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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.

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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 set-up 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 (PTV_{CW}), supraclavicular node (PTV_{SCL}), and internal mammary node (PTV_{IMN}) 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 gastro-esophageal 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

Table 1. Clinical dose constraints for organs at risk

Organs at risk	Parameter	Desired value	Parameter	Desired value
Heart [13–15]	V_{5Gy}	≤ 40 %	V_{25Gy}	≤ 10 %
	V_{35Gy}	≤ 5 %	D_{Mean}	≤ 5 Gy
LAD [14]	V_{35Gy}	≤ 10 %	D_{Mean}	≤ 20 Gy
RCA	D_{Mean}	≤ 4 Gy		
IL [16–18]	V_{5Gy}	≤ 60 %	V_{20Gy}	≤ 30 %
	V_{35Gy}	≤ 10 %	D_{Mean}	≤ 12 Gy
CL [16–18]	V_{5Gy}	≤ 5 %	D_{Mean}	≤ 2 Gy
CB [19,20]	V_{5Gy}	≤ 5 %	D_{Mean}	≤ 2 Gy
Esophagus [21]	D_{Mean}	≤ 10 Gy		
Trachea	D_{Mean}	≤ 10 Gy		
Thyroid	$D_{10\%}$	≤ 35 Gy		
Humeral Head	$D_{1\%}$	≤ 40 Gy		
GEJCP [22]	D_{Mean}	≤ 3 Gy		
SC	D_{Max}	≤ 10 Gy		
NT	V_{5Gy}	≤ 20 %	D_{Mean}	≤ 5 Gy

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; V_{XGy} — volume receiving X Gy dose; $D_{Y\%}$ — dose to Y % of volume; D_{Mean} — mean dose; D_{Max} — maximum dose

fields for the PTV_{CW}, PTV_{IMN} and one anterior oblique, one posterior oblique, half beam blocked field for the PTV_{SCL}. 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:

Table 2. Planning target volume dosimetric indices and limits

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

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

$$Integrated\ Score = \frac{\sum_{i=1}^{n} Individual\ Score_i}{n}$$

$$Individual\ Score_i = \left(\frac{A_i}{D_i}\right) X\ P_i\ X\ W_i$$

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. 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_i/D_i) 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

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.

Table 3. The mean achieved value and individual score results for all planning target volume (PTV) related dosimetric indices

