Physica Medica 44 (2017) 11–17

Contents lists available at ScienceDirect

Physica Medica

journal homepage: www.elsevier.com/locate/ejmp

Original paper

The robustness of dual isocenter VMAT radiation therapy for bilateral lymph node positive breast cancer

Eeva Boman[a,b,c,*], Maija Rossi[a,b], Mika Kapanen[a,b]

[a] Department of Oncology, Tampere University Hospital, PO BOX 2000, FI-33521 Tampere, Finland
[b] Department of Medical Physics, Tampere University Hospital, PO BOX 2000, FI-33521 Tampere, Finland
[c] Department of Radiation Oncology, Wellington Blood and Cancer Centre, Wellington Hospital, Wellington 6242, New Zealand

ARTICLE INFO

Keywords:
Synchronous bilateral breast cancer
Radiotherapy
Treatment planning
VMAT
Multiple isocenters

ABSTRACT

Purpose: To investigate the use of dual isocenters for VMAT planning in patients with lymph node positive synchronous bilateral breast cancer (BBC) compared to a single isocenter option.

Methods: Treatment plans of 11 patients with lymph node positive BBC were retrospectively analyzed using two different VMAT planning techniques: dual-isocenter split-arc VMAT plans (Iso2) were compared with mono-isocenter VMAT plans (Iso1). For Iso2 plans, PTV dose was investigated after introducing ± 2 and ± 5 mm couch shift errors between the two isocenters in the lateral, longitudinal and vertical direction.

Results: For both techniques the planning aims for PTV coverage and OARs were met. The mean dose for the bilateral lungs and heart was reduced from 11.3 Gy and 3.8 Gy to 10.9 Gy ($p < .05$) and 3.6 Gy ($p < .05$), respectively, for Iso2 plans when compared to Iso1 plans. Positive statistically significant correlation (rho = 0.76, p = .006) was found between PTV volume and $D2cc_{PTV}$ for Iso1 plans. No clinically significant change was seen in the $D98_{CTV}$ or $D2cc_{PTV}$ after the 2 and 5 mm errors were introduced between isocenters for Iso2 plans.

Conclusions: The split arc method was shown to be a feasible treatment technique in the case of synchronous BBC for both mono and dual isocenter techniques. The dose parameters were slightly favoring dual-isocenter option instead of mono-isocenter. The dual-isocenter method was shown to be a robust treatment option in the presence of ≤5 mm errors in the shifts between the two isocenters.

1. Introduction

Adjuvant breast cancer radiotherapy (RT) is shown to halve the risk of locoregional recurrence and reduce the breast cancer mortality by one-sixth in patients with diagnosed breast cancer [1]. It is recommended for node-positive (N+) breast cancer patients after mastectomy [2]. However, RT is associated with long-term cardiac and pulmonary toxicity and a risk of secondary malignances [3–5]. Synchronous bilateral breast cancer (BBC) is estimated to occur in 2.1% of all patients with breast cancer [6]. Kheirelseid et al. [6] found that BBC was more common with younger patients with smaller tumour size and earlier stage at diagnoses than those with unilateral cases. Also HER2/neu positivity was identified as a risk factor for BBC. No significant difference was found in survival between BBC and unilateral cases. However, synchronous BCC was associated with poorer survival in comparison to BCC with metachronous tumour, in which the contralateral breast cancer was diagnosed 12 months after the unilateral diagnosis.

RT planning becomes more challenging in the case of synchronous BBC treatment and even more with the inclusion of axillary lymph nodes and/or internal mammary nodes to the planning target volume (PTV). In this case, the traditional tangential half-field technique applied to both sides might result in high maxima in regions above the sternum where the tangential fields are overlapping; and/or in unacceptably low target coverage in the internal mammary nodes [7]. In addition, heart and/or lung doses might be high with traditional techniques in the treatment of synchronous BBC. Nicolini et al. [8] have published a planning study of ten synchronous BBC patients with simultaneous integrated boost without axillary lymph node involvement. They found that volumetric modulated arc therapy (VMAT) improved dosimetry and reduced treatment time when compared to fixed field intensity modulated therapy (IMRT). In a case study of two synchronous BBC patients with axillary lymph node involvement, Seppälä et al. [7] reported that VMAT was superior in PTV coverage to traditional tangential half-fields. VMAT resulted in lower dose maxima, lower mean lung dose and higher dose fractions to the heart, but increased

