Paper

DOSIMETRIC COMPARISON OF FOUR DIFFERENT TECHNIQUES FOR SUPRACLAVICULAR IRRADIATION IN 3D-CONFORMAL RADIOTHERAPY OF BREAST CANCER

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Abstract—**This study aimed to compare and evaluated the dosimetric characteristics of esophagus, spinal cord, carotid artery, lungs, and brachial plexus in patients with breast cancer undergoing four various techniques of supraclavicular irradiation. By keeping unchanged the breast tangential radiotherapy fields, four different treatment field arrangements were created to irradiate the supraclavicular region as follows: (1) four field (4F; 1 anterior-posterior and 1 posterior-anterior), (2) six field (6F; 2 anterior-posterior and 2 posterior-anterior), (3) five field-1 (5F-1; 2 anterior-posterior and 1 posterior-anterior), and (4) five field-2 (5F-2; 1 anterior-posterior and 2 posterior-anterior). Then, the dosimetric parameters for the above-mentioned organs were evaluated. The mean dose (D_{mean}) of the esophagus had significant difference between 6F and 5F-2 techniques. For the spinal cord, the D_{mean} dosimetric parameter demonstrated significant difference between the 4F and 6F techniques, and between the 4F and 5F-1 techniques, with lower values for the 4F technique. There was no significant difference between the different irradiation techniques in all the dosimetric parameters for the carotid artery. The D_{mean} of the left lung significantly differed between the 4F and 5F-2 techniques, with lower values for the 5F-2 technique. Furthermore, the V_{20Gy} dosimetric parameter had significant difference between the 4F and 6F, and also 4F and 5F-2, techniques with lower values for 5F-2. The maximum dose (D_{max}) of the brachial plexus showed significant difference between the two techniques of 5F. The V_{45Gy} dosimetric parameter of the brachial plexus revealed significant difference between the 4F and 6F techniques, and also between the 4F and 5F-1 techniques, with lower values for 5F-1. In general, these techniques had similar dosimetric results, with little differences. The dosimetric parameters for the esophagus and lung showed better results with the 5F-2 technique in comparison with other techniques. Dosimetric results for the brachial plexus and spinal cord improved with the 5F-1 and 4F techniques, respectively, against other techniques. Dose distribution for the carotid artery did not differ in the four irradiation techniques.**
Health Phys. 116(0):000–000; 2019

Key words: accelerators, medical; cancer; dose; radiation therapy

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The authors declare no conflicts of interest.

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(*Manuscript accepted* 29 *August* 2018)
0017-9078/19/0

DOI: 10.1097/HP.0000000000000991

INTRODUCTION

BREAST CANCER is the most common cancer and the leading cause of cancer death among women worldwide (Farhood et al. 2018; Ferlay et al. 2015). Nowadays due to the effective screening and combination of different treatment modalities such as surgery, radiation therapy (RT), and hormone therapy, the mortality of breast cancer has decreased significantly in the last three decades (Ma et al. 2015). RT has been established as the primary treatment option for breast cancer at most institutions due to its easier application and long-term advantages (Brown et al. 2015). It is noteworthy that the need for RT depends on the type of surgery, whether the cancer has spread to the lymph nodes or metastasized, and, in some cases, age. Hence, breast cancer treatment may have need just one type of radiation or a combination of different modality types (Brown et al. 2015).

Various treatment techniques have been introduced to increase target dose homogeneity and decrease received dose to organs at risk (OARs) during RT. Although novel techniques such as intensity-modulated radiotherapy (IMRT) have higher uniformity of dose delivery to tumor and OARs (Abdulmoniem et al. 2014), these techniques involve complicated treatment plans that are closely related to long planning and treatment times and also require additional pretreatment quality assurance in busy clinics (Cheung 2006). In particular, IMRT is associated with higher risk of inaccurate dose delivery to moving targets, which results from the interplay between multi-leaf-collimator and organ motions (Court et al. 2010). So three-dimensional conformal RT (3DCRT) is still used for breast cancer radiotherapy. Recently emerging data on RT in the head and neck region and in breast cancer patients showed an increased frequency of secondary strokes, transient ischemic attacks, carotid artery stenosis, and radiation toxicity effects on OARs such as the brachial plexus, spinal cord, esophagus, and lungs (Abdulmoniem et al. 2014; Cheng et al. 1999; Dubec et al. 1998; Kori 1995; Lam et al. 2001; Ma et al. 2015; Nieder et al. 2007; Truong et al. 2010). There are several studies that have measured dosmetric parameters for the OARs in different treatment planning methods.

