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Original article

Segmented photon beams technique for irradiation of postmastectomy patients

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ABSTRACT

Aim: To present the segmented photon beams technique (SPBT) for irradiation of postmastectomy patients.

Background: In majority of techniques for irradiation of posmastectomy patients, a few adjacent photon or electron beams were usually implemented in order to encompass different parts of the target. In the presented SPBT technique, the radiotherapy plan consists of 6 isocentric photon beams and the area CTV includes both the chest wall and the supraclavicular area. This makes it possible to provide a uniform dose to the CTV with no hot and cold points and enables the determination of doses for the entire volume of critical organs.

Methods and material: The treatment forward-IMRT plan comprises six isocentric 4 and 15 MV photon beams. Modulation of the dose distribution for each field was obtained by applying three segments on average. The total dose of 45 Gy was administered in 20 fractions. Dose distributions in target volume and organs at risk were evaluated for 70 randomly chosen patients.

Results: On average, 94.8% of the CTV volume received doses within 95–107% of the prescribed dose. The average volume of the heart receiving a dose of 30 Gy and lager was 2% for patients with left breast cancer. The average dose to the lung on the irradiation side was always lower than 15.5 Gy and the average V20 Gy was below 35.5%.

Conclusions: The SPBT complies with requirements for high dose homogeneity within the target volume and satisfactory level of sparing of organs at risk.

1. Background

Breast cancer is the most common malignancy in women. Treatment of choice is either removal of the whole breast (mastectomy) combined with adjuvant radiotherapy and chemotherapy/hormonotherapy or local excision of the tumor, with safety margin (BCT), and adjuvant systematic therapy.[1] Although currently many women undergo a conserving surgery, postmastectomy patients still constitute a large group of radiotherapy patients. Available data suggest that in patients with positive postmastectomy margins, primary tumors of more than 5 cm, involvement of four or more lymph nodes at the time of mastectomy, or feature T4

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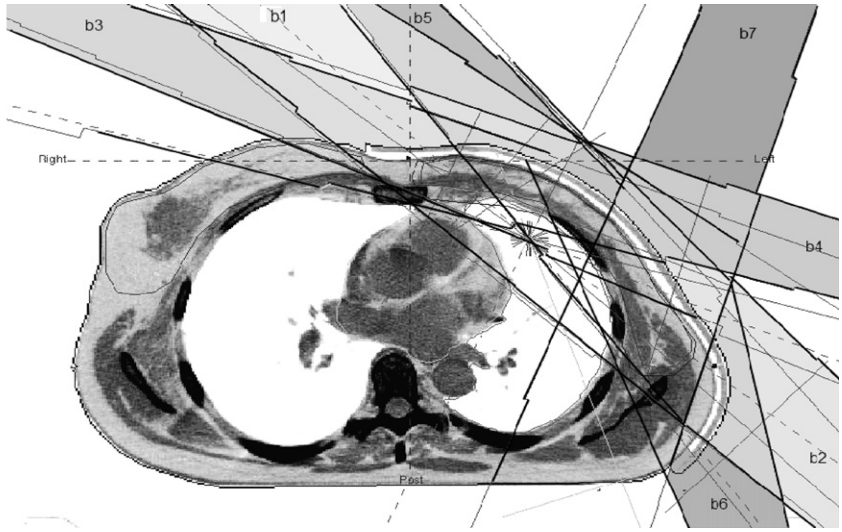

Fig. 1 – Schematic illustration of directional beams for SPBT technique for the patient with the left-sided cancer.

(skin or chest wall infiltration) the risk of locoregional failure remains high enough to consider postmastectomy radiation therapy.[1] Clinical target volume for this specific radiotherapy (CTV) usually includes the chest wall (CW) and regional lymph nodes. Extensive, irregularly shaped target volume and the proximity of the lung and heart, makes the preparation of a treatment plan for postmastectomy patients difficult and time consuming. Despite a tremendous technical progress in radiotherapy achieved in recent years and implementation of new methods of radiotherapy for many other tumor sites, an optimal treatment technique for postmastectomy patients is still being searched. There are many techniques of irradiation described in the literature.[2–4] In all methods described, a few adjacent photon or electron beams were usually implemented in order to encompass different parts of the target. Electron beams of energies ranging from 6 MeV to 15 MeV were used to irradiate the chest wall (CW) and internal mammary chain (IMC), while anterior photon beams were used to irradiate the supraclavicular nodes (SC) and high axilla (AX).[5–7] Irradiation with electrons, including arc technique,[6] was usually implemented with the use of bolus. In the "inverse hockey stick technique" SC region with lateral part of the CW was irradiated with one anterior 6 MV photon beam with the individual shielding of the lung.[8–10] The IMC and medial CW were treated with electron beams, with energy chosen individually for each patient. The most common method of CW irradiation is based on the application of two opposed tangential photon beams.[2] At some institutions the combination of photon and electron fields to CW and IMN region was applied: lateral part of the CW was irradiated with two tangential photon beams while the medial part of the CW and IMC with electron beam of 9–12 MeV.[2,11] Such field arrangements were implemented at the 1st Radiotherapy Department of Maria Skłodowska Curie Memorial Cancer Center in Warsaw until 2007. This method included mono-isocentric half beams of photons in combination with an oblique electron beam. None of the techniques mentioned above can be regarded as a gold standard. All of them are based on the application of a few adjacent beams which encompass different parts of the target and thus all of them have disadvantages on the match lines.

