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Half Beam Block Technique in Breast Cancer and It's Dosimetric Analysis using different Algorithms

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ABSTRACT

Introduction: Single isocentre half-beam block (HBB) technique permits the avoidance of hot and cold spots. This technique is very useful in sparing the underlying ipsilateral lung and heart, if the left breast is treated. The major advantage of this technique is that it facilitates the complete sparing of both contralateral breast and lung. Regarding this, the present study aimed to analyse the dosimetric results obtained from the HBB technique in the treatment of breast cancer using three different algorithms.

Materials and Methods: For the purpose of the study, a total dose of 5000 cGy was prescribed to the planning target volume (PTV) in 25 fractions per fraction daily, five days a week. The PTV was derived by using 4-7 mm isotropic expansion of the clinical target volume (CTV) clipping 1-3 mm from the patient's surface in the breast-conserving cases. Three plans were created for each patient using three different algorithms, including convolution, fast superposition, and superposition with the same parameters.

Results: The mean doses of PTV-breast and CTV-supraclavicular fossa (SCF) were tabulated and analysed. In the PTV-breast, the maximum and minimum mean doses were 5428.8 and 4930.2 cGy, which were observed in the fast superposition and convolution algorithms, respectively. In the CTV-SCF, the maximum and minimum mean doses were 5428.8 and 5126.8 cGy, respectively, detected in only fast superposition algorithm.

Conclusion: As the findings of the present study indicated, the convolution algorithm gives slightly better dosimetric results in breast cancer treatment, compared to the fast superposition and superposition algorithms. Therefore, it is prudent to apply the HBB technique with convolution algorithm using the Elekta XiO planning system in the treatment of breast cancer including supraclavicular lymph node metastasis.

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Introduction

Breast cancer accounts for approximately 26% of the cancers occurring in the females. According to the statistics, 209,000 new cases of breast cancer were detected in the United States in 2010 [1]. The incidence of breast cancer increases at a rate of 1-2% throughout the world, and approximately one million new cases are diagnosed with this disease each year [1-3].

The single isocentre half-beam block (HBB) technique facilitates the avoidance of both hot and cold spots. Although planning is a time-consuming measure, it saves up the overall time in the everyday irradiation and patient setup. The HBB technique is very useful in sparing the underlying ipsilateral lung and heart in the treatment of breast. Breast-conserving radiotherapy uses tangential half beams. The major advantage of HBB technique is that both contralateral breast and lung are completely spared. Furthermore, this technique can also easily solve the field junction problem. A single isocentre can be set at the junction of supraclavicular and tangential beams in the treatment of breast [4].

The selection of algorithm plays an important role in generating the treatment plan for the patients. It is of great importance for the modern conformal radiotherapy technique to have more accuracy in dose calculation in almost all relevant clinical situations [5]. The success of any treatment planning system (TPS) depends on the type of algorithm used in different steps of the planning process for the treatment [6]. Many of the available algorithms have tried to take into account the effect of heterogeneities in the attenuation of primary radiation in the scattering properties [7]. In this study, we used the convolution, superposition, and fast superposition algorithms in treatment planning for breast cancer and the surrounding lymph nodes.

The selection of dose calculation algorithm is very important in the achievement of a good plan. In Elekta XiO TPS, the superposition and fast Fourier transform (FFT) convolution algorithms are similar. In other words, they both compute the dose by convolving the total energy deposited in the patient with MonteCarlo-generated energy deposition kernels [7]. TERMA is the total energy released per unit mass, which is calculated by the product of mass attenuation coefficient and the primary energy fluence [8].

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The sampling and interpolation of kernels from spherical to Cartesian coordinates are complicated by steep kernel gradients. Adaptive quadrature techniques ensure that the correct energy at and near the interaction point is represented in the Cartesian coordinates [9]. The XiO system performs a separate high- and low-resolution FFT calculation for the primary and scatter kernels, which achieves a time saving of about 65% over performing a single calculation at high resolution. The superposition dose deposition method is an alteration of the collapsed-cone dose calculation method [10]. All calculations are performed in beam coordinates, and the dose in the beam coordinates is interpolated to the user specified calculation volume.

