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Original research article

Dosimetric feasibility of an "off-breast isocenter" technique for whole-breast cancer radiotherapy

Juan-Francisco Calvo-Ortega, Sandra Moragues, Miquel Pozo, Joan Casals*

Servicio de Oncología Radioterápica, Hospital Quirón Barcelona, Plaza Alfonso Comín, 5, 08023 Barcelona, Spain

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ABSTRACT

Aim: To investigate the viability of placing the treatment isocenter at the patient midline for breast cancer radiotherapy in order to avoid the risk of collisions during image-guided setup and treatment delivery.

Background: The use of kilovoltage orthogonal setup images has spread in last years in breast radiotherapy. There is a potential risk of an imaging system–patient collision when the isocenter is laterally placed.

Materials and methods: Twenty IMRT plans designed by placing the isocenter within the breast volume ("plan_ref"), were retrospectively replanned by shifting the isocenter at the patient's midline ("plan_off-breast"). An integrated simultaneous boost (SIB) technique was used. Multiple metrics for the planning target volumes (PTVs) and organs at risk (OARs) were compared for both approaches using a paired *t* test.

Results: Comparing plan_ref vs. plan_off-breast, no significant differences in PTV coverage (V95%) were found (96.5% vs. 96.2%; $p = 0.361$ to PTVbreast; 97.0% vs. 97.0%; $p = 0.977$ to PTV-tumor_bed). With regard to OARs, no substantial differences were observed in any analyzed metric: V5Gy (30.3% vs. 31.4%; $p = 0.486$), V20Gy (10.3% vs. 10.3%; $p = 0.903$) and mean dose (7.1 Gy vs. 7.1 Gy; $p = 0.924$) to the ipsilateral lung; V5Gy (11.2% vs. 10.0%; $p = 0.459$), V30Gy (0.7% vs. 0.6%; $p = 0.251$) and mean dose (2.3 Gy vs. 2.2 Gy; $p = 0.400$) to the heart; and average dose to the contralateral breast (0.4 Gy vs. 0.5 Gy; $p = 0.107$).

Conclusions: The off-breast isocenter solution resulted in dosimetrically comparable plans as the reference technique, avoiding the collision risk during the treatment session.

1. Aim

This work describes a practical planning solution to avoid collisions between the on-board imaging (OBI) system of the linear accelerator (linac) and the patient that may occur during an image-guided protocol used in our department for breast radiotherapy. The solution consists in shifting the lateral position of the treatment isocenter at the center of the couch, instead of the traditional way of placing it inside the breast

* Corresponding author. Tel.: +34 932554011; fax: +34 932381645.
E-mail address: jfcdrr@yahoo.es (J.-F. Calvo-Ortega).

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volume. We conclude that there are no significant dosimetric differences between the proposed "off-breast isocenter" planning technique and the traditional approach.

2. Background

Breast cancer is the most common cancer in women worldwide.[1] Adjuvant radiotherapy following breast-conserving surgery significantly improves the overall survival of breast cancer patients.[2] Radiotherapy has been traditionally performed sequentially, i.e., after completion of whole breast irradiation, with doses of 1.8–2.0 Gy per fraction to a total dose of approximately 50 Gy, a boost dose is delivered to the tumor bed. This boost may be applied using external photon and/or electron beams up to a total dose of 60–66 Gy in same fractional dose sizes as a preceding whole breast irradiation.

A simultaneous integrated boost (SIB) approach was proposed as an alternative to the traditional sequential boost practice. SIB consists in delivering the boost to the tumor bed simultaneously with the whole breast irradiation.[3] The use of a SIB schedule for the breast cancer irradiation was initially reported by Smitt et al.[4] and Guerrero et al.,[5] resulting in an improved dose distribution and reduced number of treatment fractions. SIB using intensity-modulated radiotherapy (IMRT) has been reported by several groups, emphasizing the improvement of the dose distribution in the breast and the increased sparing of normal tissues over the conventional treatment.[4–9] The isocenter is often placed at the center of the whole breast and so located several centimeters lateral to patient midline. Due to this issue, the treatment couch often needs to be shifted medially to enable full gantry rotation without couch or patient collisions.

The risk of collision also exists during the patient setup imaging stage in a linac equipped with a kilovoltage (kV) OBI system. The addition of the kV source and detector arms to the linac, in conjunction with the treatment position of the patients with their arms raised and the noncentral isocenter (in respect to the linac couch center in the lateral direction) can make clearance between the patients and the linac problematic.

The mentioned collision risk could be avoided by shifting the isocenter at the lateral midline of the couch (~patient midline) during the treatment planning, i.e., placed in an off-breast position. In this work, the dosimetric effect of using an off-breast isocenter was evaluated by comparing the target dosage and critical structures dose sparing against our traditional procedure of locating the isocenter inside the breast.