According to the quoted papers most patients received doses of up to 50 Gy in 1.8–2 Gy fractions. A portion of CW was frequently boosted to higher doses. Methods of planning varied from 2D,[5,8] through combination of 2D with 3D restricted to one target region, to conformal 3D techniques. Switching from 2D to 3D planning could lead to some improvements. For example, the "modified hokey-stick technique" with conformal 3D planning introduced customized bolus in electron beams.[9] However, the introduction of 3D planning could also reveal dosimetric defects of the technique with 2D origin, which could not be easily overcome by minor changes within the technique. In respect to IMRT techniques, so far, dosimetric studies on the potential of IMRT for postmastectomy patients treatment are presented.[12] The helical tomotherapy technique is used in planning of locoregional breast radiation, including the internal mammary chain and chest wall tumors.[13,14]

Also, some technologically advanced techniques are described, e.g. tomotherapy, IMRT and rapid arc. However these are usually applied for irradiation of patients with early-stage breast cancer who had undergone breast conservation surgery.[15–18]

2. Aim

The aim of this paper is to present a novel – segmented photon beams technique (SPBT) of postmastectomy breast cancer patients irradiation which can be implemented in all radiotherapy centers equipped with MLC accelerators and to evaluate the results of dose distribution for a selected group of patients.

3. Materials and methods

In the period between October 2007 and May 2009, about 400 postmastectomy patients were treated using the SPBT technique.

The dose distribution parameters were evaluated for 70 postmastectomy patients: 35 right-sided and 35 left-sided, treated with the segmented beams technique, irradiated between October 2007 and February 2008.

Patients were positioned supine on a breast board of our own design with arms above head. The head was turned to the healthy side. A 5 mm thick bolus was placed on the chest wall to increase the dose to the CW. CT examination of each patient placed in the treatment position with bolus present were taken at 5 mm covering the CW. The CTV, heart, entire lung on the irradiation side, opposite breast and the spinal cord were delineated on the CT slices. CTV comprised the scar, chest wall (CW), skin and muscles without ribs (if there was no cancer invasion), axillary, supraclavicular and internal mammary chain (IMC) (if metastatic or if the tumor was localized in the internal quadrants) and lymph nodes. PTV comprised the area of CTV with a 5 mm safety margin. Cardiac area comprised the right and left ventricle, right and left atrium and anterior descending coronary artery (LAD).

The prescribed dose was 45 Gy in 20 fractions, 5 days per week.[19]

The planning was performed with the forward-IMRT method (fIMRT). The target volume was treated as a whole without dividing it into separate parts.

The advantage of this technique was that the area of CTV included both the chest wall and supraclavicular area. This made it possible to provide a uniform dose to the CTV with no hot and cold points, which were always created in other techniques, in the regions linking the fields.[5–7,9]

At the same time, this enabled the determination of doses for the entire volume of critical organs, such as the lung.

The radiotherapy plan consisted of 6 isocentric photon beams of 4 MV and 15 MV.

If the CTV volume exceeded 1200 cm^3, 4 MV photon beams were replaced with 6 MV beams.

Isocentre point was located near the top of the lung in the irradiated site. The isocentre point was determined for each patient individually. Typical beam arrangement is shown in Fig. 1.

One anterior – "b1" 4 MV beam covered the entire PTV volume. The opposed field – "b2" was restricted to the CW volume. The most horizontal – "b3" and/or "b4", oblique 15 MV photon beam coming from the healthy side irradiated part of the PTV volume in the surroundings of IMC, covering the upper part of the CW and entire SC volume. The most vertical beams: anterior 4 MV beam – "b5" and posterior – "b6" 15 MV beam enclosed SC, AX and part of the CW. Another oblique anterior 4 MV beam – "b7" boosted parts of the CW and SC. Each beam comprised a few segments, usually from 2 to 6. On average, the total number of segments was 18. Typical segment beams applied in the SPBT technique are shown in Fig. 2. The size of segments was always larger than 2 cm in each direction. The angle of the beams as well as the shape, weight and number of segments were planned individually depending on the anatomy of the patient. The forward IMRT planning was performed with the PrecisePlan treatment planning system [Elekta]. A tool of Precise Plan treatment planning system called "visual DVH" was very helpful in optimization of segment shapes and weights.