Unlike the FFT convolution algorithms, in the superposition algorithm, energy deposition kernels can be modified to account for variations in electron density. The density scaling method is used to distort the kernels by finding the average density along the straight line path between the interaction and dose deposition sites. The capabilities of TPS in accurate dose distribution in complex geometries with large asymmetries like mono-isocentre technique must be verified according to the international recommendations [11].

With this background in mind, this study aimed to analyse the dosimetric results obtained from the HBB technique in the treatment of breast cancer using three different algorithms. This study would help us in the selection of the suitable gantry and collimator angles as well as algorithm during the HBB planning procedures. Obtaining knowledge about the various algorithms applied within the TPS can assist the users to understand the capabilities and limitations of the specific algorithm and planning technique.

Materials and Methods

This study was conducted on six patients diagnosed with carcinoma breast including supraclavicular lymph node metastasis. An appropriate thermoplastic sheet (Orfit, Vosveld, Belgium) was moulded for patient immobilization. Subsequently, the transverse computed tomography images were taken with a slice thickness of 3.0 mm. A total dose of 5000 cGy was prescribed to the planning target volume (PTV) in 25 fractions per fraction daily. The PTV was derived by using 4-7 mm isotropic expansion of the clinical target volume (CTV) clipping 1-3 mm from the patient's surface in the breast-conserving cases.

In the chest wall irradiation, PTV-breast was contoured up to the skin level. Spinal cord, ipsilateral lung, contralateral lung, heart, opposite breast, oesophagus, and humeral heads were delineated as the organs at risk. Axilla and supraclavicular fossa (SCF) were taken as drainage areas. Three plans were created for each patient using three different algorithms, namely convolution, fast superposition, and superposition with the same parameters.

In the supraclavicular region, the energies of the photon beams were set at 6 and 15 MV in all tangent and anterior beams, respectively. The isocentre of all beams was kept 3-5 cm below the junction of PTV-breast and CTV-SCF. In the SCF region, all tangential beams were given a single weight point; however, the anterior and posterior beams had a different weight point with a depth of 4-6 cm. Y1 jaw was fully closed and Y2 jaw was open just to irradiate PTV-SCF and vice-versa to for PTV –Breast.

On the other hand, PTV-breast was determined with fully closed Y2 jaw and open Y1 jaw. Field in filed was placed as per requirement just to reduce the hyper dose and hot spot inside the PTV. In addition, 3-6 beams were used to get a better coverage of the target with less hyper dose. The gantry and collimator angles are displayed in Table 1, which will be useful to the users in the achievement of better plan with the HBB technique.

After achieving a good plan with one algorithm, the same plan (with the same parameters) was calculated for the other two algorithms. The Elekta XiO (Impac Medical System, Riverport Drive, Pennsylvania, USA) version 4.82 was used for generating a treatment plan for all patients. Absolute dosimetry was carried out for all the plans using the farmer type chamber FC-65 (Volume 0.65 cc, PTW, Germany).

Evaluation tools

We analysed all the dosimetric parameters, such as homogeneity index (HI), mean dose, PTV-breast D95% (i.e., dose that covers 95% of the PTV), PTV-SCF D95%, global maximum dose, as well as ipsilateral lung, heart, opposite breast, and humeral heads mean. These parameters were used to evaluate all external beam plans.

Table 1. Gantry and collimator angles used in treatment planning

Sl.N0.	Case	Drainage areas 1=No; 2=SCF only, 3=SCF+Ax,	Gantry Angle(in deg.)	Collimator Angle(in degree)
1	Ca. Lt. Breast.	3	0,304,132,315	0,357,0,0
2	Ca. Lt. Breast.	3	0,304,132,315	0,357,0,0
3	Ca. Lt. Breast.	2	0,304,134	0,0,0
4	Ca. Rt.Breast	2	0,50,180,48,231	0,0,0,0,0
5	Ca. Lt.Breast	2	0,315,136,186,136,310	0,0,0,0,0,0
6	Ca. Lt.Breast	3	358 ,306 ,122	90,0,0

SCF = Supra-clavicular fossa , Ax = Axilla, Ca= Carcinoma

All these dosimetry data were taken from the dose-volume histogram (DVH) and get compared. Additionally, the monitor units were recorded for each case. The mean PTV-breast dose was also taken into account.

