

Radiation dose to the left anterior descending coronary artery during interstitial pulsed-dose-rate brachytherapy used as a boost in breast cancer patients undergoing organ-sparing treatment

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Abstract

Purpose: To assess dose received by the left anterior descending (LAD) coronary artery during interstitial pulsed-dose-rate brachytherapy (PDR-BT) boost for left-sided breast cancer patients undergoing organ-sparing treatment.

Material and methods: Thirty consecutive pT1-3N0-1M0 breast cancer patients boosted between 2014 and 2015 with 10 Gy/10 pulses/hour PDR-BT following a computed tomography (CT) simulation with the multi-catheter implant were included. The most common localization of primary tumor were upper quadrants. Patients were implanted with rigid tubes following breast conserving surgery and whole breast external beam irradiation (40 Gy/15 or 50 Gy/25 fractions). Computed tomography scans were retrospectively reviewed and LADs were contoured without and with margin of 5 mm (LAD_{5mm}). Standard treatment plan encompassed tumor bed determined by the surgical clips with margin of 2 cm. Dosimetric parameters were extracted from the dose-volume histograms.

Results: The mean D₉₀ and V₁₀₀ were 10.3 Gy (range: 6.6-13.3), and 42.0 cc (range: 15.3-109.3), respectively. The median dose non-uniformity ratio (DNR) was 0.50 (range: 0.27-0.82). The mean doses to LAD and LAD_{5mm} were 1.0 Gy and 0.96 Gy, and maximal doses were 1.57 Gy and 1.99 Gy, respectively. Dose to the 0.1 cc of the LAD and LAD_{5mm} were 1.42 Gy and 1.85 Gy (range: 0.01-4.98 Gy and 0.1-6.89 Gy), respectively.

Conclusions: Interstitial multi-catheter PDR-BT used as a boost for left-sided breast cancer is generally associated with low dose to the LAD. However, higher dose in individual cases may require alternative approaches.

J Contemp Brachytherapy 2017; 9, 1: 7-13
DOI: <https://doi.org/10.5114/jcb.2017.66043>

Key words: breast carcinoma, LAD, pulsed-dose-rate brachytherapy.

Purpose

Adjuvant radiotherapy after breast-conserving surgery constitutes an indispensable part of breast conserving therapy in early breast cancer. The standard technique of radiation therapy is to treat the entire breast up to a total dose of 40-50 Gy, with or without a boost dose of 10-15 Gy to the tumor bed depending on boost indications. A decreased risk of local recurrence, particularly in younger patients, as a result of a boost dose has been confirmed in a large randomized trial [1]. For selected low-risk patients, accelerated partial breast irradiation (APBI) is an alternative treatment option to whole-breast radiotherapy (WBRT). A non-inferiority of APBI with interstitial multi-catheter brachytherapy (BT) technique was recently proved by GEC-ESTRO (Groupe Européen

de Curiethérapie European Society for Radiotherapy and Oncology) trial [2]. Brachytherapy is an attractive option for both tumor-bed boost and APBI, allowing local dose escalation while reducing the dose to the surrounding normal structures.

Radiotherapy for breast cancer often involves some incidental exposure of the heart to ionizing radiation. This exposure has been associated with increased risk of cardiac morbidity and mortality [3]. Darby *et al.* demonstrated that the relative risk of major cardiac events including myocardial infarction, coronary revascularization, and death from ischemic heart disease, increases linearly with the mean heart dose (MHD) by 7.4% per gray with no apparent threshold [4]. The increase of the subsequent rate of ischemic heart disease in irradiated

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Received: 12.09.2016

Accepted: 11.01.2017

Published: 28.02.2017

patients is proportional to MHD, begins within a few years after exposure, and continues for at least 20 years. Apart from individual characteristics i.e. co-morbidities and age, systemic therapy such as anthracyclines and trastuzumab may further potentiate the radiation's effect on the heart [5].

The aim of this study was to assess dose received by the left anterior descending (LAD) coronary artery during interstitial multi-catheter pulsed-dose-rate BT (PDR-BT) boost with 3-dimensional (3D) computed tomography (CT) based planning for left-sided breast cancer patients undergoing organ-sparing treatment.