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

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

Parameter	Mean achieved value (Individual Score)				
	FinF	IMRT	VMAT	H-IMRT	H-VMAT
Heart					
D_{Mean} [Gy]	4.65 (0.93)	6.46 (2.58)	8.20 (3.28)	5.90 (2.36)	6.27 (2.51)
V_{5Gy} (%)	15.40 (0.39)	40.69 (2.03)	53.02 (2.65)	27.25 (0.68)	29.56 (0.74)
V_{25Gy} (%)	7.36 (0.74)	3.23 (0.32)	6.42 (0.64)	6.68 (0.67)	7.09 (0.71)
V_{35Gy} (%)	4.53 (0.91)	0.50 (0.10)	1.48 (0.30)	0.68 (0.14)	2.23 (0.45)
LAD					
D_{Mean} [Gy]	25.11 (2.51)	17.94 (0.90)	23.32 (2.33)	21.42 (2.14)	23.48 (2.35)
V_{35Gy} (%)	44.64 (8.93)	1.98 (0.20)	10.23 (2.05)	2.40 (0.24)	20.90 (4.18)
RCA					
D_{Mean} [Gy]	1.34 (0.34)	4.36 (2.18)	4.45 (2.22)	3.89 (0.97)	2.85 (0.71)
IL					
D_{Mean} [Gy]	11.18 (0.93)	12.04 (2.01)	13.98 (2.33)	12.00 (1.00)	12.71 (2.12)
V_{5Gy} (%)	40.19 (0.67)	66.95 (2.23)	71.80 (2.39)	55.23 (0.92)	56.65 (0.94)
V_{20Gy} (%)	25.60 (0.85)	21.63 (0.72)	27.37 (0.91)	25.70 (0.86)	26.71 (0.89)
V_{35Gy} (%)	14.35 (5.74)	5.10 (2.04)	8.78 (3.51)	7.13 (2.85)	10.56 (4.22)
CL					
D_{Mean} [Gy]	0.29 (0.14)	2.16 (2.16)	2.35 (2.35)	1.40 (0.70)	1.39 (0.70)
V_{5Gy} (%)	0.20 (0.04)	7.73 (3.09)	6.91 (2.76)	1.16 (0.23)	0.65 (0.13)
CB					
D_{Mean} [Gy]	1.15 (0.57)	2.70 (2.70)	2.26 (2.26)	1.93 (0.97)	1.67 (0.84)
V_{5Gy} (%)	3.92 (0.78)	13.15 (5.26)	8.22 (3.29)	6.00 (2.40)	4.49 (0.90)
Esophagus					
D_{Mean} [Gy]	4.80 (0.48)	8.68 (0.87)	11.45 (2.29)	7.91 (0.79)	7.80 (0.78)
Trachea					
D_{Mean} [Gy]	4.59 (0.46)	7.98 (0.80)	11.55 (2.31)	7.03 (0.70)	6.99 (0.70)
Thyroid					
$D_{10\%}$ [Gy]	32.34 (0.92)	31.50 (0.90)	31.94 (0.91)	32.06 (0.92)	32.16 (0.92)
Humeral head					
$D_{1\%}$ [Gy]	20.02 (0.50)	22.85 (0.57)	24.11 (0.60)	20.43 (0.51)	20.47 (0.51)
GEJCP					
D_{Mean} [Gy]	0.37 (0.12)	2.01 (0.67)	2.04 (0.68)	1.27 (0.42)	1.42 (0.47)
SC					
D_{Max} [Gy]	2.92 (0.29)	12.14 (2.43)	13.76 (2.75)	8.00 (0.80)	7.67 (0.77)
NT					
D_{Mean} [Gy]	3.57 (0.71)	4.56 (0.91)	4.65 (0.93)	4.08 (0.82)	4.02 (0.80)
V_{5Gy} (%)	11.58 (0.58)	21.89 (2.19)	22.71 (2.27)	16.26 (0.81)	15.56 (0.78)
OARs 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; GEJCP — coeliac plexus and gastroesophageal junction; SC — spinal cord; NT — normal tissue; Gy — Gray; D_{Mean} — mean dose; D_{Max} — maximum dose; V_{XGy} — volume receiving X dose; $D_{Y\%}$ — dose to Y % of volume

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

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

Group 1		Group 2	
Dosimetric indices	Correlation coefficient	Dosimetric indices	Correlation coefficient
PTV_{CW} COI	0.4	PTV_{SCL} UI	–0.1
PTV_{CW} UI	0.5	PTV_{IMN} COI	–0.7
PTV_{SCL} COI	0.8	All PTVs CI	–0.7
PTV_{IMN} UI	0.2	All PTVs GI	–0.7
Heart D_{Mean}	0.5	MU	–0.1
Heart V_{5Gy}	0.9	TT	–0.6
RCA D_{Mean}	0.8	Heart V_{25Gy}	–0.6
IL D_{Mean}	0.6	Heart V_{35Gy}	–0.2
IL V_{5Gy}	0.9	LAD D_{Mean}	–0.4
CL D_{Mean}	0.9	LAD V_{35Gy}	–0.2
CL V_{5Gy}	0.9	IL V_{20Gy}	–0.2
CB D_{Mean}	0.9	IL V_{35Gy}	–0.3
CB V_{5Gy}	0.7	Thyroid $D_{10\%}$	–0.6
Esophagus D_{Mean}	0.7		
Trachea D_{Mean}	0.7		
Humeral Head $D_{1\%}$	0.9		
GEJCP D_{Mean}	0.6		
SC D_{Max}	0.9		
NT D_{Mean}	0.7		
NT V_{5Gy}	0.9		

