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CASE STUDY: DOSIMETRIC COMPARISON OF VMAT, IMRT AND 3DCRT TECHNIQUES FOR LEFT-SIDED BREAST CANCER TREATED IN DEEP INSPIRATION BREATH-HOLD

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Abstract. The aim of this case study was to compare 3D conformal radiotherapy (3DCRT) plans for patients treated for left-sided breast cancer (whole breast without positive lymph nodes in deep inspiration breath-hold (DIBH)) to volumetric modulated arc therapy (VMAT) and intensity modulated radiation therapy (IMRT) plans. The original clinical plans used tangential field-in-field 3DCRT technique with a combination of 6 MV and 18 MV photon beams. VMAT and IMRT plans were based on several previously published techniques and used 6 MV beams. Two patients were included in this case study and 4 plans were created and compared for each one. All plans were compared in terms of tumour coverage, gradient measure and conformity index, doses to organs at risk (OARs), the volume of body receiving 5 Gy and also the number of Monitor Units (MUs). While better tumour coverage and conformity was achieved with IMRT and VMAT plans, OARs were better spared with the 3DCRT technique, which also resulted in the lowest dose bath and number of MUs.

Keywords: Breast cancer, DIBH, treatment planning, VMAT.

1. Introduction

The state-of-the-art technique in radiotherapy treatment planning is undoubtedly volumetric modulated arc therapy (VMAT). Although, the traditional 3D conformal radiotherapy planning (3DCRT) might still be the method of choice for breast cancer because with tangential fields, healthy tissues on the contralateral side are spared and the integral dose is kept low [1–5]. However, studies have shown that intensity modulated radiation therapy (IMRT) and VMAT techniques might improve the dose conformity and homogeneity in the planning target volume (PTV) and reduce the dose to the ipsilateral lung and heart (in the case of left breast treatment) [1, 5–8]. Other studies have shown that the heart can be better spared with 3DCRT techniques [2, 4]. IMRT and VMAT treatment can comprehensively be applied only when the movement of target is suppressed, such as with deep inspiration breath hold (DIBH) treatment or other gating methods, as these methods reduce interplay effects. The outcome of comparisons of 3DCRT and IMRT or 3DCRT and VMAT might depend on the particular treatment technique used, including the chosen respiratory gating method and treatment position with fixation devices. Also, the treatment goals might be different in different situations. Thus, it is useful to perform such a comparison for each particular treatment strategy and technique that is to be used clinically on a particular treatment site, especially when any of the methods are being newly established in the clinic. In this case study, a tangential field-in-field 3DCRT technique using a combination of 6 MV and 18 MV energies will be compared to several IMRT and VMAT techniques published in literature [1, 9, 10]. The original studies by Boman et al. [9], Popescu et al. [1] and Karpf et al. [10] took into account different criteria when selecting the patients. While Boman et al. [9] designed the study for both left and right sided tumours, both with and without DIBH and including irradiation of axillary and regional lymph nodes (19 patients in total), Popescu et al. [1] focused on left breast or chest wall irradiation with regional lymph nodes, probably without gating (5 patients in total). Popescu et al. [1] evaluated the proposed VMAT technique compared to a clinically used IMRT technique while Boman et al. [9] investigated different VMAT techniques and compared them to a conventional field-in-field technique. However, their patients were selected so that the heart dose and lung dose were already high in the original conventional plans (V20 > 30 %) [1]. Karpf et al. [10] compared their IMRT technique to a VMAT technique (similar to Boman's [9]) and included only patients with left breast cancer without pathologic lymph nodes, all of them were treated in DIBH (20 patients in total). The aim of this case study is to show the advantages and drawbacks of each of the previously published techniques [1, 9, 10] for adjuvant radiotherapy of the left breast without pathologic lymph nodes performed in DIBH and to compare them to a conventional 3D radiotherapy. Not only the outcomes, but also the design of this case study might serve as an example to radiotherapy departments who are introducing new techniques to the clinic.