In a study by Hong et al. (2016), different neck RT techniques including 3DCRT, IMRT, tomohelical-IMRT, and tomohelical-3DCRT were investigated in terms of their dosimetric characteristics and treatment time efficiencies for the carotid artery in early glottic cancer. In another study, Abdulmoniem et al. (2014) evaluated the carotid artery dose during supraclavicular (SC) radiotherapy in adjuvant treatment of breast cancer with three-field CRT (3F-CRT) and four-field CRT (4F-CRT) techniques. Ma et al. (2015) compared and evaluated received doses to OARs of heart, right breast, left lung, left humeral head, and spinal cord in patients with left-sided breast cancer which had undergone post-modified radical mastectomy radiotherapy plans by utilizing 3DCRT with field-in-field, 5-field IMRT, and 2-partial volumetric modulated arc therapy (VMAT) techniques.

In the present study utilizing 3DCRT with four different techniques of SC irradiation, dosimetric characteristics of the esophagus, spinal cord, carotid artery, lungs, and brachial plexus of patients with left-breast cancer by were compared and evaluated.

MATERIALS AND METHODS

Patient selection and definition of the target volume

Fifteen consecutive patients with left-sided, locally intermediate-to-advanced breast cancer (average age 47 ± 9 y) were investigated in this study. All of the patients had breast-conserving surgery before the radiotherapy. The planning images were acquired by a computed tomography (CT) simulator (Siemens Somatom Plus16; Siemens Healthineers, Munich, Germany) in standard supine position during free breathing. The patients had their arms elevated above the head and were not immobilized by masks or any other dedicated devices. Slice thickness was chosen to be 5 mm for all patients. This scanner had been calibrated during commissioning and installation, and periodically it is calibrated every 6 mo. Also, since all of the exposure parameter data (such as kVp, mAs, etc.) were the same for all patients included in this study, the volume computed tomography dose index ($CTDI_{vol}$) value was 6.48 mGy. The CT data were transferred via the computer network to the treatment planning system. A physician-contoured clinical target volume (CTV) and OARs including the esophagus, left lung, left carotid artery, left brachial plexus, spinal cord, heart, and contralateral breast on the CT slices (Fig. 1) using the Isogray Version 4.1.64 (Dosisoft, Cachan, France) treatment planning system.

A prescription dose of 50 Gy was used in 2 Gy per fraction to the planning target volume (PTV). All the patients were treated by a 6-MV photon beam from an Elekta Compact accelerator (Elekta AB, Stockholm, Sweden).

Treatment planning

Because of the lack of electron beams in our study, all of the treatment fields were planned with photon beams. For this end, two tangential fields (medial and lateral) were planned to irradiate the breast and internal mammary lymph nodes. This technique includes a small part of the lung in these fields. Opposed tangential fields with dynamic wedges (to achieve higher dose homogeneity in PTV) were designed to encompass the contoured breast. Gantry angles of medial and lateral tangential fields were chosen to avoid the lung volume as much as possible (Banaei et al. 2015). Dose-volume histograms (DVHs) were created to check the PTV coverage and to obtain dosimetric parameters for the OARs for each plan. The algorithm used for dose calculations was the collapsed cone convolution, as it is the proper algorithm for dose calculation in breast cancer radiation therapy in that the heterogeneous effect is also considered (Basran et al. 2010; Chakarova et al. 2012; Knöös et al. 2006).