Dose reporting and evaluation

The DVHs was generated for each patient using the XiO planning system. Figures 1, 2, and 3 represent the DVHs of plans with three different algorithms. The maximum percentage of variation between the algorithms was tabulated for PTV-breast. The evaluation parameters including CI and HI were compared and analysed for each plan. The CI is defined as the quotient of the treated volume and the volume of the PTV, which is formulated as:

$$CI = VRI/TV \quad (1)$$

Where VRI is the volume of the reference isodose, and TV is the target volume [12].

Homogeneity index was calculated using the following formula:

$$HI = D5/D95 \quad (2)$$

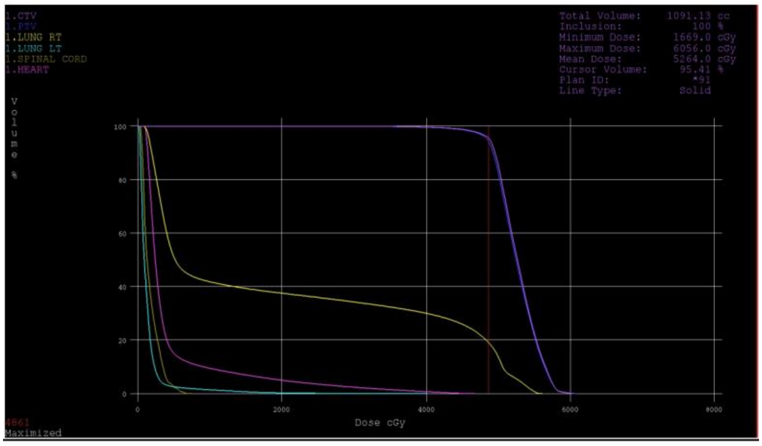

Figure 1. Dose-volume histogram of convolution algorithm

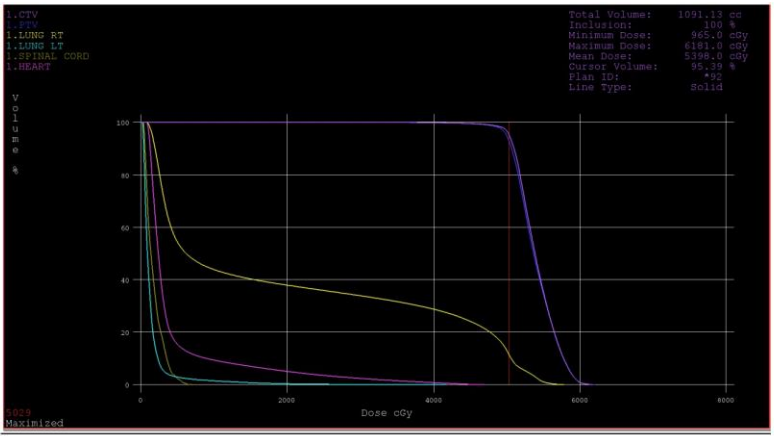

Figure 2. Dose-volume histogram of fast superposition algorithm

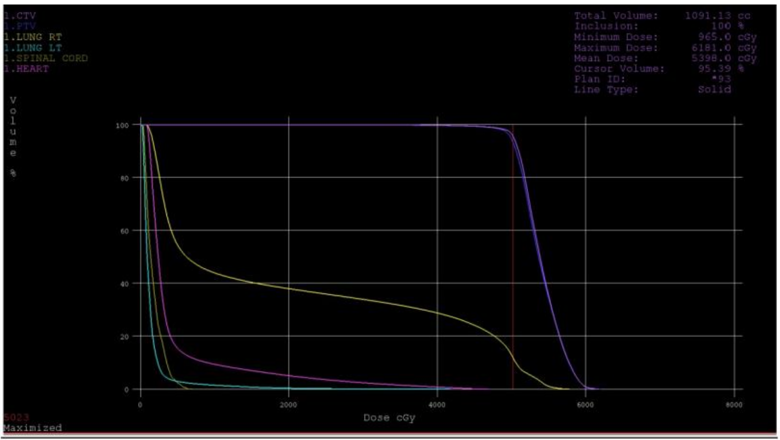

Figure 3. Dose-volume histogram of superposition algorithm

Where D5 is the minimum dose in 5% of the target volume, and D95 is the minimum dose in 95% of the target volume [13].