2. Materials and methods

Two patients already treated for left-sided breast cancer (without pathologic lymph nodes but one of them with higher tangent irradiation) after breast conserving surgery and in deep inspiration breath hold were chosen for this study. In addition to the original 3DCRT clinical plans, an IMRT plan and two VMAT plans were created for each patient. The planning techniques are described in the following sections. The prescribed dose to the PTV was 43.2 Gy in 16 fractions. Treatment planning was performed in Eclipse v. 16.1 (Varian Medical Systems, Palo Alto, USA) and the AAA algorithm v. 16.1 (Varian Medical Systems, Palo Alto, USA) was used for calculating the dose. The dose grid was set to 2.5 mm. The Photon Optimizer v. 16.1 (Varian Medical Systems, Palo Alto, USA) was used for optimising the IMRT and VMAT plans. The plans were created for a Varian TrueBeam accelerator with a Millenium120 multi-leaf collimator (MLC). Gating (DIBH) was performed with the Varian RPM Respiratory Gating system (Varian Medical Systems, Palo Alto, USA) where the Marker Block must be placed on the patient's surface to capture the patient's breathing pattern. The Marker Block was (for technical issues) placed, at least partially, in the treatment fields, so it was delineated as a support structure in Eclipse. This means that the dose calculation engine takes into account it's Hounsfield Units (HUs) but it does not optically display the dose in the support structure in the final treatment plan. Delineating the Marker Block usually causes hot spots in tissues just below, in contrast to the situation without the Marker Block, in our experience.

2.1. Planning CT scans

Patients were scanned on a Philips Brilliance Big Bore (Philips Medical Systems, Netherlands) CT scanner in helical mode. They were in supine position on a CIVCO (CIVCO Radiotherapy, USA) breast board with both arms positioned above the head and the head turned to the contralateral side. The axial CT slices were reconstructed with 3 mm steps. Patients were asked to hold their breath during the scan with the help of audio and video coaching using the Varian RPM Respiratory Gating system (Varian Medical Systems, Palo Alto, USA).

2.2. Dose objectives

The clinical dose objectives used for organs at risk during plan preparation and evaluation are listed in Table 1. Dose constraints in the optimisation process were chosen in order to meet these dose objectives in the final plan but could differ from these numbers. The primary clinical goal was to achieve a coverage of PTV so that at least 98 % of PTV would receive 85 % of the prescribed dose (V85 % $\geq$ 98 %).

Organ at risk	**Dose objective**
Spinal cord	$D_{max} < 39.5$ Gy
Heart	$D_{mean} < 4.8$ Gy
Ipsilateral lung	V23.2 Gy ≤ 15 %
	$D_{mean} < 9.6$ Gy
Controlateral breast	$D_{mean} < 3.0$ Gy

Table 1. Clinical dose objectives for OARs.

2.3. Delineation of PTV, CTV and OARs

The clinical target volume (CTV) and PTV were delineated according to ICRU 50 and ICRU 62 [11, 12]. The margin from CTV to PTV was 0.5 cm in the lateral direction and 1 cm in all other directions (anterior, posterior, cranial and caudal). Then, the PTV was cropped from the patient surface by 3 mm. The organs at risk (OARs) considered were: the left lung, right lung, spinal cord, heart and contralateral breast. For one of the patients, the humerus head was also contoured.

2.4. 3DCRT planning

The 3D conformal plans were made using tangential fields with a combination of 6 MV and 18 MV energies and using the field-in-field technique. The isocentre was placed in the central part of the PTV and inside the lung, the position was similar to the VMAT plans created according to Boman et al. [9] and described below, i.e. approximately 2 cm from the chest wall boundary. Different dynamic wedges were applied, so the collimator had to be turned to 90° and then the collimator angle was adjusted according to the shape of the PTV. When fitting the MLC leaves, there was no margin left in the direction of the lung but an appropriate margin was left between the PTV and the leaves on the opposite side (in the air) to account for variations in patient's positioning and swelling. The dose distribution was normalised to an ICRU point inside the PTV.