3. Materials and methods

3.1. *Simulation and organ definition*

At our institution, patients with breast cancer are immobilized in supine position using an arm support (with the ipsilateral or both arms above the head) and a knee support (CIVCO Medical Solutions, Orange City, IA). A free-breathing computed tomography (CT) scan is obtained with a 3-mm slice distance. After planning CT is done, the CT images are transferred to a commercially available (Varian, Eclipse 10.0, Varian Medical Systems, Palo Alto, CA) treatment planning system (TPS).

The Radiation Therapy Oncology Group (RTOG) breast cancer atlas[10] was followed as guideline for delineation of the clinical target volumes (CTVs). CTV of the whole breast (CTVbreast) was the entire mammary gland. CTV for boost (CTVboost) was the surgical bed, as defined by surgical clips placed in the lumpectomy cavity during surgery. Planning target volumes (PTVbreast and PTVtumor_bed) were generated from CTVs by adding a 5 mm margin, but limited to 5 mm within the skin surface, and excluding ribs and lung parenchyma. Finally, and for dose calculation purpose, the definitive PTVbreast did not include PTVtumor_bed.

Twenty patients (10 right side/10 left side) treated in our department using an SIB fractionation scheme were retrospectively enrolled in this study. The prescribed dose (PD) was performed in 28 fractions, with 2.3 Gy per fraction to a total dose of 64.4 Gy for the PTVtumor_bed, and 1.8 Gy per fraction to a total dose of 50.4 Gy for the PTVbreast. A Boolean "whole breast" PTV (PTVwb) was generated as PTVtumor_bed or PTVbreast. Volume of PTVwb ranged from 163 cm^3 to 1207 cm^3 with a mean of 463 cm^3. Regarding the organs at risk, the lungs were auto-contoured, while the cardiac silhouette and the contralateral breast were manually outlined. An additional structure called the "healthy tissue" was defined as the total patient body volume minus the PTVwb.

3.2. *Treatment planning*

Every patient enrolled in our study was treated in our department using a SIB-IMRT plan designed by placing the isocenter approximately at the center of the whole breast volume (plan_ref). This approach required a considerable lateral shift of the linac couch (ranged from 8 to 11 cm) to align the patient for treatment delivery.

For each patient case, a coplanar IMRT-SIB reference plan was designed in the Eclipse TPS. The dose was planned using 6 MV photon beams from a Varian 2100 CD linac equipped with the Millennium 120 multileaf collimator (MLC) and the OBI system.

For right-side breast patients, the treatment plan consisted of two tangential fields covering the PTVwb, plus 3–4 oblique fields aiming at the PTVtumor_bed. All beams had the same isocenter. First, the two tangential fields were forwardly optimized (field-in-field IMRT technique) to deliver 50.4 Gy to the PTVwb. Then, boost fields were sequentially planned to give 64.4 Gy to PTVtumor_bed by taking into account the accumulated dose from tangential fields. Two modalities were used for the boost fields: five patients were planned using conformal beams; while boost fields were inversely optimized (sliding-window technique) for the rest of patients.

For left-side breast cases, multiple IMRT fields (sliding-window) were used with all the beam fluences optimized simultaneously. The beam arrangements consisted of two tangential beams irradiating the PTVwb and 2–4 additional ones aiming at the PTVtumor_bed.

The patient dose distribution was calculated with the Anisotropic Analytical Algorithm[11] (AAA), with a 1.0 mm calculation grid size and tissue heterogeneity correction. All SIB

plans were normalized to provide 64.4 Gy as mean dose to PTVtumor_bed, while the plan objectives were the following:

(1) Target coverage: V95% ≥95% for both PTVs; where V95% is the percent of PTV volume receiving ≥95% of the PD, i.e., 47.9 and 61.2 Gy for PTVbreast and PTVtumor_bed, respectively. Target coverage was considered clinically acceptable if V95% ≥90%.
(2) Target homogeneity: percent of PTVtumor_bed volume receiving ≥107% of its PD was limited to 2%.
(3) Regarding the dose constraints for the organs at risk (OARs), all plans were optimized to try to fulfill the requirement that less than 10% of the heart volume may receive ≥30 Gy,[9] while less than 20% of the ipsilateral lung may receive more than 20 Gy.[9] The mean dose to the contralateral breast was tried to be limited to less than 5 Gy.[9]

Each reference plan ("plan_ref") was replanned using the same beam arrangement but shifting the isocenter at the lateral midpoint of the couch, i.e., placing the isocenter in an off-breast position ("plan_off-breast") as shown in Fig. 2. Obviously, the same objectives used in the reference plan for dose coverage of the PTVs and dose limits to the OARs were required in the new plans.