All these indices were used to quantify the dose distribution in the target volume. The statistical analysis was performed by comparing the mean relative differences of the prescribed dose and mean dose to the organ at risk.

Results

The mean doses of PTV-breast and CTV-SCF were tabulated and analysed. In the PTV-breast, the maximum and minimum mean doses were 5428.8 and 4930.2 cGy, which were observed in the fast superposition and convolution algorithms, respectively (Table2). Furthermore, in the CTV-SCF, the maximum and minimum doses were 5428.8 and 5126.8 cGy, respectively, which were indicated in the fast superposition algorithm. The opposite lung was almost saved, the maximum mean dose to the opposite lung was 168.7 cGy, which was noted in the fast superposition.

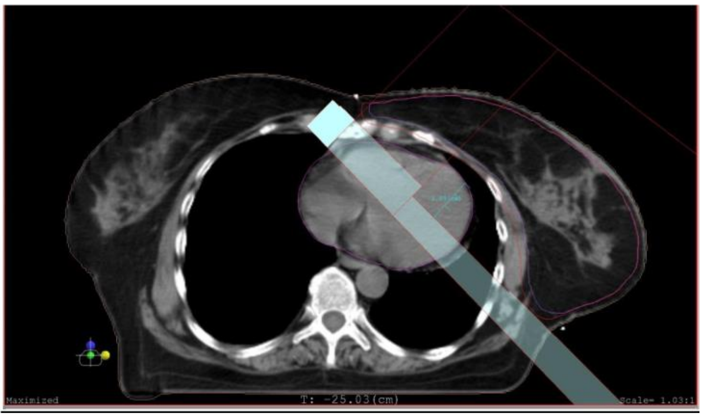

Figure 4. Maximum involvement of the heart in medial tangent beam

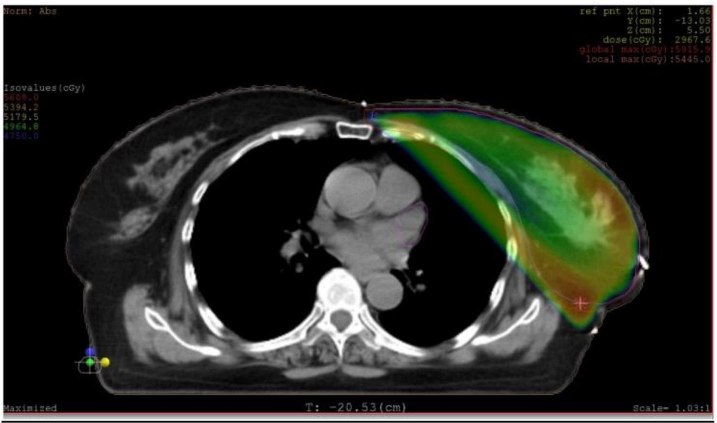

Figure 5. Target coverage in convolution algorithm

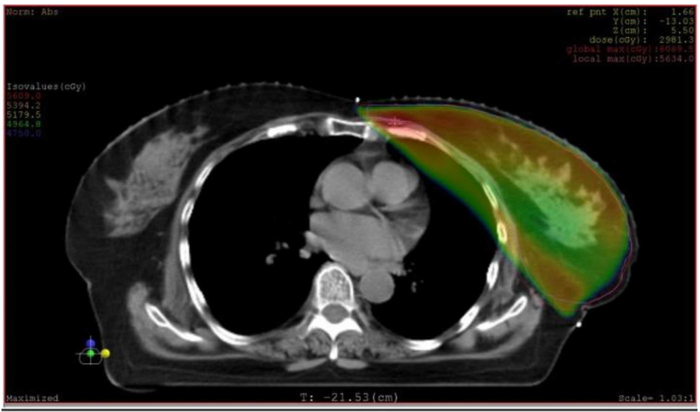

Figure 6. Target coverage in fast superposion algorithm

Table 2. Dose coverage of targets.