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; 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; D_{Mean} — mean dose; D_{Max} — maximum dose; V_{XGy} — volume receiving X dose; $D_{Y\%}$ — dose to Y % of volume

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-σ to μ 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

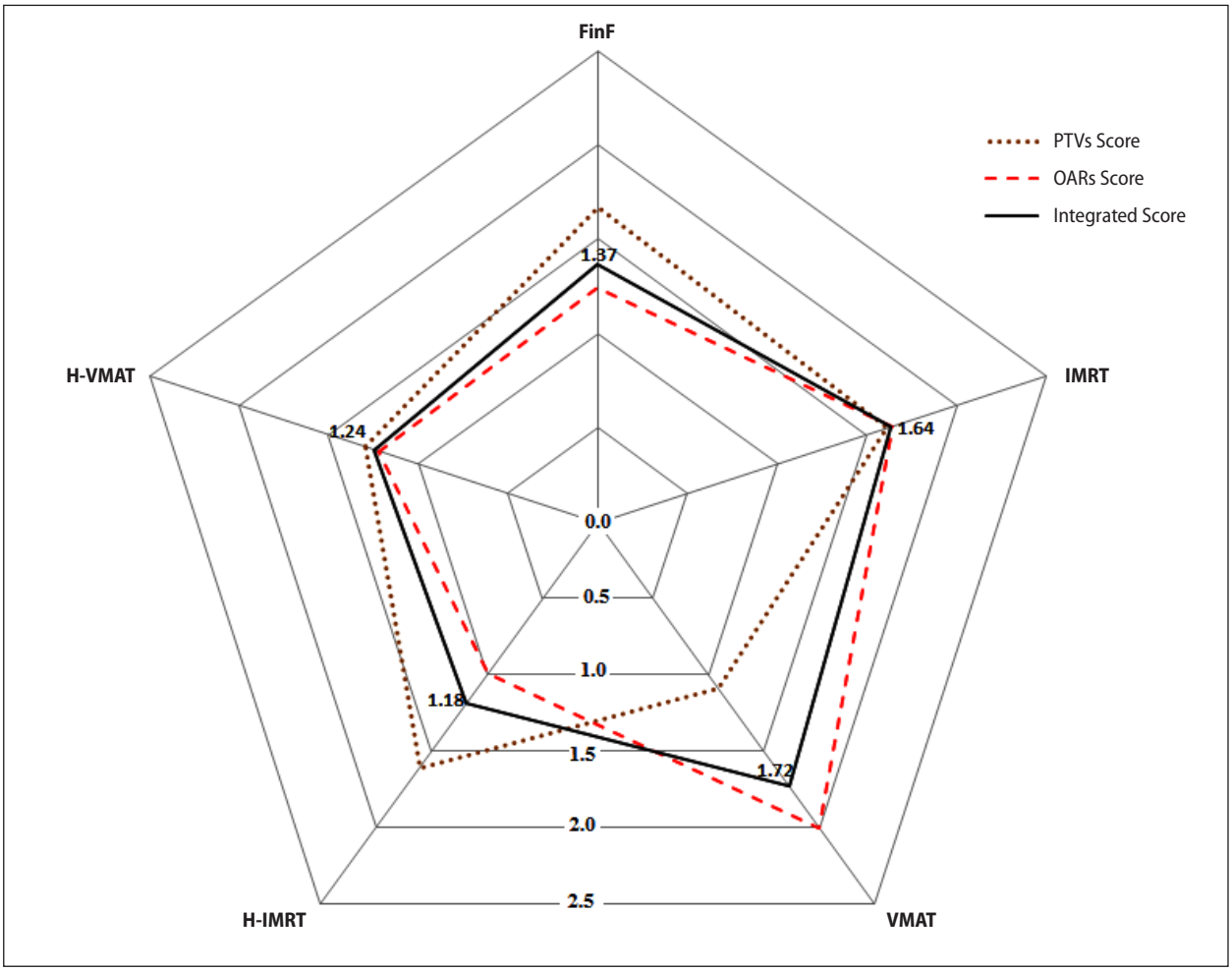

Figure 1. Radar plot of individual and integrated scores of planning target volumes (PTVs), organs at risks (OARs) for field-in-field (FinF), intensity modulated radiation therapy (IMRT), volumetric modulated arc therapy (VMAT), hybrid IMRT (H-IMRT), and hybrid VMAT (H-VMAT) plans

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 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 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-

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 (V_{5Gy}) 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 (V_{35Gy}) 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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References