2.5. IMRT planning

For IMRT plans, the technique described by Karpf et al. [10] was considered. Each plan had 6 fields, starting from 315° for Patient no. 1 and 310° for Patient no. 2 and ending at 179° for both patients. The rest of the fields were placed equidistantly in between. The collimator was left at 0° and the isocentre was placed at the boundary of the chest wall and left lung, in the centre of the PTV. The plan normalisation was not changed after the optimisation and dose calculation (the No Plan Normalisation option in Eclipse), so that the absolute dose values were taken from the optimisation process. The IMRT plan used the 6 MV photon beams only.

Evaluated parameter	**3DCRT**	**IMRT**	**VMAT1**	**VMAT2**
Spinal cord				
D_{max} [Gy]	0.6	3.2	4.9	3.8
Heart				
D_{mean} [Gy]	0.1	5.2	5.7	4.4
Ipsilateral lung				
D15 % [Gy]	28.1	20.7	27.6	16.8
D_{mean} [Gy]	8.8	10.1	13.0	9.2
Contralateral lung				
D_{mean} [Gy]	0.1	1.8	2.3	1.6
PTV coverage				
D_{mean} [Gy]	42.2	43.2	42.9	42.3
D98 % [Gy]	36.0	39.1	38.4	36.8
V95 % [%]	83.6	93.8	90.7	81.4
D2 % [Gy]	44.6	45.4	44.8	44.6
V105 % [%]	0.0	2.8	0.5	0.0
Gradient index [cm]	3.33	2.69	2.82	2.62
Conformity index	0.37	0.54	0.53	0.45
Number of MU	293.0	1,361.1	587.3	488.9
Volume of 5 Gy isodose [cm^3]	3,264	5,812	5,846	5,042

TABLE 2. Results for Patient no. 1. VMAT1 is the technique based on [9] and VMAT2 on [1].

2.6. VMAT planning

Two different planning techniques were investigated in the case of VMAT. For both of them, the 6MV energy was used. The normalisation of the plan was not changed after the optimisation and dose calculation (the No Plan Normalisation option in Eclipse).

The first technique (VMAT1) was according to Popescu et al. [1] who suggested using two arcs of 190° in total (60° on the contralateral side and 130° on the ipsilateral side, i.e. from 300° to 130° in the case of left-sided breast tumour). This had to be adjusted to the individual patient's anatomy and in the case of Patient no. 1, it resulted in two arcs of 220° between gantry angles 310° and 170° because the breast was atypically positioned to the patient's posterior side. In the case of Patient no. 2, it was 300° to 150°. The isocentre was located in the centre of the PTV and on the boundary between the lung and the chest wall. The collimator angle was set to 10° and 350° in order to suppress leakage between leaves (in contrast to the original technique by Popescu who used a collimator angle of 0°).

The second technique (VMAT2) was based on the work by Boman et al. [9] who proposed a split VMAT design with two arcs, each split into two parts. The advantage of splitting the arcs is that the collimator angle and the field fitting in each of the subarcs can be adjusted to the PTV in the beam's eye view, so that each field attempts to avoid the lung and the heart as much as possible. The total angle of the arc design was 239°, split at 35° (the first two arcs from 300° to 35° and the other two arcs from 35° to 179°). The isocentre was shifted 2 cm in the direction of the lung in the axial plane according to Boman et al. [9].

2.7. Plan evaluation

The plans were evaluated visually in terms of slice-by-slice dose distribution looking at the relevant isodose levels and the position of dose maxima. The PTV coverage was assessed in terms of mean dose (D_{mean}), near maximum dose (D2 %), near minimum dose (D98 %), volume covered by the 95 % isodose (V95 %) and volume covered by the 105 % isodose (V105 %). The PTV was also evaluated in terms of Gradient Measure and Conformity Index. In Eclipse, these indices are defined as follows:

Gradient Measure is the difference between the equivalent sphere radius of the prescription isodose and the equivalent sphere radius of half the prescription isodose. It is given in centimetres. In our case, the prescription isodose was 100 %.

Conformity Index is defined as the volume of the prescription isodose (100 % in our case) divided by the volume of PTV.

To compare the amount of tissue receiving small doses with the different treatment techniques, the volume (in cm^3) covered by 5 Gy isodose was assessed (V5 Gy). The number of Monitor Units (MUs) was also assessed.