Table 1. Patient and tumor characteristics ($n = 30$)

Parameter	n (%)
Age (years)	
Median (range)	59 (39-75)
pT stage	
pT1	22 (73)
pT2-3	8 (27)
pN stage	
pN0	25 (83)
pN1	5 (17)
Histological subtype	
Ductal	26 (87)
Lobular	3 (10)
Other	1 (3)
Grading	
G1	9 (30)
G2	13 (44)
G3	7 (23)
Unknown	1 (3)
WBRT	
40 Gy/15 fractions	26 (87)
50 Gy/25 fractions	4 (13)
WBRT technique	
3D-tCRT	30 (100)
Quadrants of the breast	
Upper inner	12 (40)
Upper outer	10 (33)
Lower inner	3 (10)
Lower outer	2 (7)
Central	3 (10)

WBRT – whole breast radiotherapy, 3D-tCRT – 3-dimensional tangential conformal radiotherapy

Material and methods

Thirty consecutive patients were selected from women who received interstitial multi-catheter 3D PDR-BT boost dose to the conserved left breast, following WBRT at the Medical University of Gdańsk between 2014-2015 (Table 1). Rigid needles were implanted under general anesthesia. Catheter implantation was performed in a geometrically uniform way using the standardized templates for a triangular array with 16 mm separation of the holes. Post-implant, non-contrast CT with a slice thickness of 3 mm was done. The contours of PTV (planning target volume) and critical organs (skin and ribs) were imported and analyzed in treatment planning system Oncentra v. 3.3 (Nucletron, an Elekta company, Elekta AB, Stockholm, Sweden). The clinical target volume (CTV) consisted of the tumor bed with an adequate safety margin. The size of the safety margin was calculated as the sum of the width of the clear pathological surgical margins, and the radiation safety margin based on the localization of the clips left in tumor bed. It had to be approximately 20 mm, as defined individually for every patient, considering clinical information. The PTV was contoured 5 mm below the skin and above the chest wall, or just above the chest wall along the pectoralis muscle for superficial and deep tumors, respectively. Paris system rules, with graphical and manual optimization to deliver adapted homogenous dose distribution to the PTV, and to keep the dose non-uniformity ratio (V_{150}/V_{100} ; DNR) as close as recommended (< 0.35) were applied. Dose-volume histogram analyses were used to confirm that 100% of the prescribed dose covered at least 90% of the target volume. The maximum skin dose was restricted to less than 100% of the prescribed dose. A dose of 10 Gy with pulses of 1 Gy/h was delivered.

The LAD was retrospectively contoured on the CT scans by one of the radiation oncologists, based on guidelines described by the Feng *et al.* [6]. Left anterior descending coronary artery was contoured from its origin to each utmost visible part on planning CT image (Figure 1). A margin of 5 mm was added to each LAD (LAD_{5mm}) to allow for uncertainties regarding the exact position of the coronary artery. Dosimetric parameters extracted from dose-volume histograms including LAD doses of standardized plans were analyzed.

Statistical analysis

Statistical analysis was performed using SPSS software (version 20.0, IBM Corporation, USA). Quantitative data were expressed as mean \pm standard deviation (SD). For statistical analyses, four quadrants of the breast were assumed. If $> 50\%$ of the PTV was situated above the line dividing the breast into equal upper and lower portions, than the location was assigned as "upper". The same approach was applied for the medial and lateral assignments. Dose distribution to LAD, according to the tumor bed localization was compared by *U*-Mann Whitney test with two-sided *p*-values and significance level of $\alpha = 0.05$.