3.3. *IGRT and patient setup*

Breast patient setup verification is performed in our department using kV imaging from the OBI system. It includes a kV X-ray source and a kV detector mounted on the linac orthogonal to the treatment beam axis. The kV images are useful for verifying accurate alignment of the breast patient based on bony anatomy.[12]

Pre-image patient setup is performed using laser alignment of the skin marks made at CT simulation. After that, two orthogonal kV images (anterior and lateral) are acquired with the OBI detector at 160 cm from the linac focus, giving a spatial resolution of 0.2 mm. In an online way, the kV images are matched their corresponding DRRs using the visible anatomy such as the ribs, vertebral column, and sternum (Fig. 3). The

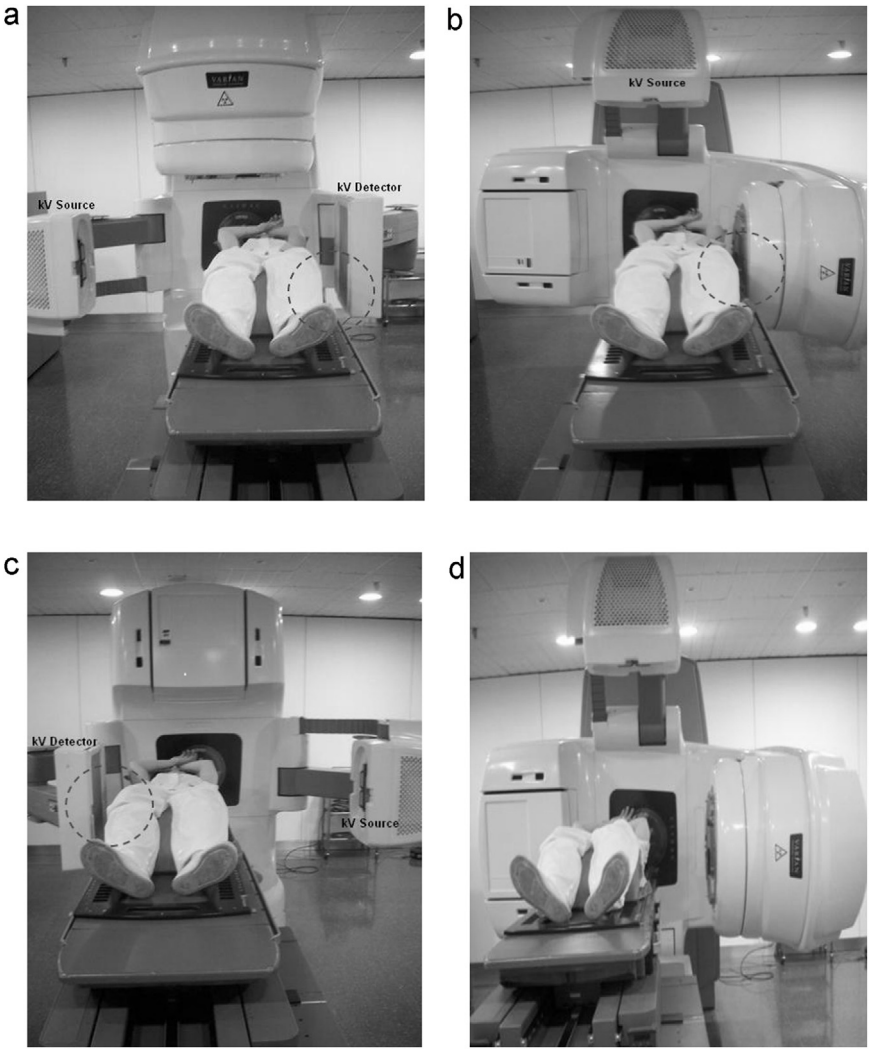

Fig. 1 – (a) Risk of collision between patient/couch and kV detector for right-sided breast during the lateral kV imaging. (b) Risk of collision between patient/couch and linac gantry for right-sided breast during the frontal kV imaging. (c) Risk of collision between patient/couch and kV detector for left-sided breast during the lateral kV imaging. (d) No risk of collision for left-sided breast during the lateral kV imaging.

final matching position was the compromise of these bony landmarks.[13] Online kV imaging-based correction is applied for each treatment session with a level action of zero millimeters.

For right-sided breast, two orthogonal images with the kV source at 270° and 0° (IEC: International Electrotechnical Commission, Geneva, Switzerland) are scheduled for each treatment plan. For that situation, there is a potential risk of collision between the kV flat panel detector and the linac couch/patient when the kV source is at 270° for lateral imaging (Fig. 1a), and a potential possibility of linac gantry colliding with the couch/patient when it rotates to position the kV source at 0° for anterior imaging (Fig. 1b).

For left-sided breast, orthogonal images with the kV source at 90° and 0° (IEC) are programmed. In this case, the potential risk of collision exists between the kV flat panel detector and the linac couch/patient for the lateral imaging (Fig. 1c), while no collision would occur for anterior-posterior imaging (Fig. 1d).