1. Balaji K, Subramanian B, Yadav P, et al. Radiation therapy for breast cancer: Literature review. Med Dosim. 2016; 41(3): 253–257, doi: 10.1016/j.meddos.2016.06.005, indexed in Pubmed: 27545009.
2. Wagner TH, Bova FJ, Friedman WA, et al. A simple and reliable index for scoring rival stereotactic radiosurgery plans. Int J Radiat Oncol Biol Phys. 2003; 57(4): 1141–1149, doi: 10.1016/s0360-3016(03)01563-3, indexed in Pubmed: 14575847.
3. Hernandez V, Hansen CR, Widesott L, et al. What is plan quality in radiotherapy? The importance of evaluating dose metrics, complexity, and robustness of treatment plans. Radiother Oncol. 2020; 153: 26–33, doi: 10.1016/j.radonc.2020.09.038, indexed in Pubmed: 32987045.
4. Akpati H, Kim C, Kim B, et al. Unified dosimetry index (UDI): a figure of merit for ranking treatment plans. J Appl Clin Med Phys. 2008; 9(3): 99–108, doi: 10.1120/jacmp.v9i3.2803, indexed in Pubmed: 18716596.
5. Mambretti M, Romanò C, Marvaso G, et al. A global Unified Dosimetry Index (gUDI) to evaluate simultaneous integrated boost radiotherapy plans in prostate cancer. Radiother Oncol. 2018; 128(2): 315–320, doi: 10.1016/j.radonc.2018.06.002, indexed in Pubmed: 29945720.