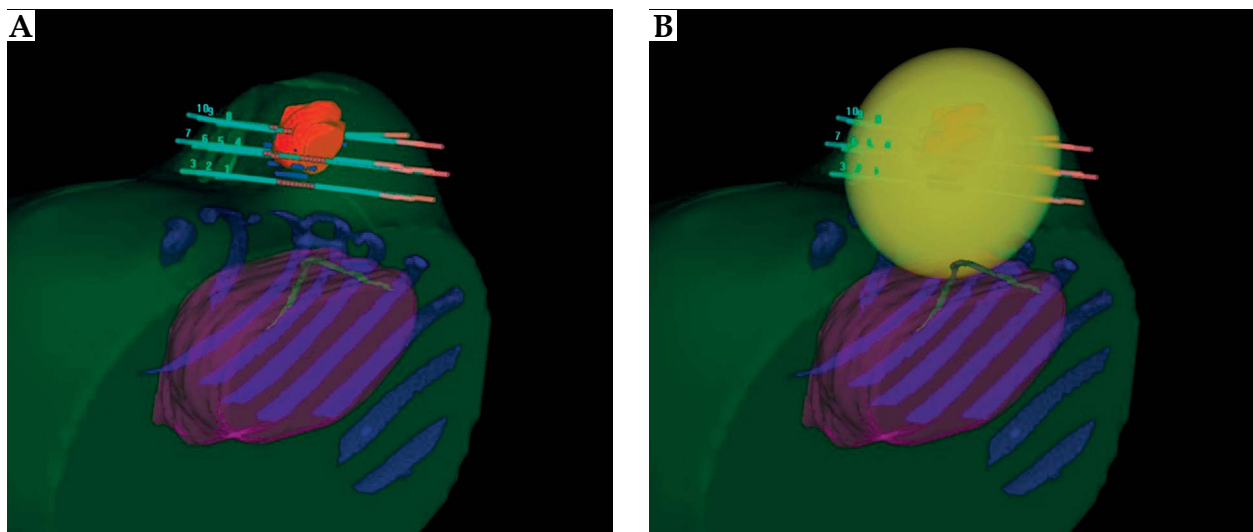


Fig. 1. Rigid needles, planning target volume, and organs at risk including left anterior descending (LAD) coronary artery (A), and isodose 10% of the prescribed dose with reference to LAD (B)

Results

Selected parameters of BT implants are presented in Table 2. The volume enclosed by the reference isodose ranged from 15.3 cc to 109.3 cc (mean 42 cc). Tumor bed was in upper quadrants in 80% of cases, with the upper inner quadrant being the most common localization. Unsatisfactory higher DNR in half of the cases was related to our learning curve in 3D planning. A summary of radiation doses to the LAD and LAD_{5mm} including D_{0.1cc} (representing the highest dose received by 0.1 cc of the LAD, i.e. the dose peak) is presented in Table 3. The average (D_{mean}) and maximal dose (D_{max}) to LAD were 1 Gy and 1.57 Gy, respectively. There is substantial patient-to-patient variability with the LAD D_{max} up to 55% of the prescribed dose. D_{0.1cc} of the LAD and LAD_{5mm} were 1.42 Gy and 1.85 Gy (range: 0.01-4.98 Gy and 0.1-6.89 Gy, respectively). Dose distribution to LAD according to the tumor bed localization is presented in Table 4. There was no difference in D_{max} to LAD for medial versus lateral parts of the breast ($p = 0.92$). No differences were noted for average dose according to tumor bed location (lower vs. upper quadrants; $p = 0.35$, medial vs. lateral quadrants; $p = 0.92$). D_{max} to LAD was significantly higher for tumors located in lower versus upper part of the breast ($p = 0.04$).

Discussion

Micro- and macro-vascular injury in tissues within the radiotherapy field is considered the main pathophysiological cause of radiation-related heart disease [4]. The LAD artery is of particular interest by its anatomical localization within the high dose region (denoted by 95% of the radiation prescription) of the WBRT fields. An increased risk of stenosis in the LAD for left-sided radiotherapy (RT) was reported [7]. According to Darby *et al.*, a study based on doses estimated from the RT charts, the MHD was a better predictor of the rate of major coronary events (angina episodes were not included) than the mean dose to the LAD [4].