* Corresponding author at: Department of Oncology, Tampere University Hospital, PO BOX 2000, FI-33521 Tampere, Finland.
E-mail address: Eeva.Boman@pshp.fi (E. Boman).

https://doi.org/10.1016/j.ejmp.2017.11.006
Received 30 June 2017; Received in revised form 6 November 2017; Accepted 9 November 2017

slightly the mean heart dose, when compared to traditional tangents.

The deep inspiration breath hold (DIBH) technique has become a common technique in left-sided breast cancer RT to reduce cardiac dose [9,10]. DIBH also enables the treatment of internal mammary nodes while keeping the dose to the organs at risk (OARs) at reasonably low level compared to free breathing [11]. In addition, DIBH decreases lung dose due to the increase of the total lung volume. However, patients that are incapable of maintaining sufficient breath hold level for relevant time or follow instructions are not suitable candidates for DIBH RT [12]. For synchronous BBC RT, DIBH can be also used to reduce the lung and heart dose, which otherwise might be considerably high.

We recently presented the benefit of a split-arc VMAT planning technique in the treatment of left or right breast with the regional lymph node involvement [13]. This split-arc technique was shown to reduce the dose to ipsilateral lung in both left and right sided treatments and to heart in the left side treatments, when compared to conventional VMAT designs or static half fields. This dose reduction came with the cost of increased dose to the contralateral breast. The split-arc design was also seen to be beneficial with DIBH as the split arcs were delivered in only 20 s each, which is the approximate time that patients are capable of holding their breaths.

In this study, the split-arc technique is applied to bilateral breast treatments with lymph node involvement. The aim is to study the dosimetric differences between mono and dual isocenter plans. The robustness of the dual isocenter plans are studied by introducing ± 2 mm and ± 5 mm set-up errors between the isocenters in lateral, longitudinal and vertical directions.

2. Materials and methods

Eleven patients with lymph node positive synchronous BBC were retrospectively selected to this study. Patient characteristics are shown in Table 1. The patients had undergone breast conserving surgery and/or mastectomy on both sides. DIBH was used for eight of the patients (RPM™, Varian Medical systems, Palo Alto, CA).

Candor's ConBine (Candor, Gislev, Denmark) breast board with head holder was used for patient immobilization. Patient setup was supine with both hands above the head. Computed tomography (CT) images for treatment planning were acquired with 3-mm slice thickness (Philips Brilliance Big Bore, Philips Medical Systems, Eindhoven, Netherlands or Toshiba Aquilion LB, Toshiba Medical System, Tokyo, Japan). Clinical target volumes (CTV) included bilateral breast(s), chest wall(s), supraclavicular and/or intra-mammary nodes as described in Table 1 and following the given guidelines [14]. A 5-mm margin was added to the CTV to create the PTV, which was cropped 5 mm inside the skin. An optimization PTV (PTVopt) was created from the PTV to extend 5 mm outside of the skin in the breast region. In these extended regions, a 10-mm water equivalent bolus was added over the breast tissue to take into account the breast/chest wall movement and possible swelling between treatment fractions (adapted from [15]). Final dose calculation was performed without the optimization bolus.

Table 1
Patient characteristics for eleven patients indicating the mastectomy for left and/or right breast, axillary lymph node (ALN) and mammary lymph node (MLN) involvement in the target volume, use of DIBH, PTV volume (cm^3) and maximum width of the PTV in lateral direction (cm).

