) | 7.13 (2.85) | 10.56 (4.22) |
| **CL** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 0.29 (0.14) | 2.16 (2.16) | 2.35 (2.35) | 1.40 (0.70) | 1.39 (0.70) |
| $V_{5\text{Gy}}$ (%) | 0.20 (0.04) | 7.73 (3.09) | 6.91 (2.76) | 1.16 (0.23) | 0.65 (0.13) |
| **CBS** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 1.15 (0.57) | 2.70 (2.70) | 2.26 (2.26) | 1.93 (0.97) | 1.67 (0.84) |
| $V_{5\text{Gy}}$ (%) | 3.92 (0.78) | 13.15 (5.26) | 8.22 (3.29) | 6.00 (2.40) | 4.49 (0.90) |
| **Esophagus** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 4.80 (0.48) | 8.68 (0.87) | 11.45 (2.29) | 7.91 (0.79) | 7.80 (0.78) |
| **Trachea** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 4.59 (0.46) | 7.98 (0.80) | 11.55 (2.31) | 7.03 (0.70) | 6.99 (0.70) |
| **Thyroid** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 32.34 (0.92) | 31.50 (0.90) | 31.94 (0.91) | 32.06 (0.92) | 32.16 (0.92) |
| **Humeral head** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 20.02 (0.50) | 22.85 (0.57) | 24.11 (0.60) | 20.43 (0.51) | 20.47 (0.51) |
| **GEJP** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 0.37 (0.12) | 2.01 (0.67) | 2.04 (0.68) | 1.27 (0.42) | 1.42 (0.47) |
| **SC** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 2.92 (0.29) | 12.14 (2.43) | 13.76 (2.75) | 8.00 (0.80) | 7.67 (0.77) |
| **NT** |      |      |      |        |        |
| $D_{\text{max}}$ [Gy] | 3.57 (0.71) | 4.56 (0.91) | 4.65 (0.93) | 4.08 (0.82) | 4.02 (0.80) |
| $V_{5\text{Gy}}$ (%) | 11.58 (0.58) | 21.89 (2.19) | 22.71 (2.27) | 16.26 (0.81) | 15.56 (0.78) |
| OA Rs Total Score | 1.24 | 1.65 | 2.00 | 1.00 | 1.22 |

LAD — left anterior descending coronary artery; RCA — right coronary artery; IL — ipsilateral lung; CL — contralateral lung; CB — contralateral breast; GEJP — coeliac plexus and gastroesophageal junction; SC — spinal cord; NT — normal tissue; Gy — Gray; $D_{\text{max}}$ — mean dose; $D_{\text{max}}$ — maximum dose; $V_{\text{vol}}$ — volume receiving X dose; $D_{\text{vol}}$ — dose to Y % of volume

Table 4. The mean achieved value and individual score results for all dosimetric indices related to organs at risk

In addition, for a case of two plans comparison, the H-IMRT and H-VMAT plans that secure the top two scores among the five studied techniques were analyzed statistically. The PTVs dosimetric parameters scores that comprise penalty for statistical significance were 2.23 and 1.50 for...
the H-IMRT and H-VMAT plans, respectively. Similarly, the OARs dose parameters scores that comprise penalty for statistical significance were 1.23 and 1.87 for the H-IMRT and H-VMAT plans, respectively. The integrated scores that incorporate both PTVs and OARs dosimetric indices were 1.53 and 1.76 for the H-IMRT and H-VMAT plans, respectively.

**Discussion**

The selection of an ideal plan in a clinical set-up as well as in a dosimetric comparison study that involves multiple planning techniques is a challenging task. Further, the mixed results of various dosimetric indices create complexity in choosing a better plan. The integrated scoring approach used in this study accumulates the results of all dosimetric indices of the PTVs, OARs and provides a quantitative measure for each planning technique. The present study appraised five different RT techniques (FinF, IMRT, VMAT, H-IMRT, and H-VMAT) for left-sided CW and nodal stations RT using this integrated scoring approach and it was found as a good tool to establish a ranking for these treatment plans.

To demonstrate how far a plan differs from others, all planning techniques were categorized as “Poor”, “Good”, “Average” and “Excellent” based on the mean (μ) and standard deviation (σ) of the integrated scores attained by these five techniques. The treatment plans with an integrated score greater than μ+σ were categorized as “poor”, while scores ranging from μ to μ+σ were categorized as “average” plans. Similarly, plans with integrated scores ranging from μ to μ+σ were categorized as “good” and scores lower than μ-σ were categorized as “excellent” plans [4]. The μ and σ of integrated scores of the five studied techniques were 1.43 and 0.24, respectively. The μ+σ and μ-σ

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**Table 5.** Correlations between the individual and integrated scores for all dosimetric indices

| Dosimetric indices | Correlation coefficient | Dosimetric indices | Correlation coefficient |
|--------------------|-------------------------|--------------------|-------------------------|
| PTVcran, COI       | 0.4                     | PTVcran, UI        | -0.1                    |
| PTVcran, UI        | 0.5                     | PTVcran, COI       | -0.7                    |
| PTVcran, UI        | 0.2                     | All PTVs COI       | -0.7                    |
| Heart Dmean       | 0.5                     | MU                 | -0.1                    |
| Heart V\text{cran} | 0.9                     | TT                 | -0.6                    |
| RCA Dmean        | 0.8                     | Heart V\text{cran} | -0.6                    |
| IL Dmean        | 0.6                     | Heart V\text{cran} | -0.2                    |
| IL V\text{cran} | 0.9                     | LAD Dmean         | -0.4                    |
| CL Dmean        | 0.9                     | LAD V\text{cran} | -0.2                    |
| CL V\text{cran} | 0.9                     | IL V\text{cran} | -0.2                    |
| CB Dmean        | 0.9                     | IL V\text{cran} | -0.3                    |
| CB V\text{cran} | 0.7                     | Thyroid D\text{cran} | -0.6          |
| Esophagus Dmean | 0.7                     |
| Trachea Dmean | 0.7                     |
| Humeral Head D\text{cran} | 0.9             |
| GEJCP Dmean | 0.6                     |
| SC D\text{cran} | 0.9                     |
| NT Dmean | 0.7                     |
| NT V\text{cran} | 0.9                     |