In clinical practice, the avoidance of the heart and LAD exposure is one of the highest priorities. Several reports evaluated heart dose during breast irradiation and have provided (for standard fractionation) current recommendations of MHD and dose and volume constraints for this organ-at-risk (OAR) to keep the probability of long-term cardiac mortality < 1% [8,9,10,11]. More recently, Danish

Table 2. Selected parameters of brachytherapy implants (10 Gy in 10 pulses per hour, $n = 30$)

Characteristics	
D ₉₀	
Median	10.58 Gy
Range	(5.4-13.3)
Percent of the prescribed dose	54-133%
V ₁₀₀	
Median	42.03 cc
Range	(15.3-109.26)
DNR	
Median	0.5
Range	(0.27-0.82)
Number of tubes	
Median	11
Range	7-15
Number of implant planes	
Two	4 (13%)
Three	26 (87%)

DNR – dose non-uniformity ratio, V₁₀₀ – the percentage of the planning target volume (PTV) receiving 100% of the prescribed dose or more, D₉₀ – the percentage of the prescribed dose received by 90% volume of the PTV

Table 3. Radiation dose to left anterior descending (LAD) coronary artery for 30 left-sided breast cancer patients treated with 10 Gy/10 pulses/hour pulsed-dose-rate brachytherapy tumor-bed boost

Dosimetric parameters	Median dose (range) (Gy)	Maximum dose (range) (Gy)	Relative to prescribed dose (range) (%)	Mean dose (range) (Gy)
LAD	1.4 (0.1-3.9)	1.57 (0.1-5.5)	15.7 (1-55)	1.0 (0.1-3.4)
LAD 5 mm	0.8 (0.1-3.0)	1.99 (0.1-7.5)	19.9 (1-75)	0.96 (0.1-3.0)
LAD 0.1 cc	1.33 (0.01-4.98)		14.2 (1.4-49.8)	1.42 (0.01-4.98)
LAD 5 mm 0.1 cc	1.69 (0.1-6.89)		18.5 (1.68-68.9)	1.85 (0.1-6.89)

LAD – left anterior descending coronary artery

Table 4. Dose distribution to left anterior descending (LAD) coronary artery according to the tumor bed localization

Breast quadrant	Number (%)	LAD mean dose (range) (Gy)	LAD maximal dose (range) (Gy)
Upper outer	10 (33.3)	0.83 (0.1-1.5)	1.19 (0.1-1.8)
Upper inner	14 (46.7)	0.89 (0.4-1.5)	1.34 (0.5-2.4)
Lower outer	2 (6.7)	1.2 (1.1-1.3)	2 (1.7-2.4)
Lower inner	4 (13.3)	1.4 (0.6-3.4)	2.5 (1-5.5)

LAD – left anterior descending coronary artery

experts have suggested to respect dose constrains to the heart as well as maximal dose to LAD of 20 Gy [12].

In the literature, there are limited data of LAD doses during breast irradiation, with only two published reports considering multi-catheter high-dose-rate BT (HDR-BT) as a form of APBI [13,14,15,16,17,18,19,20,21] (Table 5). Chan *et al.* [14] performed a quantitative intra-patient comparison of OAR dosimetry between HDR-BT versus WBRT in a group of 15 patients with left breast cancer. They contoured the whole heart to represent myocardium. The authors assumed the maximum dose for the heart as a parameter to report LAD dose. The mean LAD dose was 6.0 Gy, which constitutes 17.6% of the prescribed BT dose of 34 Gy in 10 twice daily fractions, and 5.9% (after adjusting for EQD₂) of 50 Gy. Accelerated partial breast irradiation with the use of HDR-BT compared to conformal WBRT was associated with a significant reduction in radiation dose for the LAD (D_{mean} 6.0 Gy vs. 45.9 Gy; $p < 0.01$; dose differed by a factor of 7.7). The LAD dose was the highest (7.8 Gy) in lower inner quadrant-located tumors. In this study, the $D_{0.1\text{cc}}$ of the heart and the MHD were 16.3 Gy and 2.3 Gy for APBI, respectively, and were significantly lower than for WBRT. In Sato *et al.* [19] study, which compared radiation dose to the LAD during HDR-BT APBI and WBRT, LAD was outlined as in our series, but in uncertain BT cases each artery was identified with reference to the preoperative enhanced CT images to determine LAD. In the BT group (100 cases), mean PTV was 35.8 cc (6.8-135.8), mean V_{100} 29.8 cc (7.0-106.5), and mean DNR was 0.3 (0.2-0.6). The mean number of catheters and implant planes was 6.1 (3-12) and 1.6 (1-3), respectively. In this series, the mean and maximal LAD doses for tumors in inner quadrants or central locations (2.54 ± 0.21 and 4.43 ± 0.38 Gy, respectively) were significantly higher than those in outer quadrants (1.02 ± 0.17 and 2.1 ± 0.29 Gy, respectively; $p < 0.0001$). After adjustment of the cumulative LAD dose