With the above described kV/kV imaging protocol, there may be situations where the linac gantry and/or the OBI detector collide with the couch/patient, when the planned isocenter is located around the center of the breast, i.e., in a noncentral position in respect to the midline of the linac couch. This potential risk of collision is not alerted by the Eclipse TPS during treatment planning task. Therefore, a solution to avoid any collision during the imaging for patient setup is to design a treatment plan with the isocenter at the lateral midpoint of the couch, i.e., using an "off-breast isocenter" approach (Fig. 2).

3.4. *Dosimetric comparison*

The two plans generated for each patient (plan_ref and plan_off-breast) were compared objectively using the dose-volume histograms (DVHs) for PTVs and different OARs. The following metrics were used for each PTV:

(1) PTV coverage (V95%), defined as the percentage of PTV volume receiving ≥95% of its PD.
(2) PTV hot spot (V107%), defined as a relative volume of PTV receiving ≥107% of its PD.
(3) High dose spillage into PTVbreast (Vexcess), defined as the percent volume of the PTVbreast receiving ≥95% of the boost PD. Because of the higher dose prescription to PTV-tumor_bed, there is an inevitable excess of dose (>107% of 50.4 Gy) in the contiguous PTVbreast. Vexcess is used to measure this excessive dose.
(4) Homogeneity index (HI), defined as:

$$HI = (D2\% - D98\%)/Dmean$$

where *Dx* means the minimum dose received by the x% of the PTV, and *Dmean* is its average dose. *D*98% and *D*2% represent the near-to-minimum and near-to-maximum doses of PTV, respectively. HI with a result closer to zero indicates greater homogeneity.
(5) Conformity index (CI), calculated as described by van't Riet et al.[14]:

$$CI = (TV_{RI}/TV) \times (TV_{RI}/V_{RI})$$

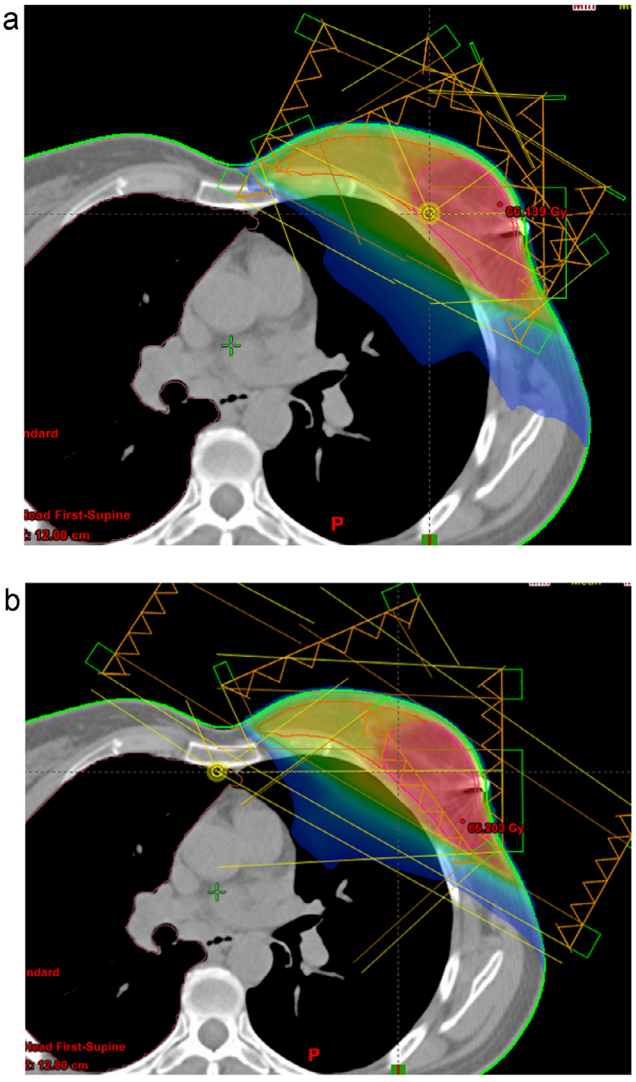

Fig. 2 – (a) Reference plan with the isocenter (indicated by the yellow circle) placed within the breast volume. (b) Off-breast isocenter plan with the isocenter (indicated by the yellow circle) laterally located at the center of the treatment couch.

where TV_{RI} is the volume (in cm^3) of the PTV covered by the 95% of its PD (reference isodose, RI), *TV* is the volume (in cm^3) of the PTV, and V_{RI} is the volume (in cm^3) of the 95% isodose. This value ranges from zero to 1, where 1 is the ideal value and a result closer to zero indicates either total absence of conformity or a very large volume of healthy tissue being irradiated compared with the target volume. CI was assessed for PTVtumor_bed and PTVwb, with 61.2 Gy and 47.9 Gy as reference isodoses, respectively.