In the current study, tangential fields remained unchanged for all four techniques in all cases. For each patient, four sets of treatment plans were created to analyze the

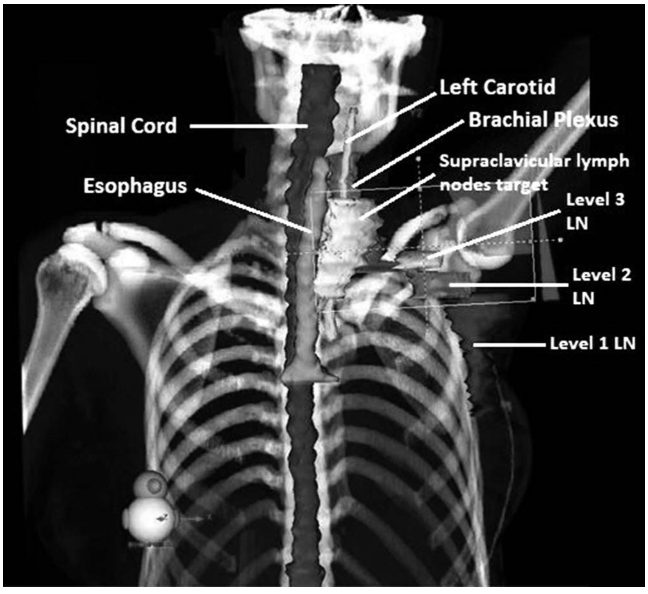

Fig. 1. CT image showing planning target volume, organs at risk, and contouring view in three dimensions in a patient with left-breast cancer. LN: lymph node.

Table 1. Gantry, collimator, and wedge angles for different techniques

Techniques	4F;1AP and 1PA		6F; 2AP and 2PA				5F-1; 2AP and 1PA			5F-2; 1AP and 2PA		
Field type	AP	PA	AP-R	AP-L	PA-R	PA-L	AP-R	AP-L	PA	PA-R	PA-L	AP
Gantry angle	15	170	311	51	180	150	339	19	168	174	151	344
Collimator angle	95	275	272	93	180	150	93	93	272	272	93	93
Wedge angle	10 or 20	10	20 or 10	10 or 20	10	10	15	15	20	10	10	30

dosimetric characteristics and treatment dose distribution; these plans had differences just in the SC region as follows: (1) four-field plan (4F; 1 anterior-posterior [AP] and 1 posterior-anterior [PA]), (2) six-field plan (6F; 2 AP and 2 PA), (3) five-field plan-1 (5 F-1; 2 AP and 1 PA), and (4) five-field plan-2 (5F-2; 1 AP and 2 PA). All of these techniques are described below.

1. **4F (1 AP and 1 PA)**: Two opposed tangential fields were designed as mentioned above. Two additional SC segments were used to conform the dose distribution between 105% and 95% of the prescribed dose. A single AP field was matched to the superior border of the tangential fields to encompass the planning target volume of the lymph nodes (LN-PTV), and a small gantry angle of 5–15° was applied to remove the OARs from the treatment field. Wedges were used to improve the dose homogeneity for each patient with regard to anatomy. Also, a posterior opposing field was added to the AP field. Differential weighting between the AP/PA fields was used to attain higher homogeneity and conformity. It is notable that this technique is used as a routine technique in our center.
2. **6F (2 AP and 2 PA):** For this technique, the arrangement of treatment fields was similar to that of the 4F technique, except that one anterior field and one posterior field were added to this arrangement.
3. **5F-1 (2 AP and 1 PA):** An arrangement of treatment fields similar to the 4F technique was used for this technique, except for an additional anterior field.
4. **5F-2 (1 AP and 2 PA):** For this technique, the arrangement of treatment fields was similar to that of the 5F-1 technique, with the difference that the posterior field was used instead of the anterior field.

Average (± 6 standard deviations [SD]) of gantry, collimator, and wedge angles for the four above-mentioned techniques are listed in Table 1.

Dosimetric parameters

For a dosimetric overview of the different techniques, the following parameters were tested (Beckham et al. 2007; Ma et al. 2015; Ritter et al. 2011; Sakumi et al. 2012; Wang et al. 2015). D_{mean} and $V_{(xGy)}$ represent the average dose delivered to an organ and the percentage of an organ's volume receiving x Gy or higher, respectively.