Doses to OARs were evaluated according to Table 1. The contralateral lung mean dose and the humerus head mean dose and maximum dose (for Patient no. 2 only) were also assessed, even though there was no specific clinical dose objective for these organs in Table 1.

3. Results

The evaluated parameters – doses to OARs, PTV coverage, the gradient measure and conformity index, low dose volume and the number of MUs – are listed

Evaluated parameter	3DCRT	IMRT	VMAT1	VMAT2
Spinal cord				
D_{max} [Gy]	0.6	4.4	5.1	3.3
Heart				
D_{mean} [Gy]	0.8	4.4	4.0	4.2
Ipsilateral lung				
D15 % [Gy]	10.0	16.0	18.0	17.0
D_{mean} [Gy]	6.2	9.3	9.3	8.7
Contralateral lung				
D_{mean} [Gy]	0.1	3.6	2.1	2.2
Contralateral breast				
D_{mean} [Gy]	0.2	2.2	2.8	2.5
Humerus head				
D_{mean} [Gy]	8.2	6.5	4.6	4.6
D_{max} [Gy]	36.9	27.4	24.8	23.1
PTV coverage				
D_{mean} [Gy]	42.1	43.2	42.7	42.7
D98 % [Gy]	36.0	40.3	37.9	38.1
V95 % [%]	83.0	96.7	91.3	91.6
D2 % [Gy]	44.4	45.1	44.7	44.7
V105 % [%]	0.0	0.7	0.5	0.0
Gradient index [cm]	3.43	2.63	3.01	3.08
Conformity index	0.35	0.54	0.43	0.44
Number of MU	294.2	1,354.9	578.6	521.2
Volume of 5 Gy isodose [cm^3]	2,880	6,536	4,998	4,921

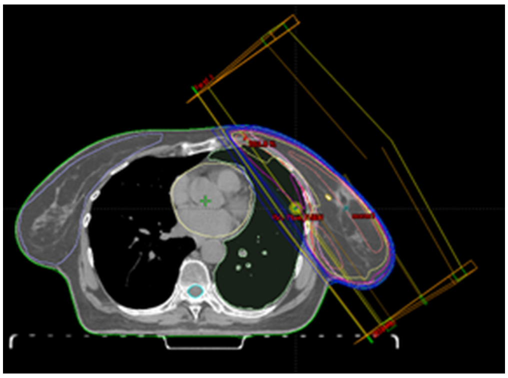
Table 3. Results for Patient no. 2. VMAT1 is the technique based on [9] and VMAT2 on [10].

in Table 2 for Patient no. 1 and in Table 3 for Patient no. 2. The resulting plans were a trade-off between the PTV coverage and the OAR sparing. While the IMRT plans had the best PTV coverage, the OAR sparing was poor as compared to the 3DCRT plans and also to the VMAT2 (the split-arc technique). The body volume receiving 5 Gy was also larger for the IMRT plan as well as the total number of MUs. On the contrary, the 3DCRT plans were much better in OAR sparing, with the exception of the high dose tail in left lung. The 5 Gy isodose volume and the total number of MUs were the lowest for the 3DCRT plans. However, the 3DCRT field-in-field plans had the worst gradient and conformity index and worse PTV coverage as compared to the other techniques. For Patient no. 1, the PTV coverage was actually similar for the 3DCRT and VMAT2 techniques, while the VMAT2 technique resulted in higher doses to all OARs. VMAT1 technique (based on Popescu et al. [1]) was not very good at OAR sparing, for some parameters, it was even worse than the IMRT plans. VMAT1 was comparable to VMAT2 (the split-arc design) in terms of the PTV coverage for Patient no. 2. For Patient no. 1, the VMAT1 technique was better. For both patients, VMAT1 resulted in higher or comparable doses to OARs in comparison with VMAT2. VMAT1 and VMAT2 techniques were similar in the 5Gy isodose volume and the total number of MUs for Patient no. 2. In the case of Patient no. 1, these parameters were higher for VMAT1 than for the VMAT2 technique.