6. Balaji K, Yadav P, BalajiSubramanian S, et al. Hybrid volumetric modulated arc therapy for chest wall irradiation: For a good plan, get the right mixture. Phys Med. 2018; 52: 86–92, doi: 10.1016/j.ejmp.2018.06.641, indexed in Pubmed: 30139614.
7. Jin GH, Chen LX, Deng XW, et al. A comparative dosimetric study for treating left-sided breast cancer for small breast size using five different radiotherapy techniques: conventional tangential field, filed-in-filed, tangential-IMRT, multi-beam IMRT and VMAT. Radiat Oncol. 2013; 8: 89, doi: 10.1186/1748-717X-8-89, indexed in Pubmed: 23587298.
8. Van Parijs H, Reynders T, Heuninckx K, et al. Breast conserving treatment for breast cancer: dosimetric comparison of different non-invasive techniques for additional boost delivery. Radiat Oncol. 2014; 9: 36, doi: 10.1186/1748-717X-9-36, indexed in Pubmed: 24467916.
9. Leung LH, Kan MW, Cheng AC, et al. A new dose-volume-based Plan Quality Index for IMRT plan comparison. Radiother Oncol. 2007; 85(3): 407–417, doi: 10.1016/j.radonc.2007.10.018, indexed in Pubmed: 18023487.
10. Ruan D, Shao W, Demarco J, et al. Evolving treatment plan quality criteria from institution-specific experience. Med Phys. 2012; 39(5): 2708–2712, doi: 10.1118/1.4704497, indexed in Pubmed: 22559641.
11. Song T, Staub D, Chen M, et al. Patient-specific dosimetric endpoints based treatment plan quality control in radiotherapy. Phys Med Biol. 2015; 60(21): 8213–8227, doi: 10.1088/0031-9155/60/21/8213, indexed in Pubmed: 26447829.
12. Alfonso JCL, Herrero MA, Núñez L. A dose-volume histogram based decision-support system for dosimetric comparison of radiotherapy treatment plans. Radiat Oncol. 2015; 10: 263, doi: 10.1186/s13014-015-0569-3, indexed in Pubmed: 26715096.
13. Duane FK, McGale P, Brønnum D, et al. Risk of ischemic heart disease in women after radiotherapy for breast cancer. N Engl J Med. 2013; 368(11): 987–998, doi: 10.1056/NEJMoa1209825, indexed in Pubmed: 23484825.
14. Gagliardi G, Constine LS, Moiseenko V, et al. Radiation dose-volume effects in the heart. Int J Radiat Oncol Biol Phys. 2010; 76(3 Suppl): S77–S85, doi: 10.1016/j.ijrobp.2009.04.093, indexed in Pubmed: 20171522.
15. Chung E, Corbett JR, Moran JM, et al. Is there a dose-response relationship for heart disease with low-dose radiation therapy? Int J Radiat Oncol Biol Phys. 2013; 85(4): 959–964, doi: 10.1016/j.ijrobp.2012.08.002, indexed in Pubmed: 23021709.
16. Blom Goldman U, Wennberg B, Svane G, et al. Reduction of radiation pneumonitis by V20-constraints in breast cancer. Radiat Oncol. 2010; 5: 99, doi: 10.1186/1748-717X-5-99, indexed in Pubmed: 21034456.
17. Marks LB, Bentzen SM, Deasy JO, et al. Radiation dose-volume effects in the lung. Int J Radiat Oncol Biol Phys. 2010; 76(3 Suppl): S70–S76, doi: 10.1016/j.ijrobp.2009.06.091, indexed in Pubmed: 20171521.
18. Chung Y, Yoon HIn, Kim YB, et al. Radiation pneumonitis in breast cancer patients who received radiotherapy using the partially wide tangent technique after breast conserving surgery. J Breast Cancer. 2012; 15(3): 337–343, doi: 10.4048/jbc.2012.15.3.337, indexed in Pubmed: 23091547.
19. Hall EJ. Intensity-modulated radiation therapy, protons, and the risk of second cancers. Int J Radiat Oncol Biol Phys. 2006; 65(1): 1–7, doi: 10.1016/j.ijrobp.2006.01.027, indexed in Pubmed: 16618572.
20. Stovall M, Smith SA, Langholz BM, et al. Women's Environmental, Cancer, and Radiation Epidemiology Study Collaborative Group. Dose to the contralateral breast from radiotherapy and risk of second primary breast cancer in the WECARE study. Int J Radiat Oncol Biol Phys. 2008; 72(4): 1021–1030, doi: 10.1016/j.ijrobp.2008.02.040, indexed in Pubmed: 18556141.
21. Yaney A, Ayan AS, Pan X, et al. Dosimetric parameters associated with radiation-induced esophagitis in breast cancer patients undergoing regional nodal irradiation. Radiother Oncol. 2021; 155: 167–173, doi: 10.1016/j.radonc.2020.10.042, indexed in Pubmed: 33157173.
22. Lazzari G, Terlizzi A, Leo MG, et al. VMAT radiation-induced nausea and vomiting in adjuvant breast cancer radiotherapy: The incidental effect of low-dose bath exposure. Clin Transl Radiat Oncol. 2017; 7: 43–48, doi: 10.1016/j.ctro.2017.09.009, indexed in Pubmed: 29594228.
23. Ventura T, Lopes Md, Ferreira BC, et al. SPIDERplan: A tool to support decision-making in radiation therapy treatment plan assessment. Rep Pract Oncol Radiother. 2016; 21(6): 508–516, doi: 10.1016/j.rpor.2016.07.002, indexed in Pubmed: 27698591.