Various dosimetric parameters for the OARs (esophagus, lung, carotid artery, brachial plexus, and spinal cord) and PTV were evaluated and measured (Abdulmoniem et al. 2014; Hong et al. 2016; Ma et al. 2015). These parameters include minimum dose D_{min}, maximum dose D_{max}, and mean dose D_{mean} for all of the OARs. The volumes of the organ that received a minimum dose of 5, 10, 20, and 40 Gy (V_{5Gy}, V_{10Gy}, V_{20Gy}, and V_{40Gy}), respectively, were also considered for the lung. In the same way, V_{30Gy} and V_{40Gy} were evaluated for the esophagus; V_{45Gy} for the spinal cord; V_{35Gy}, V_{50Gy}, and V_{63Gy} for the carotid artery; and V_{40Gy}, V_{45Gy}, V_{50Gy}, and V_{55Gy} for the brachial plexus.

The volumes of PTV which received 95% and 110% of the prescribed dose ($V_{95\%}$ and $V_{110\%}$), the conformity index (CI), and the homogeneity index (HI) (for evaluation of the PTV dose coverage) (Paddick 2000; Prasana Sarathy 2008) were calculated for PTV under each plan for the four different techniques.

Plan comparison and statistical analysis

DVHs for PTV, esophagus, lung, carotid artery, spinal cord, and brachial plexus were calculated for all the plans, and the mean dosimetric parameters were evaluated based on the findings. The nonparametric Kolmogrov-Smirnov test was initially performed to determine the normality of data distributions. Then, the repeated-measurement test was used for comparisons between the four different techniques to establish a hierarchy in terms of plan quality and dosimetric benefits. SPSS Version 11.5 software (SPSS Inc., Chicago, Illinois, US) was used for statistical data management and analysis. Statistical significance was defined as P values < 0.05.

RESULTS

Table 2 shows the dosimetric parameters averaged over all the patients for all the OARs in the four different SC radiation techniques.

The repeated-measurement statistical test showed that there was no any significant difference for the D_{min} in the four different SC irradiation techniques for all the critical organs. For the esophagus, there was no significant difference between the four techniques in all the dosimetric parameters, except for the D_{mean} which indicates a significant

Table 2. Different dosimetric parameters of various organs at risks, averaged over all patients.

Organ	Parameters	4F; 1AP and 1PA	6F; 2AP and 2PA	5F; 2AP and 1PA	5F; 1AP and 2PA
Esophagus	D_{min}	1.32±0.18	1.34±0.13	1.25±0.15	1.27±0.06
	D_{max}	41.53±12.59	33.39±13.70	35.42±11.82	34.03±15.35
	D_{mean}	8.27±8.89	10.6±6.77	8.35±5.06	7.35±4.14
	V_{30Gy}	6.28±8.05	5.11±8.03	2.98±6.34	3.77±5.22
	V_{40Gy}	2.64±3.70	2.73±3.54	2.15±3.44	1.8±3.19
Spinal cord	D_{min}	0.04±0.10	0	0	0
	D_{max}	25.53±14.51	25.41±13.63	20.91±10.89	21.7±18.32
	D_{mean}	1.51±0.35	2.66±1.08	2.48±0.85	1.57±0.69
	V_{45Gy}	0.03±0.07	0.08±0.20	0	0
Carotid artery (L)	D_{min}	1.35±0.28	1.65±0.83	1.47±0.58	1.51±0.72
	D_{max}	53.76±1.69	52.53±2.22	52.73±2.53	53.41±1.76
	D_{mean}	30.63±2.88	27.87±4.56	28.53±4.59	29.01±4.28
	V_{35Gy}	54.27±4.21	54.15±4.58	51.86±60	52.66±3.30
	V_{50Gy}	31±12.38	30.77±12.60	30.68±12.93	30.79±12.98
	V_{63Gy}	0	0	0	0
Lung (L)	D_{min}	0.137±0.26	0.25±0.06	0.27±0.06	0.25±0.06
	D_{max}	53.83±1.62	53.88±0.77	47.63±15.67	54.72±1.04
	D_{mean}	14.31±1.21	13.87±1.04	14.07±1.09	13.84±1.31
	V_{5Gy}	44.13±3.76	45.03±2.40	45.24±1.88	45.06±2.05
	V_{10Gy}	32.84±3.33	32.88±2.96	33.16±2.29	32.62±2.31
	V_{20Gy}	26.72±2.53	25.79±2.78	25.08±2.25	25.53±1.96
	V_{40Gy}	19.62±2.57	18.32±1.83	18.49±2.21	17.72±2.59
Brachial plexus (L)	D_{min}	1.42±0.23	1.83±0.76	1.62±0.52	1.67±0.59
	D_{max}	54.15±1.56	54.55±1.40	53.4±1.71	55.02±1.44
	D_{mean}	40.35±1.19	38.56±3.46	38.95±2.45	39.8±3.02
	V_{40Gy}	75.5±3.69	69.55±7.06	47.97±28.66	71.2±8.12
	V_{45Gy}	73.5±4.33	66.02±26.01	43.18±7.84	66.06±7.92
	V_{50Gy}	49.6±15.69	55.64±24.07	33.44±7.99	56.4±7.54
	V_{55Gy}	1.98±4.85	0.7±1.76	2.6±4.93	3.6±8.15