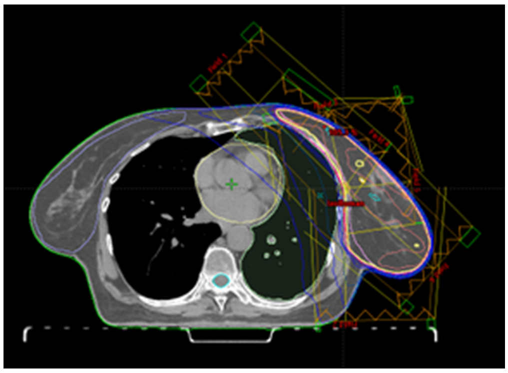
Some of the clinical objectives set in Table 1 were not met with some of the techniques. Namely, the mean ipsilateral lung dose and the mean heart dose criteria were not met with the IMRT technique and with the VMAT1 technique for Patient no. 1. However, the results are comparable to the originally published results by Popescu, Boman and Karpf [1, 9, 10]. Also, the V23.2 Gy $\leq$ 15 % criterion was not met for Patient no. 1 with the 3DCRT technique as well as the VMAT1 technique. The IMRT plans and the VMAT2 technique performed better in terms of higher doses in the left lung.

For Patient no. 2, the humeral head was close to the irradiated volume because in this particular case, the PTV was extended to the higher tangent area (even though the lymph nodes were intact). The mean dose to the humeral head was improved with the more conformal techniques (6.5 Gy for IMRT, 4.6 Gy for both VMATs) as compared to 3DCRT radiotherapy (8.2 Gy). The same conclusion is drawn for the maximum dose to the humeral head (36.9 Gy for 3DCRT as compared to 27.4 Gy for IMRT, 24.8 Gy for VMAT1 and 23.1 for VMAT2).

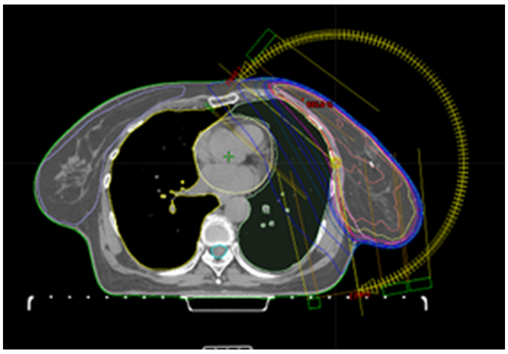
In order to understand the differences among the techniques, the dose distributions in all plans were additionally renormalised so that 98 % of the PTV volume receives 85 % of the prescribed dose (the minimum primary clinical goal). Tables A1 and A2 in Appendix show these renormalised values. This type



(a).



(b).



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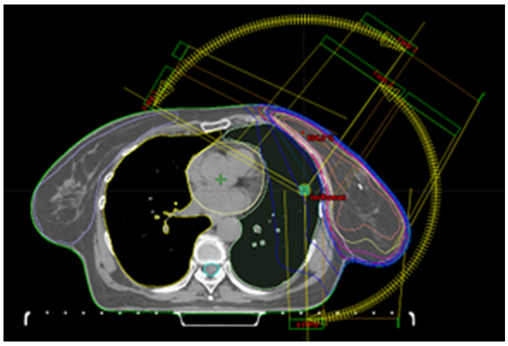

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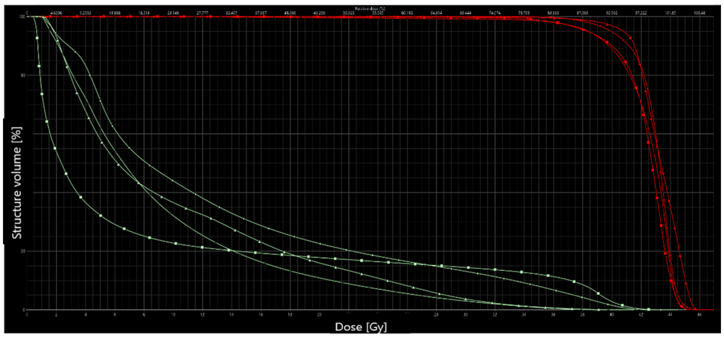
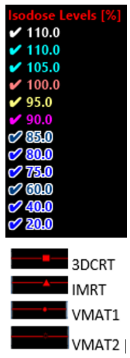


(e).