Sl	Case	Algorithm	Global Max dose(cGy)	CTV-Breast				PTV-Breast				CTV- SCF			
				CTV D95 (cGy)	CTV Mean (cGy)	CTV V95 (% Cc)	Dose Max (cGy)	PTV D95 (cGy)	PTV Mean (cGy)	PTV V95 (%cc)	Dose Max (cGy)	CTV SCF D95 (cGy)	CTV SCF Mean (cGy)	CTV SCF V95 (cGy)	Dose Max (cGy)
1	Ca. Lt. Breast.	COVOLUTION	6022	4734	5256	94.87	6008	4286	5164	91.63	6006.6	4708.2	5128	93.98	5584
		FAST SUPERPOSITION	6121	4788	5342	95.49	6109	4322	5235.2	92.24	6108.4	4741.6	5126.8	94.78	5588
		SUPERPOSITION	6109	4792	5332	95.48	6101	4322	5225.8	92.28	6100.9	4730.6	5124.1	94.49	5585
2	Ca. Lt. Breast.	COVOLUTION	6125	4608.5	4959	87.03	5572	4464	4930.2	83.89	5575.6	4648.2	5239.2	93.09	6125
		FAST SUPERPOSITION	6259	4768	5079	95.78	5693	4607	5031.5	91.21	5740.6	4756.7	5304.4	95.15	6246
		SUPERPOSITION	6255	4754.2	5067	95.19	5671	4596	5020.8	90.64	5710	4763.5	5308.2	95.28	6250
3	Ca. Lt. Breast.	COVOLUTION	6248	4891.8	5284	96.98	6169	4256	5168.4	89.37	6248	4594	5231.1	90.72	5231
		FAST SUPERPOSITION	6371	4872.4	5300	97.18	6335	4274	5175.4	88.95	6340	4613.6	5249.6	91.31	5250
		SUPERPOSITION	6350	4879.4	5301	97.23	6352	4277	5177.2	89.12	6345.1	4620.5	5257.4	91.58	5257
4	Ca.Rt. Breast	COVOLUTION	6394	4878	5265	97.19	6060	4846	5248.6	96.95	6083.4	5062.6	5476.8	99.8	6343
		FAST SUPERPOSITION	6364	5034.8	5401	98.95	6188	4997	5386.2	98.88	6206.4	4930.4	5371.8	99.64	5372
		SUPERPOSITION	6364	5034.8	5401	98.95	6188	4997	5386.2	98.88	6206.4	4930.4	5371.8	99.64	5372
5	Ca. Lt. Breast.	COVOLUTION	5922	4380.9	4777	52.72	5534	4257	4744.4	50.06	5534	4724.7	5142.2	94.62	5918
		FAST SUPERPOSITION	6100.8	4727.6	5089	94.39	5895	4609	5055.8	91.68	5894.7	4813.6	5179.0	96.28	6100
		SUPERPOSITION	6072.5	4705.2	5071	93.55	5864	4588	5037.6	90.65	5864.4	4812.8	5170.7	96.25	5171
6	Ca. Lt. Breast.	COVOLUTION	6124	4565.4	5051	86.44	5649	4499	5001.6	82.76	5648.9	4778.9	5321.1	95.88	6120
		FAST SUPERPOSITION	6176	4663.5	5152	91.62	5859	4567	5101.1	88.16	5851.1	4781.5	**5428.8**	95.92	6173
		SUPERPOSITION	6119	4672.7	5155	91.93	5155	4581	5104.1	88.52	5104.1	4782.1	5405.5	95.94	6117