difference between the 6F and 5F-2 techniques, with lower values for the 5F-2 technique. The spinal cord data was similar to the esophagus data, as there was just one dosimetric parameter that demonstrated significant differences between different techniques, and it was the D_{mean} between the 4F and 6F techniques and between the 4F and 5F-1 techniques, with lower values for the 4F technique. For the carotid artery, there was not any significant difference for all parameters between the four different irradiation techniques. There was no significant difference between various techniques in all the dosimetric parameters for the lung, except for the D_{mean} and V_{20Gy}: D_{mean} significantly differed between the 4F and 5F-2 techniques, with lower values in 5F-2 technique. Furthermore, the V_{20Gy} revealed a significant difference between the 4F and 6F techniques and the 4F and 5F-2 techniques, with lower values for the 5F-2 technique. The D_{max} dosimetric parameter in the brachial plexus had a significant difference between the 5F-1 and 5F-2 techniques, with lower values for the 5F-1 technique. In the brachial plexus, the V_{45Gy} dosimetric parameter showed a significant difference between the 4F and 6F techniques and the 4F and 5F-1 techniques, with lower values for the 5F-1 technique.

DISCUSSION

The treatment of invasive breast cancer has varied considerably during the past few decades. A larger proportion of these patients, particularly in developed countries, is now treated with breast-conserving surgery, followed by radiotherapy (Farhood et al. 2014; Recht et al. 2001). IMRT plans, compared with 3DCRT plans, would require longer times for treatment planning and therapeutic sessions, and for pretreatment dosimetric verification. It is noteworthy that in our radiotherapy center, most of the adjuvant treatments for breast cancer RT are done with the 3DCRT technique.

In the current study, three new techniques for SC irradiation were created, and their dosimetric characteristics in OARs of esophagus, spinal cord, carotid artery, lungs, and brachial plexus were compared with the routine technique (4F). The tangential fields remained unchanged in the different techniques, because the SC radiation fields include our intended OARs. The PTV coverage, HI, and CI of the three new techniques were in the range and comparable with our routine technique (the differences were less than 5%) and were acceptable.

The D_{mean} and V_{20Gy} dosimetric parameters for the esophagus and lungs in the 5F-2 technique showed lower values against the other techniques. In this technique, we can exclude the esophagus from SC treatment fields, and the location of the lungs is far from the beam central axis. In the spinal cord, the D_{mean} dosimetric parameter had lower values in the 4F technique compared to other techniques because in this technique both of the SC fields did not pass through the spinal cord field. Dosimetric parameters for the carotid artery did not reveal significant differences for the four irradiation techniques. In all techniques, a part of the carotid artery is located inside the lymph nodes' contour. Therefore, these parts of the carotid artery received the lymph nodes' prescribed dose in all four techniques.