(f).

Figure 1. The isodose distribution, field layout and isocenter placement for Patient no. 1 and (A) the 3DCRT plan, (B) the IMRT plan, (C) the VMAT1 plan, (D) the VMAT2 plan. (E) The DVH for Patient no. 1 shows the PTV (red) and left lung (green) for all plans. Legend is shown in (F).

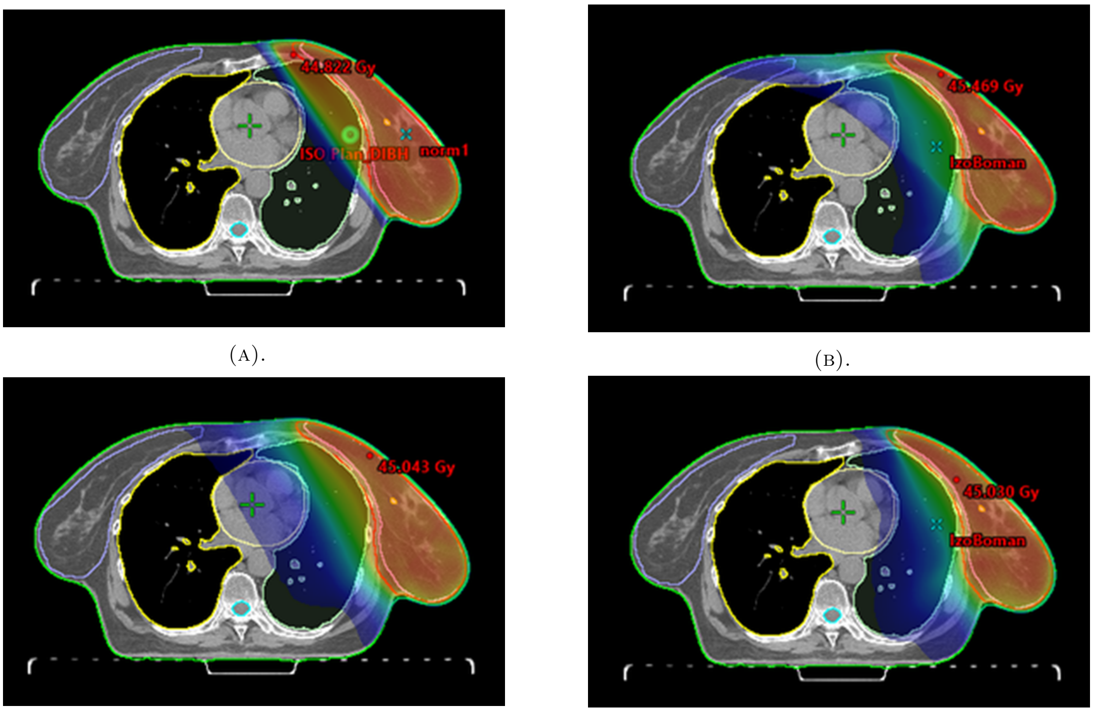
of normalisation seems to be favourable for the 3DCRT technique (almost all parameters were better as compared to other techniques). A different type of renormalisation (95 % of PTV receives 95 % of prescribed dose) would, as an example, be favourable for the IMRT technique (data not shown).

Figure 1 shows the dose distribution for all the investigated techniques for Patient no. 1 as an example. It illustrates the layout of the treatment fields (arcs) and the location of the isocentre. It also shows the dose-volume histogram for the PTV and left lung for all the investigated techniques to better compare the PTV coverage and to show the high dose tail in left lung that is inevitable with the 3DCRT technique.

Figure 2 shows the volume of the 5 Gy isodose for Patient no. 1 as an example. A similar behaviour was seen for Patient no. 2. The IMRT plan and possibly the VMAT1 plan extend more to the contralateral breast. VMAT1 covers the heart volume more extensively while VMAT2 spares the heart better but still covers the ipsilateral lung. The 3DCRT plan seems to be the best both qualitatively and quantitatively (see Table 1) in this aspect.

