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Flattening filter free technique in breath-hold treatments of left-sided breast cancer: The effect on beam-on time and dose distributions

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ABSTRACT

Background and purpose: The use of flattening filter free (FFF) beams has potential to speed up deep-inspiration breath-hold treatments. In this study, the beam-on time and dose characteristics of left-sided breast treatment plans with FFF and flattened beams were evaluated.
Material and methods: Twelve plans were generated for 20 patients. The techniques utilized were volumetric modulated arc therapy with two limited tangential arcs (tVMAT) and tangential intensity modulated radiotherapy with dynamic (dIMRT) as well as step-and-shoot (FinF) dose delivery. Each technique was planned with FFF and flattened beams with 6 and 10 MV photons. All plans were irradiated and the beam-on times were measured. Dose characteristics of planning target volume (PTV) and organs at risk (OAR) were evaluated.
Results: The mean beam-on times were reduced by 18–39% using FFF. Mean PTV dose coverage was least reduced with tVMAT (0.6–0.8%) compared to dIMRT (4%) and FinF (5.6–9.1%), when FFF beams were used instead of flattened beams. Only small differences were observed in OAR doses between equivalent plans (FFF vs. flattened).
Conclusions: A significant reduction was observed in beam-on time when utilizing FFF beams with tVMAT, dIMRT and FinF. tVMAT was the only technique for which the use of FFF did not degrade the treatment plan dose distributions.

Adjuvant radiotherapy (RT) after breast-conserving surgery of breast cancer increases overall survival by decreasing the rate of cancer recurrence [1]. The RT treatments of left-sided breast cancer are increasingly being delivered with deep-inspiration breath-hold (DIBH) techniques. The main rationale behind the DIBH treatments is cardiac sparing, as cardiac exposure has been reported to increase the risk of cardiac morbidity [2]. Breath-hold treatments have been found effective in reducing cardiac exposure in tangential left breast irradiation using 3D conformal radiotherapy (3D-CRT) and intensity modulated radiotherapy (IMRT) techniques [3]. Recently, volumetric modulated arc therapy (VMAT) has also been shown to be effective in cardiac sparing [4]. The advantage of IMRT and VMAT techniques compared to 3D-CRT in left-sided breast treatments is the equal or better target coverage and simultaneous decrease in doses to critical organs such as heart or ipsilateral lung [4–5].

Typically, the DIBH treatments require several breath-hold periods which can be troublesome for some patients. DIBH treatments are also more time-consuming than traditional treatments. The removal of the flattening filter enables high dose rates to be delivered from the medical linear accelerators and thus the decrease in RT treatment duration [6]. The use of flattening filter free (FFF) technique has been originally introduced with small target volumes [6], but has also been studied with larger targets using modulated techniques [7–9]. In addition to high dose rate, the absence of the filter decreases the head scatter and reduces the out-of-field dose to the patient. However, it has also been suggested that these effects may be mitigated by the higher amount of monitor units (MU) typically required in intensity modulated treatments [8].

The technical feasibility of the FFF technique in breast irradiation has been studied earlier in a few papers [8–12]. To the best of our knowledge, the FFF technique has not been investigated in breast cancer treatments with VMAT techniques in DIBH setup. The aim of this planning study was to investigate the reduction of beam-on time in left-sided breast treatments by the use of FFF beams using three major RT techniques, that is, IMRT with dynamic and step-and-shoot dose delivery as well as VMAT. All

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the techniques were systematically compared with 6 and 10 MV photons. Further, to evaluate the advantages and disadvantages of the FFF implementation, the dose characteristics of the planning target volume (PTV) and a set of organs at risk (OAR) were evaluated.

Materials and methods

This retrospective study was conducted using the data of 20 consecutive left-sided breast cancer patients who were treated in our institution. One of the patients was staged as DCIS, one as papillary carcinoma in situ, seven as T1bN0, seven as T1cN0, one as T1bN1 and three as T2N0. The mean age of the patients was 61 ± 5 years and the mean PTV volume was 1211 ± 452 cm^3. The study was approved by the Research Ethics Committee of Kuopio University Hospital.

The treatment planning CT data were acquired in supine position using 2 mm slice thickness (Aquilion LB scanner, Toshiba Medical Systems Co., Tochigi, Japan). The respiratory motion was controlled by a moderate DIBH technique with an optical Sentinel system (C-RAD AB, Uppsala, Sweden). The patient's respiration depth was guided via goggles.

The clinical target volume (CTV) was delineated in CT images by a single clinical oncologist according to Radiation Therapy Oncology Group guidelines [13]. A 5 mm margin was added to the CTV resulting in PTV. For the treatment planning, a 5 mm or 7 mm build-up volume from the body surface was excluded from PTV (PTVin) depending on the photon energy used, 6 MV or 10 MV, respectively. The OARs were automatically delineated using Atlas-Based Auto Segmentation software (ABAS v2.01.0, Elekta AB, Stockholm, Sweden) and subsequently verified by a physician and the physicists responsible for the treatment planning. The OAR included the heart, left anterior descending coronary artery (LAD), contralateral breast as well as contralateral and ipsilateral lung.