In accordance with a report by Truong et al. (2010) related to brachial plexus contouring with CT and magnetic resonance (MR) imaging in RT planning for head and neck cancer and breast cancer, the brachial plexus was considered to be an OAR in the current study. For contouring this OAR, the guidelines described by Hall et al. (2008) were used, which constitute the current Radiation Therapy Oncology Group (RTOG) brachial plexus atlas and the Truong et al. (2010) study. The V_{45} and D_{max} dosimetric parameters for the brachial plexus for the 5F-1 technique showed lower values against other techniques. The supraclavicular lymph nodes are above the brachial plexus, and targeting these lymph nodes with PA fields caused elevation of the brachial plexus dose. On the other hand, irradiating the SC lymph nodes with AP fields reduced the brachial plexus dose because these nerves are located behind the lymph nodes.

In a study by Abdulmoniem et al. (2014), carotid artery dose during SC radiotherapy in adjuvant treatment of breast cancer with 3F-CRT and 4F-CRT techniques was evaluated. They found that the maximum dose to carotid vessels in the 3F-CRT and 4F-CRT techniques was 54.5 ± 1.3 Gy and 51.6 ± 1.3 Gy, respectively; however, the mean dose did not vary significantly. Furthermore, their findings revealed that the 4F-CRT technique is better than the 3F-CRT technique in CTV coverage without significantly higher dose received by the ipsilateral lung and with the lowest dose to the carotid vessel. Regarding the results of this study and the current study, the 3F-CRT irradiation technique was not considered in our investigation. In another study, Ma et al. (2015) compared and evaluated received doses to OARs in patients with left-sided breast cancer in post-modified radical mastectomy radiotherapy by utilizing 3DCRT with field-in-field, 5-field IMRT, and 2-partial VMAT techniques. They noted that 5-field IMRT technique has dosimetric benefits in comparison to the other two techniques in post-modified radical mastectomy radiotherapy for left-sided breast cancer, as there is an optimal balance between covering of PTV and sparing of OAR (particularly heart sparing). In their study, received dose to esophagus, carotid, and brachial plexus was not assessed, but the dosimetric parameters for these organs were evaluated in the current study. Nieder et al. (2007) compared three various RT techniques during breast cancer treatment in order to evaluate heart and mean lung dose. They reported that IMRT might lead to a reduced cardiac complication risk. Nevertheless, in younger women this benefit might be offset by the risk of breast cancer. The best technique for use in patients with breast cancer in our study depends on priority of structure. Garcez et al. (2014) evaluated radiation dose to the carotid with T1 glottic cancer and reported that using an anterior oblique field arrangement in T1 glottic cancer RT can lead to a significantly lower dose to carotid arteries.

It is notable that the complexity of treatment planning and the number of treatment fields affects the total time of patient setup. In the current study, the highest and lowest setup times were for the 6F and 4F techniques, respectively.

As future research, it was suggested that another dose evaluation technique (such as thermoluminescent dosimeters, film, or an electronic portal imaging device) should be used for measurement of the dose distribution in different structures and organs for each of the planning techniques.

CONCLUSION

In the current study, the dosimetric parameters for OARs in four different SC irradiation techniques were evaluated. Generally, our findings demonstrated that these techniques have similar dosimetric results, with little differences. The dosimetric parameters for the esophagus and lung showed better results with the 5F-2 technique in comparison with other techniques. Dose distribution in the carotid artery did not differ in the four irradiation techniques. Dosimetric results for the brachial plexus and spinal cord improved with the 5F-1 and 4F techniques, respectively, against other techniques. As a result, it is recommended that in patients with high priorities for brachial plexus and spinal cord protection, the 5F-1 and 4F techniques should be used for SC irradiation and, in other cases, the 5F-2 technique should be applied. Therefore, the best technique for use in patients with breast cancer (in our study) depends on the priority of structure protection.

Acknowledgments—The authors would like to thank the Medical Physics Department at the Radiotherapy and Oncology Center of Shohaday-e-Tajrish Hospital (Tehran, Iran) for their sincere cooperation.

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