4. Discussion

Four different planning techniques were investigated in this case study for irradiation of the left breast without pathologic lymph nodes – conventional tangential field-in-field technique, intensity modulated radiotherapy using 6 equidistant fields and two different volumetric modulated arc therapy techniques. The choice of the intensity modulated techniques to be compared in this case study was based on a literature review. The VMAT technique by Popescu et



(a). (b). (c). (d).

Figure 2. The 5 Gy isodose in colorwash is shown for Patient no. 1 and (A) the 3DCRT plan, (B) the IMRT plan, (C) the VMAT1 technique, (D) the VMAT2 technique.

al. [1] was chosen because many papers using Varian's RapidArc (Varian Medical systems, CA, USA) refer to this work from 2010 [13, 14]. The split-arc VMAT technique by Boman et al. was chosen because in their paper [9] they already compare several different VMAT techniques and this one (referred to as VMAT2 in our case study) seems to be the optimal one for a variety of patients (left and right breast, with and without DIBH, regional and/or axillary lymph nodes). The IMRT technique by Karpf et al. [10] was chosen because in their original paper, they compare this IMRT technique to a similar VMAT design as the one published by Boman et al. [9] (a non-split arc technique, but with four different collimator angles in four arcs ranging from 300° to 179°).

It should be noted that in this comparative dosimetric study, the fluence of the fields was not artificially extended into the air to account for variations in patient positioning, breath hold variation, and swelling for the IMRT and VMAT plans. This was only done for the 3DCRT technique, which was originally used to treat the patient in the clinic. This was because the treatment was not to be administered clinically. Therefore, attention was not paid to several technical issues, such as the deliverability and complexity of the plans, isocentre placement with regard to feasibility of gantry rotation around the patient, suitable fixation strategy or feasibility of DIBH with prolonged intensity modulated fields or arcs. If all these aspects were taken into account, it could influence the resulting treatment plans and the outcome of the comparisons.

A combination of energies was considered only for the 3DCRT plans. Adding the 18 MV beams improved the dose distribution and plan quality. While for the IMRT and VMAT techniques, combining 6 MV beams with 18 MV beams was not necessary.

For one of the patients (Patient no. 1), the dose objectives given in Table 1 were not met for the mean (left) lung dose and mean heart dose with the IMRT and VMAT1 plans. The mean dose to the ipsilateral lung was 10.1 Gy with the IMRT technique and 13.0 Gy with the VMAT1 technique. The mean heart dose was 5.2 Gy with the IMRT technique and 5.7 Gy with the VMAT1 technique. In the original paper by Karpf et al. [10], they report a mean ipsilateral lung dose of 10.42 ± 0.71 Gy for the DIBH IMRT technique and 9.89 ± 1.03 Gy for a VMAT technique similar to Boman's [9]. For the mean heart dose, Karpf et al. [10] reports 2.96 ± 0.61 Gy for the IMRT technique and 4.03 ± 0.74 Gy for a VMAT technique similar to Boman's. Their prescribed dose was 50.4 Gy in 1.8 Gy per fraction. Boman et al. [9] reports a mean lung dose of 14.4 ± 1.4 Gy and a mean heart dose of 3.9 ± 1.3 Gy for their split-arc VMAT technique and their left-sided subgroup. However, using the technique by Popescu et al. [1], Boman et al. [9] report a mean lung dose of 16.7 ± 3.1 Gy and a mean heart dose of 6.2 ± 2.5 Gy for their left-sided subgroup (lymph nodes included, with and without DIBH combined). Their prescription dose was 50 Gy in 25 fractions. The original paper by Popescu et al. [1] reports 11.2–12.3 Gy for mean lung dose (left lung) and 9.2–11.0 Gy for mean heart dose. Their prescription dose was also 50 Gy in 25 fractions. It is to be noted that their planning was performed in MATLAB (MathWorks, Massachusetts, USA) with their in-house pencil beam algorithm and without any correction for inhomogeneities. The PTV coverage should also be mentioned at this point, because higher doses to OARs are usually correlated with an improved coverage of PTV and vice versa. Karpf et al. [10] do not give any information on PTV isodose coverage in their paper. Boman et al. report the V95 % parameter being 92.9 ± 1.7 % for their split arc technique and 90.5 ± 1.6 % for the technique based on Popescu et al. [1]. However, this is for a combination of left and right breast, with and without DIBH, lymph nodes included. In their original paper [1], Popescu et al. report a volume of 95.5–98.5 % covered by the 95 % isodose. Given the differences among the studies, our results seem reasonable.