PTVcran — chest wall planning target volume; PTVcran — supraclavicular node planning target volume; PTVcran — internal mammary node planning target volume; COI — Coverage index; UI — uniformity index; CI — conformity index; GI — gradient index; MU — Monitor units; TT — treatment time; LAD — left anterior descending coronary artery; RCA — right coronary artery; IL — ipsilateral lung; CL — contralateral lung; CB — Contralateral breast; GEJCP — coeliac plexus and gastroesophageal junction; SC — spinal cord; NT — normal tissue; Gy — Gray; Dmean — mean dose; D\text{cran} — maximum dose; V\text{cran} — volume receiving X dose; D\text{cran} — dose to Y % of volume.
were 1.67 and 1.19, respectively. Based on this, the H-IMRT was categorized as an “excellent” plan and the H-VMAT, FinF were categorized as “good” plans. In the same way, the pure IMRT plan was categorized as an “average” and the pure VMAT was categorized as a “poor” plan. Although the pure VMAT plan provided better results for PTVs dosimetric indices in terms of reduced MU and TT, it fails in most of the OARs dose parameters that provided unacceptable results. Further, the indices with unacceptable results doubled the scores due to the penalty function. Thus, the pure VMAT plan was dropped into the “poor” plan category. This approach is useful to review the quality of the clinical plans that have already been delivered to patients in a treatment facility.

The correlation coefficient calculated between the integrated scores and the individual dosimetric index scores for each planning technique revealed that the favorable planning technique for each dosimetric index of the PTVs and OARs was varied. The correlation results of all dosimetric indices were separated into two groups as presented in Table 5. The dosimetric indices in group-1 were positively correlated \((r = 0 \text{ to } +1)\), which implies that the individual dosimetric index scores were in agreement with the integrated scores and the “good” and “excellent” plans provide better results for these dosimetric indices. Whereas the dosimetric indices in group-2 were negatively correlated \((r = 0 \text{ to } -1)\), which indicates that the “average” and “poor” plans provide better results for these dosimetric indices. This information indicates that the “good” and “excellent” planning techniques might improve the results of the dosimetric indices in group-2 with stringent dose constraints during the planning pro-

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**Figure 1.** Radar plot of individual and integrated scores of planning target volumes (PTVs), organs at risks (OARs) for field-in-field (FinF), intensity modulated radiation therapy (IMRT), volumetric modulated arc therapy (VMAT), hybrid IMRT (H-IMRT), and hybrid VMAT (H-VMAT) plans
cess. As a result, the overall quality of these plans can be further improved.

Albeit the penalty function is used for the plans with unacceptable and statistically differed results, it is also helpful to highly distinguish the scores of the studied techniques from each other. That decreases the complexity in choosing a better plan. Moreover, certain dose objectives of patient-specific clinical importance might be given additional weighting in score calculation. The weightings depend on the relative significance of the various dosimetric indices fixed by clinicians. For instance, minimizing the low dose levels (V5Gy) of OARs might reduce the risk of long-term toxicity and secondary cancer risk in the younger patients group. While minimizing the high dose levels (V35Gy) of OARs might reduce the early toxicity in elderly patients. The cardiac structures might be prioritized for patients presenting with cardiac problems. Similarly, certain non-cooperative patients due to pain and patients with breath-hold technique require faster treatment delivery. For these patients, TT might be weighted lesser value in the integrated score calculation. This study utilized a common weighting factor (1) for all dosimetric indices.

In a similar study, Ventura et al. [23] used priority-based weightings in their scoring method. They did not include any penalties for unacceptable and statistically significant results. Further, they have grouped the OARs and given additional weightings for each OARs group depending on the clinical demands. In the present proposed formula, the OARs were given individual penalties and weightings. This makes the process simple and flexible to give differential weightings to each OAR depending on the clinician’s requirements.

The limitation of this study was a selection of a small number of samples. Another limitation of this study was the use of a common weighting factor (1) for all dosimetric indices. Perhaps, the utilization of different weighting factors based on clinical requirements might change the selection of an optimal technique for breast cancer RT.

**Conclusion**

The integrated scoring approach that incorporated both the PTVs and OARs dosimetric indices is efficient and facilitates the dosimetric comparison of multiple planning techniques of the same treatment facility as well as different facilities. It is also a good tool to select an ideal plan from the same technique with different beam parameters and from plans generated by different treatment planners. Further, the proposed method incorporates the patient-specific clinical demands on certain dose objectives using appropriate weighting factors. This scientific approach provides a meaningful selection of an ideal plan in dosimetric comparison studies as well as in routine clinical facilities. The integrated score revealed that the H-IMRT plan was superior for the left-sided CW and nodal stations RT. Nevertheless, the choice of a treatment technique might differ when we apply patient-specific clinical weighting factors in the proposed formula.

**Conflict of interest**
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