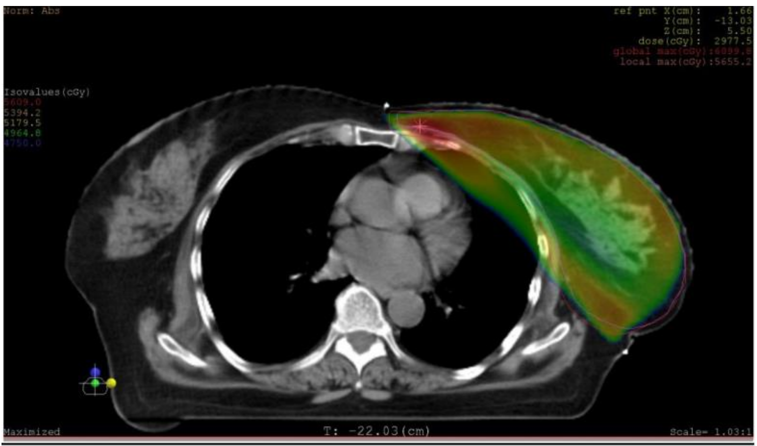

Figure 7. Target coverage in superposition algorithm

Table 3. Radiation dose received by lungs.

Sl	Case	Algorithm	Ipsilateral lung dose					Contralateral lung dose			
			Mean dose(cGy)	D25(cGy)	V5(%)	V10(%)	V20(%)	C/L Mean Lung Dose(cGy)	V5(%)	V10(%)	V20(%)
1	Ca. Lt. Breast.	COVOLUTION	2594.0	4814.4	64.9	58.93	52.9	163.8	3.61	2.1	0.80
		FAST SUPERPOSITION	2550.4	4660.6	68.07	60.47	53.3	168.7	4.13	2.18	0.88
		SUPERPOSITION	2549.2	4660.5	68.11	60.44	53.29	167.2	4.11	2.17	0.88
2	Ca. Lt. Breast.	COVOLUTION	2374.7	4805.8	59.58	53.73	48.8	124.7	0.64	0.24	0.05
		FAST SUPERPOSITION	2369.4	4680.3	63.3	55.97	49.5	123.5	0.79	0.28	0.06
		SUPERPOSITION	2367.6	4685	63.23	55.86	49.4	123	0.77	0.28	0.06
3	Ca. Lt. Breast.	COVOLUTION	1646.6	3319.2	45.11	36.96	31.42	105.9	0.04	0	0
		FAST SUPERPOSITION	1644.1	3198.5	52.21	41.36	32.83	105.6	0.1	0	0
		SUPERPOSITION	1647.7	3215.2	52.64	41.33	32.8	105.6	0.1	0	0
4	Ca. Rt.Breast	COVOLUTION	1966.1	4566.3	50.91	41.78	37.53	130.7	2.53	1.38	0.21
		FAST SUPERPOSITION	1974.9	4427.3	54.4	43.88	37.95	134	2.82	1.41	0.26
		SUPERPOSITION	1974.9	4427.3	54.4	43.88	37.95	134	2.82	1.41	0.26
5	Ca. Lt.Breast	COVOLUTION	1866.7	4237.7	52.36	43.17	37.13	115.3	0.73	0.21	0.05
		FAST SUPERPOSITION	1931.7	4077.8	58.82	47.85	38.81	121.3	0.96	0.27	0.05
		SUPERPOSITION	1927.9	4085	58.79	47.75	38.69	120.8	0.94	0.27	0.05
6	Ca. Lt.Breast	COVOLUTION	1785.6	4008.1	48.16	41.81	36.29	105.5	0.56	0.14	0
		FAST SUPERPOSITION	1792.6	3771.7	53.62	44.73	37.16	108.1	0.64	0.14	0
		SUPERPOSITION	1796.4	3791.8	53.8	44.69	37.12	106	0.63	0.14	0