5. Conclusions

In this case study, four different treatment planning techniques were compared for adjuvant radiotherapy of left breast without lymph nodes performed in DIBH – a 3DCRT field-in-field tangential technique, an IMRT technique using six equidistant fields [10], a tangential VMAT technique with two arcs [1], and a split-arc VMAT technique with four subarcs [9]. The intensity modulated techniques achieve a better target coverage and PTV dose conformity while the 3DCRT technique performs better at healthy tissue sparing, with the exception of a high dose tail in the DVH of left lung and higher dose to humeral head in the case of high tangent irradiation. The split-arc VMAT technique previously published by Boman et al. [9] might be a good compromise between the target coverage and the OAR sparing, depending on the actual treatment planning goals. This case study might serve as a guide to newly established or newly equipped radiotherapy departments when making a decision on proper treatment planning techniques for left breast.

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A. Appendix

Evaluated parameter	**3DCRT**	**IMRT**	**VMAT1**	**VMAT2**
Spinal cord				
D_{max} [Gy]	0.6	3.0	3.9	4.6
Heart				
D_{mean} [Gy]	1.1	4.9	4.5	5.5
Ipsilateral lung				
D15 % [Gy]	28.6	19.4	17.1	26.5
D_{mean} [Gy]	9.0	9.5	9.4	12.4
Contralateral lung				
D_{mean} [Gy]	0.1	1.7	1.7	2.2
Contralateral breast				
D_{mean} [Gy]	0.0	1.9	1.7	1.5
PTV coverage				
D_{mean} [Gy]	42.9	40.5	43.1	41.1
D98 % [Gy]	36.7	36.7	36.7	36.7
V95 % [%]	88.2	39.5	87.5	62.6
D2 % [Gy]	45.4	42.6	45.4	42.9
V105 % [%]	2.1	0.0	2.8	0.0
Gradient index [cm]	2.39	8.08	1.99	6.94
Conformity index	0.62	0.00	0.64	0.01
Number of MU	298.0	1,275.2	498.1	561.7
Volume of 5 Gy isodose [cm^3]	3,278	5,618	5,098	5,668

Table A1. Results for Patient no. 1 after renormalisation: 85 % of prescribed dose covers 98 % of PTV. VMAT1 is the technique based on [9] and VMAT2 on [1].

Evaluated parameter	**3DCRT**	**IMRT**	**VMAT1**	**VMAT2**
Spinal cord				
D_{max} [Gy]	0.6	4.0	3.2	4.9
Heart				
D_{mean} [Gy]	0.9	4.0	4.1	3.9
Ipsilateral lung				
D15 % [Gy]	10.0	14.7	16.4	17.6
D_{mean} [Gy]	6.3	8.5	8.4	9.0
Contralateral lung				
D_{mean} [Gy]	0.1	3.3	2.2	2.0
Contralateral breast				
D_{mean} [Gy]	0.2	2.0	2.4	2.7
PTV coverage				
D_{mean} [Gy]	42.9	39.3	41.2	41.3
D98 % [Gy]	36.7	36.7	36.7	36.7
V95 % [%]	88.3	2.2	64.3	65.9
D2 % [Gy]	45.2	41.1	43.1	43.3
V105 % [%]	1.2	0.0	0.0	0.0
Gradient index [cm]	2.11	7.67	6.33	5.65
Conformity index	0.75	0.00	0.02	0.04
Number of MU	299.7	1,232.7	502.6	560.1
Volume of 5 Gy isodose [cm^3]	2,895	6,073	4,810	4,886

Table A2. Results for Patient no. 2 after renormalisation: 85 % of prescribed dose covers 98 % of PTV. VMAT1 is the technique based on [9] and VMAT2 on [1].