Regarding the OARs, the following parameters were analyzed (where *Vx* means the percent of volume receiving *x* or more Gy):

(1) V5Gy, V20Gy and mean dose to the ipsilateral lung;
(2) V5Gy to the contralateral lung;

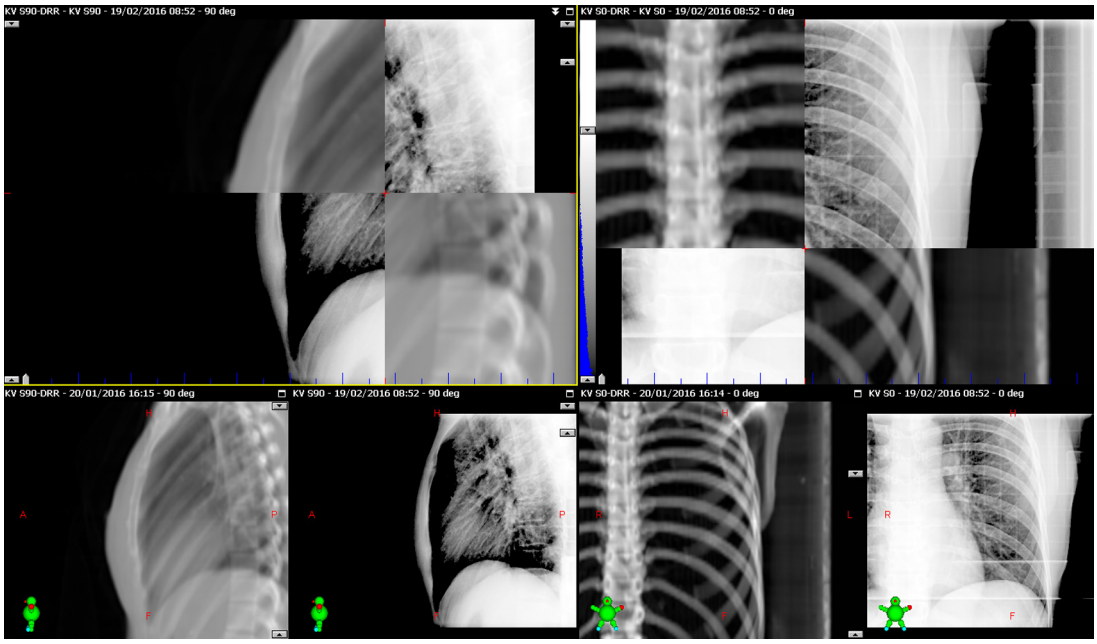

Fig. 3 – Example of patient setup using two orthogonal kV images: the sternum is used to perform the match in the lateral projections, while the vertebral column and ribs are matched in the frontal images.

(3) V5Gy, V30Gy and mean dose to the heart;
(4) V5Gy and mean dose to the contralateral breast, and
(5) V5Gy and mean dose were also evaluated in the healthy tissue.

The two-tailed paired *t*-test[15] was used to analyze the differences between the reference and off-breast plans in the metrics mentioned above. Differences were considered significant if $p < 0.05$.

Table 1a – Doses to PTVs and normal structures for the two planning techniques.[a] Left and right breast cases are included.

Structure	Metric	Plan_ref		Plan_off-breast		*p*-Value
		Mean (SD)	Range	Mean (SD)	Range	
PTVbreast[c]	V107% (%)	16.6 (11.3)	2.1–41.8	15.3 (10.3)	1.3–39.4	0.067
	V95% (%)	96.5 (1.9)	91.9–99.5	96.2 (1.8)	90.7–98.4	0.361
	Vexcess (%)	12.2 (17.0)	0.0–76.5	10.4 (11.1)	0.0–36.7	0.414
	CI[b]	0.69 (0.09)	0.5–0.8	0.69 (0.08)	0.5–0.8	0.224
	HI	0.25 (0.07)	0.1–0.4	0.25 (0.06)	0.1–0.3	0.499
PTVtumor_bed	V107% (%)	0.1 (0.2)	0.0–0.8	0.1 (0.2)	0.0–1.1	0.530
	V95% (%)	97.0 (1.7)	94.7–99.9	97.0 (1.9)	93.5–99.7	0.977
	CI	0.7 (0.18)	0.38–0.92	0.71 (0.16)	0.39–0.9	0.379
	HI	0.1 (0.02)	0.1–0.1	0.09 (0.02)	0.1–0.1	0.457
Ipsilateral lung	V5Gy (%)	30.3 (10.8)	8.7–51.1	31.4 (13.8)	8.5–64.5	0.486
	V20Gy (%)	10.3 (4.1)	3.2–18.7	10.3 (4.2)	2.9–18.4	0.903
	Dmean (Gy)	7.1 (2.1)	2.5–10.8	7.1 (2.3)	2.4–11.1	0.924
Contralateral lung	V5Gy (%)	0.2 (0.4)	0.0–1.7	0.1 (0.3)	0.0–0.9	0.431
Heart	V5Gy (%)	11.2 (15.4)	0.0–49.5	10.0 (13.5)	0.0–51.4	0.459
	V30Gy (%)	0.7 (1.1)	0.0–3.8	0.6 (1.0)	0.0–2.7	0.251
	Dmean (Gy)	2.3 (2.1)	0.2–6.4	2.2 (2.0)	0.2–7.5	0.400
Contralateral breast	V5Gy (%)	0.3 (0.4)	0.0–1.0	0.8 (1.3)	0.0–3.3	0.054
	Dmean (Gy)	0.4 (0.3)	0.1–1.1	0.5 (0.5)	0.1–1.6	0.107
Healthy tissue	V5Gy (%)	7.7 (3.7)	2.9–17.7	7.3 (2.9)	2.9–13.5	0.334
	Dmean (Gy)	2.3 (0.7)	1.1–4.0	2.2 (0.5)	1.1–3.3	0.280