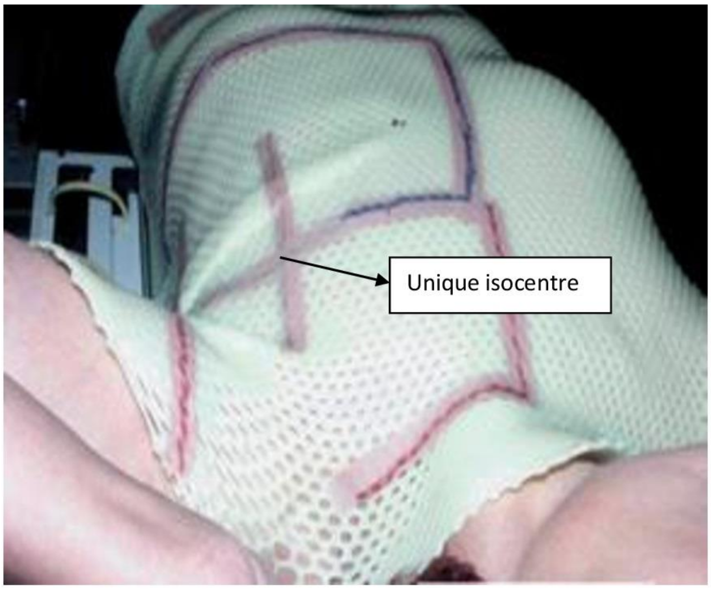

Figure 8. Position of isocentre and extension of supraclavicular fossa region

In addition, the maximum depth of the heart was 3.0 cm (Figure 4). The maximum mean heart dose was 1280.1 cGy, observed in the fast superposition. The maximum and minimum doses to the opposite breast were 403.2 and 88.4 cGy that were presented in the fast superposition and convolution algorithms, respectively. The maximum mean ipsilateral lung dose was 2594.0 cGy, which was found in the convolution algorithm (Table 3).

The global maximum dose was comparatively lower in the convolution algorithm. In the convolution algorithm, the overall mean dose to PTV-breast and CTV-SCF was relatively more satisfactory and closer to the prescribed dose. Figures 5, 6, and 7 display 95% of the prescribed dose coverage for PTV-breast and CTV-SCF in all three algorithms. The monitor units were found to be almost the same for all plans.

Table 4. Dose received by organs at risk

			Heart Dose					Opposite Breast Mean Dose(cGy)	Spinal Cord Dmax(cGy)	Oesophagus Mean Dose(cGy)	Humeral Head Mean Dose(cGy)
Sl	Case	Algorithm	Max. Heart Depth (cm)	Mean Dose(cGy)	V5(%)	V10(%)	V20(%)				
1	Ca. Lt. Breast.	COVOLUTION	2	1270.6	40.94	31.38	24	209.3	3581.4	948.9	4755.2
		FAST SUPERPOSITION	2	1280.1	42.31	32.03	24.39	205.6	3645.7	945.1	4759.4
		SUPERPOSITION	2	1278.2	41.98	31.97	24.35	204	3637	943.8	4759.9
2	Ca. Lt. Breast.	COVOLUTION	1.99	1032.2	34.08	26.18	19.69	163.9	2610.4	453.9	1023.8
		FAST SUPERPOSITION	1.99	1036.8	34.8	26.19	19.99	154.6	2696.2	475.3	1045.6
		SUPERPOSITION	1.99	1034.7	34.54	26.16	19.96	153.5	2699.4	475.8	1044.5
3	Ca. Lt. Breast.	COVOLUTION	2.4	846.4	24.95	18.25	13.77	200.8	3534.3	785.9	316.9
		FAST SUPERPOSITION	2.4	841.4	26.13	18.45	13.85	192.8	3623.6	806.6	315.8
		SUPERPOSITION	2.4	840.3	25.73	18.37	13.83	191.8	3647.7	807	318.6
4	Ca. Rt.Breast	COVOLUTION	1.7	449.2	14.94	9.39	4.98	392.7	669.3	248.6	1901.4
		FAST SUPERPOSITION	1.7	445	15.31	9.28	5.03	403.2	641.4	253	1917.1
		SUPERPOSITION	1.7	445	15.31	9.28	5.03	403.2	641.4	253	1917.1
5	Ca. Lt.Breast	COVOLUTION	3	1023.6	34.58	25.9	19.35	88.4	3543.7	889	272.2
		FAST SUPERPOSITION	3	1098.7	36.3	27.07	20.35	89.2	3579.7	895	275
		SUPERPOSITION	3	1094.7	35.96	27	20.3	88.5	3569.6	892.3	275.2
6	Ca. Lt.Breast	COVOLUTION	2.2	900.6	29.6	22.91	15.78	380.2	3418.5	407.1	1902.3
		FAST SUPERPOSITION	2.2	897	29.72	22.8	16.02	384.9	3524.2	424.2	1915.6
		SUPERPOSITION	2.2	897.6	29.51	22.76	16.03	383	3512.9	419.2	1916.5

Discussion

Regarding the incidence and mortality rates of breast cancer, this disease is still a serious problem that frequently occurs in the females. Radiotherapy, which is accepted as an integral part of the breast-conserving surgery, improves the survival by reducing the local recurrence of locally advanced breast cancers [14]. Despite the current success of radiation therapy, there has been frequent discussions over the side effects of this method, especially in the recent years [15].