of APBI to WBRT using the BED equations, the mean and maximal doses in BT patients were significantly reduced in patients with tumors in outer quadrants, but increased in inner quadrants or central location. These authors stated that in patients with left-sided breast cancer, the risk of the relatively high dose to LAD should be examined before treatment. In the present series with LAD delineated according to guidelines by Feng *et al.*, LAD dose during PDR-BT of 10 Gy boost dose applied in addition to WBRT, the D_{mean} and D_{max} to the LAD were on average 1 Gy and 1.57 Gy, respectively. However, in some cases, the latter dose constitutes up to 55% of the prescribed dose. As the LAD is a serial organ, some authors postulated D_{max} to be applicable as a parameter in reporting LAD exposure. In our series, mean $D_{0.1\text{cc}}$ was 1.42 Gy, and ranged from 0.01 to 4.98 Gy (0.1-49.8% of the tumor dose). We did show the difference between LAD maximal, but not average doses among patients with tumors located in the upper and lower quadrants. In a series of 60 left-sided breast cancer patients who were treated with balloon-based HDR-BT APBI using MammoSite (Hologic Inc., Bedford, MA, USA) or Contura (Senorx, Inc., Aliso Viejo, CA, USA) applicators, for balloons located in the upper inner quadrant of the breast, the average whole heart D_{mean} was the highest [22]. The lowest MHD (0.51 Gy) with 3D-conformal RT (CRT) APBI as compared to multi-catheter and balloon HDR-BT APBI (1.58 Gy and 2.17 Gy, respectively) for medially located left-breast tumors was demonstrated in an anthropomorphic phantom [23]. In the most recent study by Nilsson *et al.* based on coronary angiography, which was performed at a mean follow-up of 3.8 years (range: 0.3-8.2 years) after 3D-CRT, the distribution of radiation dose in the segments of the LAD differed markedly between left- and right-sided breast cancer [17]. In the left-sided tumors in mid-LAD component and in particular segment, 8 (corresponding to distal LAD) doses approached the target of 50-60 Gy.

Table 5. Recent studies on left anterior descending (LAD) coronary artery doses in breast cancer patients treated conservatively (mean and maximum dose – the values are averaged over analyzed patients)

Author (Ref.)	Number of patients/ Side of the breast	Radiotherapy, type/technique/dose	Average LAD maximum dose (Gy)	Average LAD mean dose (Gy)
Bartlett <i>et al.</i> [13]	34/Left-side	WBRT 40 Gy/15 fr		
		VDIBH supine	21.0 (15.8-26.2)	2.9 LAD NTD _{mean}
		FB prone	36.8 (35.2-38.4)	7.8 LAD NTD _{mean}
Chan <i>et al.</i> [14]	15/Left-side	CWBRT 50 Gy/25 fr		45.9 ± 6.4
		HDR-BT APBI 34 Gy/10 fr	NR	6 ± 3.9
Haclislamoglu <i>et al.</i> [15]	10/Right-side	WBRT 50 Gy/25 fr		
		3DCRT	1.00 ± 0.13	0.85 ± 0.20
		For-IMRT	1.01 ± 0.16	0.81 ± 0.10
		Inv-IMRT	8.10 ± 3.42	5.05 ± 1.56
		HT	6.54 ± 1.85	3.49 ± 1.20
Moorthy <i>et al.</i> [16]	36/Left-side	WBRT 45 (60) Gy/25 fr		
		SIB-3DCRT gated	39.5 Gy	NR
		SIB-IMRT gated	29.17 Gy	
		SIB-IMRT non-gated	35.62 Gy	
Nilsson <i>et al.</i> [17]	7/Left-side	CRT 50-56 Gy	1.6-56.5 ^a	1.5-55.2 ^a
	8/Right-side		0.7-44.8 ^a	0.5-21.4 ^a
Pham <i>et al.</i> [18]	15/Left-side	WBRT 50/25 fr		
		VMAT DIBH	33.3 ± 8.9	17.4 ± 5.8
		t-IMRT DIBH	44.5 ± 7.9	26.0 ± 9.5
		VMAT FB	40.9 ± 6.0	24.7 ± 6.5
		t-IMRT FB	50.6 ± 1.6	39.0 ± 6.8
Sato <i>et al.</i> [19]	140/Left-side (including 100 in APBI)	WBRT 50/25 fr	8.19 ± 1.21 (2.31-36.85)	2.13 ± 0.11 (1.13-4.87)
		HDR-BT APBI 34 Gy/10 fr/5-6 days	3.15 ± 0.26	1.71 ± 0.15
Taylor <i>et al.</i> [20]	50/Left-side	WBRT 40 Gy/15 fr	35.2 ± 8.8	7.6 ± 4.5
	10/Right-side		1.9 ± 0.2	1.6 ± 0.2
Yeung <i>et al.</i> [21]	11/Left-side	WBRT 42.5 Gy/16 fr ^x		
		FB	NR	10.04 ± 8.92
		DIBH		4.20 ± 2.77
Present study	30/Left-side	PDR-BT boost of 10 Gy/10p/h	1.57 ± 1.0 (0.1-5.5)	1.0 ± 0.67 (0.1-3.4)