Dose distribution constraints for dose uniformity were: at least 95% of the CTV volume should receive dose in the range of 95–107% of the prescribed dose, while the average CTV dose should be in the range of 45.0–45.5 Gy. The average dose in the lung should not exceed 18 Gy and not more than 40% of the lung volume could receive doses above 20 Gy ($V_{20\,Gy} < 40\%$). The maximum dose to the heart should be below 48 Gy. The $V_{40\,Gy}$ and $V_{20\,Gy}$ should be less than 5% and 10% of the heart volume, respectively. The maximum dose absorbed by a spinal cord was set to be 45 Gy. Hot spots in the patient body could not exceed 50 Gy in the volume of 4 cm^3.

In the present paper all the statistics are given for CTV because standard routine for the determination of PTV, which contains bolus or the airspace between bolus and patient, discredits the value of the analysis of the dose for PTV.

Dose volume histograms (DVH) and dose distributions were evaluated for each patient.

The population average values of following matrix were calculated:

1) for the target – mean target dose (MD), percentage of the target volume with doses exceeding 95% and 107% ($V_{107\%}$) of the MD ($V_{95\%}$) and the standard deviation of the dose distribution (SD%) to the target;
2) for the lung on the irradiated side – percentage volume of the lung with doses exceeding 20 Gy ($V_{20\,Gy}$) and the mean dose MD;
3) for the heart – maximum dose (D_{max}), percentage of the heart volume with doses exceeding 5 Gy ($V_{5\,Gy}$), 20 Gy ($V_{20\,Gy}$) and 30 Gy ($V_{30\,Gy}$);
4) for the contralateral breast – maximum dose (D_{max}), percentage volume of breast with doses above 5 Gy ($V_{5\,Gy}$).

To assess the influence of the set-up uncertainty on the dose distribution parameters, computer simulations of isocenter shifts were performed. In simulated plans, the position of the isocenter was moved with respect to the planned one by 2 mm, 3 mm, 5 mm; 5 mm and 2 mm, 5 mm laterally, vertically and cranio-caudally. In the modified plans, the $V_{107\%}$, $V_{95\%}$, SD%, MD for the CTV; $V_{20\,Gy}$, MD for the lung and $V_{40\,Gy}$, MD for the heart were calculated and compared with the values obtained for original plans.

4. Results

Fig. 3 shows the isodose distributions on a several transverse plane for the postmastectomy patient with a left-sided cancer. Dose volume histogram for three selected patients with a left-sided cancer are shown in Fig. 4. The dose distribution is normalized to the prescribed dose (100% = 45 Gy).

The population average values of dose distribution parameters for the target and organs at risk are presented in Table 1 and Table 2, respectively.