[a] SD: standard deviation; V95%/V107%: percent of PTV receiving ≥95%/107% of its prescription dose; VxGy: percent volume receiving ≥x Gy; Vexcess: percent of PTVbreast volume receiving ≥95% of the boost prescription dose; *Dmean*: mean dose.
[b] CI was evaluated in the Boolean whole breast given by PTVbreast or PTVtumor_bed.
[c] PTVbreast excluded PTVtumor_bed.

Table 1b – Right breast cases: doses to PTVs and normal structures for the two planning techniques.[a]

Structure	Metric	Plan_ref		Plan_off-breast		*p*-Value
		Mean (SD)	Range	Mean (SD)	Range	
PTVbreast[c]	V107% (%)	18.6 (13.6)	2.1–41.8	17.1 (12.6)	1.3–39.4	0.156
	V95% (%)	96.6 (1.8)	93.2–99.5	96.4 (1.5)	93.7–98.4	0.768
	Vexcess (%)	20.2 (21.3)	1.7–76.5	16.8 (12.1)	0.4–36.7	0.431
	CI[b]	0.65 (0.09)	0.5–0.8	0.66 (0.08)	0.5–0.8	0.042
	HI	0.29 (0.06)	0.1–0.4	0.28 (0.06)	0.1–0.3	0.219
PTVtumor_bed	V107% (%)	0.0 (0.0)	0.0–0.0	0.0 (0.0)	0.0–0.0	N.A.
	V95% (%)	97.3 (2.0)	94.7–99.9	96.9 (2.4)	93.5–99.7	0.528
	CI	0.55 (0.14)	0.38–0.77	0.58 (0.11)	0.39–0.71	0.137
	HI	0.09 (0.02)	0.1–0.1	0.09 (0.02)	0.1–0.1	0.992
Ipsilateral lung	V5Gy (%)	26.2 (8.0)	8.7–36.0	26.0 (8.5)	8.5–35.2	0.879
	V20Gy (%)	11.5 (4.0)	3.2–18.7	11.2 (4.1)	2.9–18.4	0.434
	Dmean (Gy)	7.1 (2.0)	2.5–10.2	7.1 (2.3)	2.4–10.2	0.501
Contralateral lung	V5Gy (%)	0.0 (0.0)	0.0–0.0	0.1 (0.2)	0.0 –0.6	0.343
Heart	V5Gy (%)	0.2 (0.3)	0.0–1.0	0.1 (0.2)	0.0–0.8	0.168
	V30Gy (%)	0.0 (0.0)	0.0–0.0	0.0 (0.0)	0.0–0.0	N.A.
	Dmean (Gy)	0.7 (0.6)	0.2–1.8	0.6 (0.4)	0.2–1.6	0.362
Contralateral breast	V5Gy (%)	0.1 (0.3)	0.0–1.0	0.0 (0.0)	0.0–0.1	0.219
	Dmean (Gy)	0.3 (0.1)	0.1–1.4	0.2 (0.1)	0.1–0.4	0.011
Healthy tissue	V5Gy (%)	2.1 (0.5)	1.1–2.5	2.0 (0.5)	1.1–2.6	0.442
	Dmean (Gy)	6.2 (1.8)	2.9–9.9	5.7 (1.4)	2.9–7.6	0.150

[a] SD: standard deviation; V95%/V107%: percent of PTV receiving ≥95%/107% of its prescription dose; VxGy: percent volume receiving ≥*x* Gy; Vexcess: percent of PTVbreast volume receiving ≥95% of the boost prescription dose; *Dmean*: mean dose.
[b] CI was evaluated in the Boolean whole breast given by PTVbreast or PTVtumor_bed.
[c] PTVbreast excluded PTVtumor_bed.
N.A.: not available.