Pat #	Mastectomy left breast	Mastectomy right breast	ALN	MLN	DIBH	Volume of PTV (cm^3)	Max width of PTV (cm)
1			Both			1272	30.4
2	X	X	Right			2300	35.1
3	X	X	Both	Right		4687	45.7
4			Both		X	5423	46.0
5	X	X	Both	Right	X	4104	43.2
6			Left	Left	X	3191	35.1
7	X	X	Both	Both	X	1701	34.0
8			Left	Left	X	2811	34.7
9	X	X	Both	Both	X	2218	36.9
10		X	Both	Both	X	2873	34.3
11	X	X	Both	Both	X	2155	33.9

Planning was performed using Eclipse version 13.7 (v13.7) (Varian Medical systems) using Analytic Anisotropic Algorithm (AAA) v13.7 dose calculation algorithm with a 0.25 cm grid size. Millenium 120 multi-leaf collimator (MLC) was used with a TrueBeam linear accelerator (Varian Medical systems). Dose prescription was 50 Gy delivered in 25 fractions. Plans were normalized to mean dose of 100% in PTV. The plans were optimized to receive at least 90% of the prescription dose to 98% of the PTV volume and to keep the maximum dose in 2 cm^3 volume (D2cc) less than 108% (54 Gy). Heart, bilateral lungs and humeral heads were contoured and used as OARs. The plan objectives were to achieve V20Gy ≤30% for both lungs [16] and a mean heart dose ≤5 Gy [3], although the planner aimed for dose to OARs to be as low as possible.

In the dual isocenter plans (Iso2), the split field designs for left and right targets are set to each side as described in Boman et al. [13], resulting in one plan with two isocenters (Fig. 1A). These two isocenters were located in the same vertical and longitudinal axis and lateral separation was selected to be an integer number in centimeters. The total arc rotation was 2 × 230° per isocenter (gantry start – split – stop angles: 190° – 300° – 60° for right and 300° – 60° – 170° for left isocenter) resulting 4 × 230° total arc rotation. The split-angle indicates the gantry angle, in which the 230° – arc is split into half and collimator and jaw settings are set anew to focus on PTVopt while avoiding lung and heart as seen in the beam eye views (BEVs) for each arc (Fig. 2). In the direction of MLC movement (FSx), the x-jaw shielding the lungs and/or heart was limited to 2 cm. The lateral x-jaw was opened to include all breast tissue in the BEV and was not restricted to a certain limit. The mono isocenter plan (Iso1) is constructed by moving the two isocenters from Iso2 plan to the same point medially and posteriorly while keeping the same collimator and gantry angles in each partial arc (Fig. 1B). The medial x-jaw was set to minimum setting (−2 cm) to shield the lungs and/or heart and the lateral x-jaw was opened to include all breast tissue in the BEV similarly as for Iso2 plans.

The location of the isocenters were selected to be near the center of half or quarter circle formed by the lung-breast(s) interface for Iso1 (both breast) or Iso2 (left breast for left isocenter and right breast for right isocenter) plans, respectively (Fig. 1). Hence the distance between the isocenter and lung-breast interface is almost the same during the arc rotations to allow the medial x-jaw to shield lungs and/or heart. The beam energy of 6 MV (flattened beam) was used for all VMAT plans with maximum dose rate of 600 MU/min. All optimizations used the same objectives (Table 2).

To evaluate target coverage and plan quality, the Paddick conformity index (CI) was calculated using 95% of the prescription dose [17], as

$$CI = \frac{V95_{PTV}}{V_{PTV}}\frac{V95_{PTV}}{V95}, \tag{1}$$

in which $V95_{PTV}$(cc) is the volume which receives at least 95% of the prescribed dose in PTV, V_{PTV}(cc) is the PTV volume and V95(cc) is the volume in cubic centimeters (cc) which receives at least 95% of the prescribed dose. CI = 1 means the best plan quality whereas lower values indicate a poorer plan quality. Homogeneity index (HI) was calculated as

$$HI = \frac{D2_{PTV} - D98_{PTV}}{D50_{PTV}}, \tag{2}$$

where DX_{PTV} (Gy) indicates the dose which is received by X% of the volume of PTV and $D50_{PTV}$ (Gy) is the median dose of the PTV [18]. Smaller values in HI indicate better dose homogeneity in PTV. For each patient, also $V95_{PTV}$ (%), $V105_{PTV}$ (%) and the near maximum doses