While planning radiotherapy after breast-conserving surgery, the remaining breast tissues, chest wall, and incision area are included in the irradiation field [16]. This is clearly shown in Figure 8. Depending on the lymph node metastasis, the axilla or supraclavicular area is included in the area of irradiation [17, 18]. In our study, the total applied dose was 50 Gy in 25 fractions.

As a result of the development of the technological infrastructures and software programs, various methods are invoked in the breast cancer radiotherapy planning. These methods include the three-dimensional conformal radiotherapy, intensity-modulated radiation therapy, mage-guided radiation therapy, volumetric modulated arc therapy, field-in-field technique, and HBB [19-21]. In this study, the HBB plan was generated for all the patients, and a maximum of six beams were employed to improve the target coverage. In our hospital, we use 3D supraclavicular half beam and tangential area half beam with a single isocentre.

Accordingly, the use of single isocentre solved the problem of both hot and cold spots.

The lungs are one of the first organs to receive the radiation dose; therefore, they should be protected during the breast irradiation [22]. The HBB technique with convolution algorithm provides significant advantage to reduce the ipsilateral lung dose, particularly the apex of the lung dose. Planning by the means of the HBB technique is also easier for the operator, compared to the multicentre technique. Furthermore, it reduces the coordinate shift errors. Moreover, this technique facilitates a significant reduction in the low dose volume area of the ipsilateral lung.

Another important organ affected during breast radiation is the heart. Although the exact mechanism is not clear, the dose of radiation exposure causes significant cardiac toxic effects [23] and results in significant mortality [24]. The most important study on cardiac dose affecting the heart was published by Shultz-Hector [25]. In our study, there was a significant decrease in the V25, V5, and D-mean values of the heart (Table 4). Another organ that should be taken into account during the planning and dose calculation is oesophagus. As indicate by Emami, in the HBB technique, the dose obtained in each plan, such as the maximal dose, is well below the recommended tolerance dose [26].

Mathematically, superposition and convolution algorithms are of almost similar features because both calculate the dose by convolving the entire energy released in the patient with Monte Carlo-generated energy deposition kernel. The kernel of superposition algorithm can be modified to take care of the variation in electron density. The dose calculation speed of fast superposition is 2.5 times more than that of the superposition algorithm. However, the superposition and convolution algorithm calculate the dose more accurately than the fast superposition.

Table 5. Mean dose of the target

Algorithms	Mean of mean PTV-breast dose (cGy)
Convolution	5040.9
Fast superposition	5163.0
Superposition	5158.6

PTV: planning target volume

Significant deviations are observed between these three dose calculation algorithms. The mean of mean dose PTV-breast was calculated for all three algorithms (Table 5). We compared the convolution, superposition, and fast superposition algorithms using the HBB technique. Within the target structures, the deviation of mean dose from the prescribed dose and maximum percentage of variation (PTV-breast mean dose) among these algorithms was found to be 4.6%.

Conclusion

The advancement of the treatment planning algorithms and treatment machines has led to a considerable progress in the breast radiation therapy. A practical option must be chosen so that the majority of the patients can benefit from the new dimensions of technology. The HBB technique sorts out the junction problems in the treatment of the breast and the surrounding lymph nodes. This technique provides better target dose coverage and completely spares the opposite lung, heart, contralateral breast, and oesophagus. The convolution algorithm offers slightly better dosimetric results as compared to the fast superposition and superposition algorithms. Conclusively, it is prudent to apply the HBB technique with convolution algorithm using Elekta XiO planning system in the treatment of breast cancer and subclavicular lymph node metastasis.

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