Table 1c – Left breast cases: doses to PTVs and normal structures for the two planning techniques.[a]

Structure	Metric	Plan_ref		Plan_off-breast		*p*-Value
		Mean (SD)	Range	Mean (SD)	Range	
PTVbreast[c]	V107% (%)	14.6 (8.6)	2.3–31.4	13.5 (7.6)	1.8–22.0	0.282
	V95% (%)	96.4 (2.1)	91.9–98.8	96.0 (2.1)	90.7–97.6	0.303
	Vexcess (%)	4.1 (4.0)	0.0–12.0	4.0 (4.5)	0.0–14.9	0.929
	CI[b]	0.72 (0.07)	0.6–0.8	0.72 (0.08)	0.6–0.8	0.929
	HI	0.21 (0.07)	0.1–0.3	0.23 (0.05)	0.1–0.3	0.326
PTVtumor_bed	V107% (%)	0.2 (0.3)	0.0–0.8	0.1 (0.3)	0.0–1.1	0.544
	V95% (%)	96.7 (1.2)	94.8–98.4	97.0 (1.3)	94.8–98.4	0.506
	CI	0.84 (0.04)	0.79–0.92	0.84 (0.07)	0.69–0.9	0.595
	HI	0.01 (0.02)	0.1–0.1	0.09 (0.02)	0.1–0.1	0.311
Ipsilateral lung	V5Gy (%)	34.4 (11.9)	15.5–51.1	36.8 (16.3)	16.9–64.5	0.416
	V20Gy (%)	9.1 (4.0)	3.8–15.8	9.3 (4.3)	3.2–16.1	0.365
	Dmean (Gy)	7.1 (2.2)	3.6–10.8	7.2 (2.5)	3.7–11.1	0.703
Contralateral lung	V5Gy (%)	0.4 (0.5)	0.0–1.7	0.2 (0.3)	0.0 –0.9	0.276
Heart	V5Gy (%)	22.2 (15.3)	4.0–4.49	19.9 (13.0)	5.3–51.4	0.484
	V30Gy (%)	1.4 (1.3)	0.0–3.8	1.2 (1.1)	0.0–2.7	0.262
	Dmean (Gy)	4.0 (1.7)	1.3–6.4	3.8 (1.6)	1.7–7.5	0.577
Contralateral breast	V5Gy (%)	0.4 (0.4)	0.0–0.09	1.6 (1.4)	0.0–3.3	1.833
	Dmean (Gy)	0.6 (0.3)	0.1–1.1	0.8 (0.5)	0.1–1.6	0.038
Healthy tissue	V5Gy (%)	2.5 (0.8)	1.4–4.0	2.4 (0.6)	1.4–3.3	0.417
	Dmean (Gy)	9.3 (4.4)	4.0–17.7	8.9 (3.2)	4.1–13.5	0.658

[a] SD: standard deviation; V95%/V107%: percent of PTV receiving ≥95%/107% of its prescription dose; VxGy: percent volume receiving ≥*x* Gy; Vexcess: percent of PTVbreast volume receiving ≥95% of the boost prescription dose; *Dmean*: mean dose.
[b] CI was evaluated in the Boolean whole breast given by PTVbreast or PTVtumor_bed.
[c] PTVbreast excluded PTVtumor_bed.

4. Results

Differences between the centered and off-centered techniques (plan_ref vs. plan_off breast, respectively) are presented in Table 1: mean values, standard deviations, and range for each analyzed dosimetric parameter are shown per technique, for all (Table 1a), right-side (Table 1b) and left-side breast cases (Table 1c). Average DVH-based comparison is shown in Fig. 4:

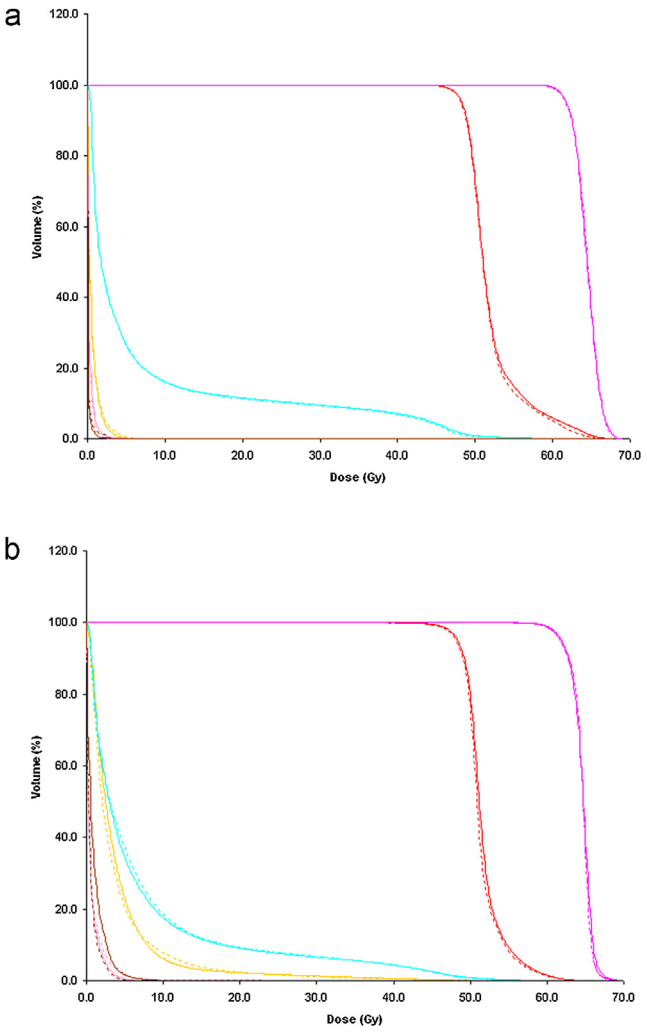

Fig. 4 – (a) Average DVH-based comparison between reference plan (solid lines) and off-breast isocenter plan (dashed lines) for right-side breast cases. Red: PTVbreast; magenta: PTVtumor_bed; cyan: ipsilateral lung; brown: contralateral lung; orange: heart; purple: contralateral breast. (b) Average DVH-based comparison between reference plan (solid lines) and off-breast isocenter plan (dashed lines) for left-side breast cases. Red: PTVbreast; magenta: PTVtumor_bed; cyan: ipsilateral lung; brown: contralateral lung; orange: heart; purple: contralateral breast.

no appreciable differences were observed by looking at the plots.

All plans were optimized to try to cover 95% of each PTV by 95% of its PD (i.e., V95% ≥ 95%), although V95% ≥ 90% was clinically acceptable in our practice. These objectives were reached for all cases. PTV coverage (V95%) was very similar between the two techniques, and no statistical differences were found (plan_ref vs. plan_off breast): 96.5% vs. 96.2%, $p = 0.361$ for PTVbreast; and 97.0% vs. 97.0; $p = 0.977$, for PTVtumor_bed (see Table 1a). No significant differences were observed in homogeneity (HI), conformity (CI) or in the magnitude of hot spot (V107%) for both PTVs (see Table 1a). The excessive dosage of PTVbreast due to the high dose spillage produced by the PTV-tumor_bed, was also analyzed using the parameter Vexcess (percent volume of the PTVbreast receiving ≥95% of the boost PD). No significant difference was found for Vexcess between the plan_ref and plan_off breast: 12.2% vs. 10.4%, respectively, $p = 0.414$ (see Table 1a).

All OAR dose constraints proposed by the documents followed in our clinical practice[9] were respected in both irradiation techniques (see Table 1a). No significant differences were found for the metrics analyzed for the ipsilateral lung (V5Gy, V20Gy and mean dose), contralateral lung (mean dose), heart (V5Gy, V30Gy and mean dose), and contralateral breast (mean dose). The proposed off-center technique did not increase the dose to the healthy tissue surrounding the PTVs. No substantial differences were noted in V5Gy and mean dose parameters of the healthy tissue.

Tables 1b and 1c reveal that no appreciable differences were detected in any metric for any group of breast cases (right and left sides).

5. Conclusions

In the last years, with the implementation of imaging systems coupled to the linac, there has been an increased use of kilovoltage imaging for breast patient setup. The addition to the linac of the source and detector arms for kV imaging poses collision risks with the patient. The non-central location of the isocentre makes clearance with the linear accelerator even more problematic.[16,17]

Willis et al.[18] identified pairs of nonorthogonal kV images as optimal for physical clearance between the patient and the linac for external beam partial breast irradiation. Donovan et al.[19] described the determination of appropriate imaging angular range for left and right breast kV cone beam computed tomography (CBCT) scans by assessing the clearance of the gantry from the patient and couch. The IMPORT (Intensity Modulated and Partial Organ Radiotherapy) High trial[20] remarks that the isocenter should be carefully placed to avoid collision risk, such as each center enrolled in the study must carefully check its own possible collision risk.

In this work we proposed to place the treatment isocenter at the midline of the linac couch to avoid any collisions risk. Right- and left-sided breast cases, as well as small and large breast volumes were included. For left-sided cases, the collision risk between the patient/couch and the kV detector only exists during the lateral kV imaging as shown in Fig. 1c. No collisions happened during the kV image-guided setup for the reference plans enrolled in this study. However, a small clearance (<2.0 cm) was alerted between the linac gantry and the patient/couch during frontal kV imaging (Fig. 1b) for some right-sided breast patients. This situation obviously stressed the radiation therapy technologists and reduced the efficiency of the treatment setup. In addition, extension of the patient's arms, laterality of the breast treatment region and immobilization devices all pose a collision risk that may be avoided with the proposed off-center irradiation technique.

Definitively, the "off-breast isocenter" technique eliminates the likelihood of any collision during the kV imaging

and the treatment delivery regardless of breast side (left or right) to treat.

Conflict of interest

None declared.

Financial disclosure

None declared.

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