WBRT – whole breast radiotherapy, VDIBH – voluntary deep-inspiratory breath-hold, FB – free-breathing, CWBRT – conformal WBRT, HDR-BT – high-dose-rate brachytherapy, APBI – partial breast irradiation, 3DCRT – three-dimensional conformal RT, IMRT – intensity modulated radiotherapy, For-IMRT – forward IMRT, Inv-IMRT – inverse IMRT, HT – helical RT, VMAT – volumetric-modulated arc RT, SIB – simultaneous integrated boost, CRT – conformal RT, t-IMRT – tangential IMRT, PDR-BT – pulsed-dose-rate brachytherapy

^x – including 4 boosted cases, the most common WBRT dose fraction was 42.5 Gy/16 fraction, ^a – depending on the LAD's segment

In 6 out of 7 left-breast cancer patients, it was substantially higher mean dose ranging from 30 to 55 Gy to the distal LAD than 3 to 13 Gy to the heart. According to these authors, mid-LAD is a critical vascular structure for developing late heart radiation effects. Patients with right-sided cancer had low MHD in a range of 1-3 Gy, and left-sided had higher MHD in a range of 3-13 Gy.

In WBRT for left-sided breast cancer, the LAD dose distribution varied among studies and depended on the technique used, being the highest with free-breathing (FB) CRT [13,16,18,21]. Techniques to reduce cardiac irradiation dose include two-tangential or multi-beam intensity-modulated RT (IMRT), prone positioning, and breath holding techniques. However, each of them has

some limitations, which should be considered in clinical practice. Intensity-modulated RT in left breast cancer is associated with an improvement in dose homogeneity in the breast as well as reduction in cardiac dose, while the integral dose to the thorax, lungs, and contralateral breast is often increased. In terms of LAD dose, D_{mean} of the LAD for prone position is substantially lower compared to supine position, but at the expense of a higher MHD. Volumetric-modulated arc radiotherapy (VMAT) resulted in a significant further reduction in both D_{mean} and D_{max} of the LAD compared with tangential IMRT, based on deep inspiration breath-hold (DIBH) [18]. Plans based on DIBH resulted in a dose reduction compared with FB for all heart and LAD parameters. Notably, VMAT-DIBH is associated with 30% greater $V_{5\text{Gy}}$, as well as greater dose to the contralateral breast. Study investigated supine voluntary deep-inspiratory breath-hold (VDIBH) and FB techniques to deliver 40 Gy in 15 fractions demonstrated significant reduction of NTD_{mean} of the LAD (a biologically equivalent mean of total dose to tissue normalized to 2 Gy fractions using a standard linear quadratic model, $\alpha/\beta = 3$ Gy) for supine VDIBH than FB prone technique (2.9 and 7.8; $p < 0.001$) [13]. Overall, cardiac doses were low for both techniques. Deep-inspiratory breath-hold for left-sided breast cancer was associated with 43.5% reduction in D_{mean} of the LAD, as compared to FB WBRT by others [21]. Comparison among current different irradiation techniques (WBRT, HDR-BT APBI, and 3D-CRT APBI) demonstrates that WBRT appears to be the most challenging, especially for patients with large breasts or when significant set-up errors are anticipated with greater probability of having cardiovascular events in the future [23]. Apart of APBI and modern external beam RT technique, intra-operative RT could further minimize dose to the coronary arteries [24].