Twelve different treatment plans were generated for each patient. The treatment techniques studied were VMAT with two limited tangential arcs (tVMAT) [5] and tangential inverse planned intensity modulated radiotherapy with dynamic (dIMRT) as well as step-and-shoot (FinF) dose delivery. In tVMAT, two 45–55° nearly opposite tangential arcs were used, for example one between 120° and −165° and the other between 295° and 345° [5]. In tVMAT plans, the control points were limited to a maximum of 120 per arc. In dIMRT and FinF, the tangential beam directions were chosen to minimize overlap with the heart and ipsilateral lung. dIMRT plans were limited to 80 control points per beam. In FinF, the number of field segments was limited to 12 in order to simulate manual forward planning IMRT. Each technique was used to produce a treatment plan with FFF and flattened beams, both with 6 and 10 MV photon energies. The plans were generated for Elekta Infinity linear accelerator with Agility multileaf collimator (MLC) using X-ray voxel Monte Carlo (XVMC) dose calculation algorithm (Monaco v3.30.01, Elekta AB, Stockholm, Sweden).

The prescribed dose to PTV was 15 × 2.67 Gy (40.05 Gy) following a hypofractionated scheme. The primary planning objective was to have 95% of the prescribed dose to cover at least 97% of the PTVin volume. The volume receiving more than 107% of the prescribed dose was restricted to be less than 3 cm^3 [14]. For OARs, the planning objectives were as follows: the mean dose of the contralateral breast <2 Gy, the mean dose of the heart <3 Gy [15], the 1 cm^3 maximum to LAD <20 Gy [16], the mean dose of the ipsilateral lung <8 Gy, the mean dose of the contralateral lung <1 Gy. In addition, the 110% maximum of the prescribed dose in the normal tissue outside PTV was limited to be 10 cm^3. The treatment plans were normalized to the mean dose of PTVin.

All plans were irradiated with Elekta Infinity linear accelerator and the beam-on times were measured. The maximum dose rates from this accelerator model were 600 (6 MV), 450 (10 MV), 1400 (6 MV FFF) and 2400 (10 MV FFF). Patient specific quality assurance dosimetry analysis was performed on all plans of three patients using I'mRT MatriXX ionization chamber array with Multicube phantom (IBA Dosimetry GmbH, Schwarzenbruck, Germany). The agreement between calculated and delivered plan was evaluated with gamma agreement index percentage (GAI%) (3%, 3 mm). The dose distributions for each plan were obtained from the treatment planning software. The target dose was evaluated by studying the coverage of the 95% of the prescribed dose as well as the 1 cm^3 maximum and minimum doses. The OAR doses were determined for the contralateral breast (mean dose, volume irradiated to 2 Gy, that is, V2Gy), heart (mean dose, 1 cm^3 maximum), LAD (mean dose), ipsilateral lung (mean dose, V20Gy, V10Gy), contralateral lung (mean dose) and the normal tissue outside PTV (1 cm^3 maximum). Further, the total amount of MUs and number of segments were recorded.

The statistical significance was evaluated using Wilcoxon test, which is suitable when $n < 30$. The level of statistical significance was set to $p < 0.05$. The statistical tests were run with SPSS (v21, IBM, Armonk, NY, USA).

Results

A significant ($p < 0.05$) reduction in beam-on time was found using FFF beams instead of flattened beams with all techniques (Table 1). With 6 MV the beam-on time was reduced on average 22 ± 6%, 18 ± 11% and 29 ± 11% with tVMAT, dIMRT, and FinF, respectively. The respective reductions with the energy of 10 MV were on average 31 ± 8%, 39 ± 15%, and 25 ± 13%. The FFF techniques required more MUs and field segments than flattened fields (Table 1). The measured dose distributions were satisfactory (GAI% > 95%) for the analyzed plans resulting in GAI% mean and standard deviation of 99.3 ± 0.6%. No systematic differences in GAI% between different modalities, energies or filtering modes were observed.

The use of FFF beams instead of flattened ones decreased PTV coverage significantly with all beam delivery techniques and energies (Table 2). The decrease in target coverage was minor with tVMAT (0.6–0.8%). Larger decrease was seen with dIMRT (4%) and FinF (5.6–9.1%) techniques. Generally, the use of FFF beams increased the maximum doses slightly and decreased the

Table 1
The mean ± standard deviation of monitor units, segments and beam-on time of each technique and energy.

Plan	Monitor units (MU)	Segments	Beam-on time (s)
tVMAT6	716 ± 104	83 ± 9	121 ± 15
tVMAT6FFF	916 ± 133*	86 ± 10*	95 ± 12*
tVMAT10	679 ± 92	80 ± 7	134 ± 16
tVMAT10FFF	1012 ± 129*	86 ± 9*	92 ± 12*
dIMRT6	395 ± 34	130 ± 24	63 ± 8
dIMRT6FFF	529 ± 60*	148 ± 16*	52 ± 8*
dIMRT10	386 ± 36	103 ± 19	73 ± 9
dIMRT10FFF	663 ± 75*	153 ± 10*	44 ± 6*
FinF6	350 ± 16	10 ± 2	67 ± 6
FinF6FFF	443 ± 40*	10 ± 2	48 ± 7*
FinF10	330 ± 23	9 ± 2	76 ± 9
FinF10FFF	538 ± 63*	11 ± 1*	57 ± 8*

tVMAT, dIMRT and FinF refer to tangential volumetric modulated arc therapy, IMRT with dynamic dose delivery and IMRT with step-and-shoot dose delivery, respectively. FFF refers to flattening filter free beam delivery and 6 as well as 10 to 6 MV and 10 MV photon energies. Statistically significant difference ($p < 0.05$) between the plans (per technique and energy) realized with flattened and FFF beams is illustrated by an asterisk after the figures describing FFF.