Hypofractionated schedules of WBRT have been adopted in BCT. Most patients in our series were hypofractionated with the UK standardization of breast radiotherapy trial (START) schedule of 40 Gy in 15 fractions. Applying the Relative Seriality Model, the risk of cardiac death at 15 years of 1.4% for conventional schedule (50 Gy in 25 fractions) and 0.7% for START regimen was assumed [25]. The others reported no statistically different cardiac mortality at 15-year follow-up among left-sided breast cancer patients treated with either conventional or hypofractionated WBRT [26]. Some authors suggested that hypofractionation might be even safer in terms of heart sparing [27].

Cardiac damage is correlated to the heart-absorbed dose, which is greater for left- than right-breast irradiation and evidently in boosted patients. The mean LAD dose from left-sided WBRT was approximately five times higher than the dose from right-sided irradiation with the distal LAD receiving the highest doses (> 30 Gy; 75% of tumor dose), and the right and circumflex coronary arteries received approximately 2 Gy mean dose [20]. In this study, patient-to-patient variability in mean dose was the greatest for LAD dose from left-sided irradiation, high LAD dose was associated with high MHD, and the patient with the highest MHD (4.4 Gy) also had the high-

est LAD dose (21.3 Gy). They reported that LAD D_{mean} for left-tangential irradiation has decreased from 63.6% in the 1970s to 19.0% of tumor dose in 2006. Apart from historical changes in heart doses during breast cancer RT, the part of heart, particularly the anterior myocardial wall with LAD lying on this surface, is receiving a dose of 20 Gy, which determine the risk of ischemic heart disease for years after RT.

A correct delineation of the heart and coronary vessels is of substantial importance. The contouring of LAD is not a routine clinical practice included in our institution. For this analysis, the LAD was retrospectively contoured by one author according to Feng *et al.* guidelines [6]. A multi-center study from Denmark and the UK demonstrated substantial inter-observer variation in the estimated dose to the LAD, even when guidelines for delineation were applied [12,28]. For the heart, there was little inter-observer variation in the estimated dose. Organ motion during the treatment including inter-fraction variations is another factor influencing the LAD estimated dose. In this series, the maximal dose for LAD with 5 mm margin was on average 1.99 Gy, and ranged from 1% to 75% of the tumor dose. Given the geometric uncertainties, it was postulated to consider all cardiac dose parameters including $V_{4\text{Gy}}$ and $V_{25\text{Gy}}$, along with MHD, when assessing the risk of future cardiac morbidity [18]. For interstitial BT with the use of both metal and plastic catheters, the planning system applied was demonstrated to influence the dose to various volumes of interest [29,30].

Conclusions

In patients with breast cancer, it is intended to minimize, as much as possible, the heart volume that is irradiated without compromising the target coverage. Recent implementation of 3D techniques has allowed delineation of the heart and coronary artery during RT planning processes including BT. The LAD dose for patients with left-sided breast cancer should be routinely examined (should be kept as low as possible) and reported to clarify its clinical consequences, and eventually establish constraints for this artery. Our data demonstrated that the mean LAD dose in interstitial multi-catheter PDR-BT boost of 10 Gy in-left breast is, on average, low. However, higher dose in individual cases may result in clinically relevant late cardiac toxicity; therefore, in selected patients, the boost dose may require alternative approaches.

Acknowledgements

This work was presented partially as a poster at the 5th Congress of Polish Brachytherapy Society held in Poznań, Poland on June 2-4, 2016.

Disclosure

Authors report no conflict of interest.

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