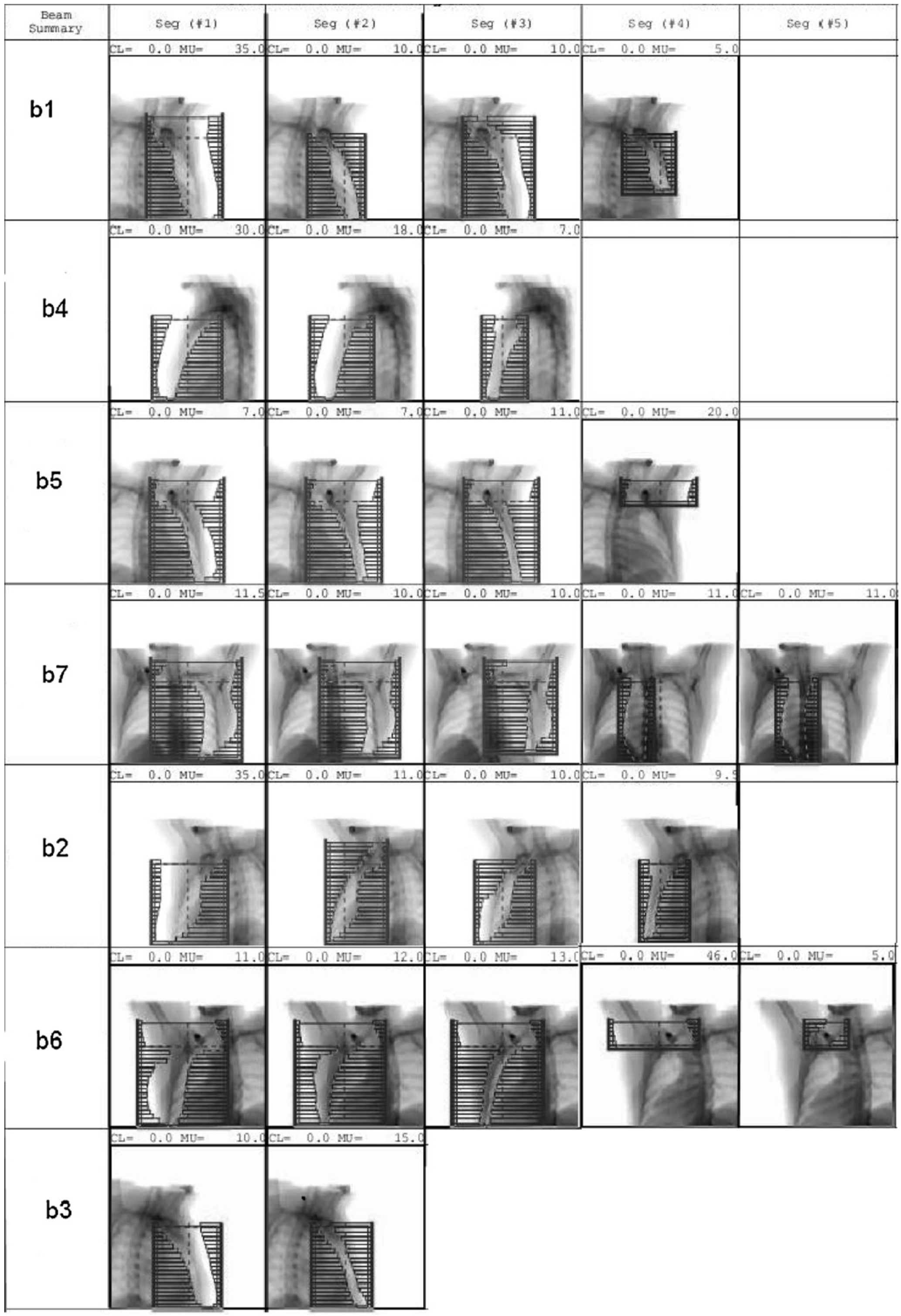

Fig. 2 – Typical segments beams applied in the SPBT technique.

Table 1 – Dosimetric data for CTV for right and left sided postmastectomy patients treated with fIMRT technique. Average values for 70 patients.

	CTV				
	$V_{95\%}$ [%]	$V_{107\%}$ [%]	$V_{95\%}$–$V_{107\%}$ [%]	MD [Gy]	SD
Right	97.6	2.5	95.1	45.5	3.1
Left	96.8	2.3	94.5	45.5	3.2

Table 2 – Dosimetric data for OAR.

	Lung		Heart				Contralateral breast		Spinal cord
	$V_{20\,Gy}$ [%]	MD [Gy]	$V_{5\,Gy}$ [%]	$V_{20\,Gy}$ [%]	$V_{30\,Gy}$ [%]	D_{max} [Gy]	$V_{5\,Gy}$ [%]	D_{max} [Gy]	D_{max} [Gy]
Right	35.4	15.6	5.5	0.2	0	13.85	16.2	34.7	13.7
Left	35.6	15.5	27.6	8.4	1.7	37.37	17.2	36.0	13.4

MD in CTV for 70 patients was 45.5 ± 1%. The percentage of the target volume receiving doses between 95% and 107% of MD was, on average, 95% (range 90–98%) for the CTV. The population average value of the standard deviation of the dose distribution to the CTV was 3.2%.

MD to the lung on the tumor side was on the level of 15.5 Gy (range 12–17 Gy) never exceeding 18 Gy, and the median ipsilateral lung $V_{20\,Gy}$ was 35.5% (range 25–40% for left sided and 27–40% for right sided tumors) and never exceeded 40%.

For left sided tumors, the median heart $V_{30\,Gy}$ and $V_{20\,Gy}$ were 2% (range 0.2–5%) and 8% (range 3–14%), respectively. Maximum dose to the heart was always much smaller than the prescribed dose (about 36 Gy vs. 45 Gy).

The average dose to the thyroid gland estimated for 15 patients treated in 2009 was 35 Gy. The higher dose of about 42.0 Gy was delivered to the ipsilateral lobe and of about 28 Gy to the contralateral lobe.

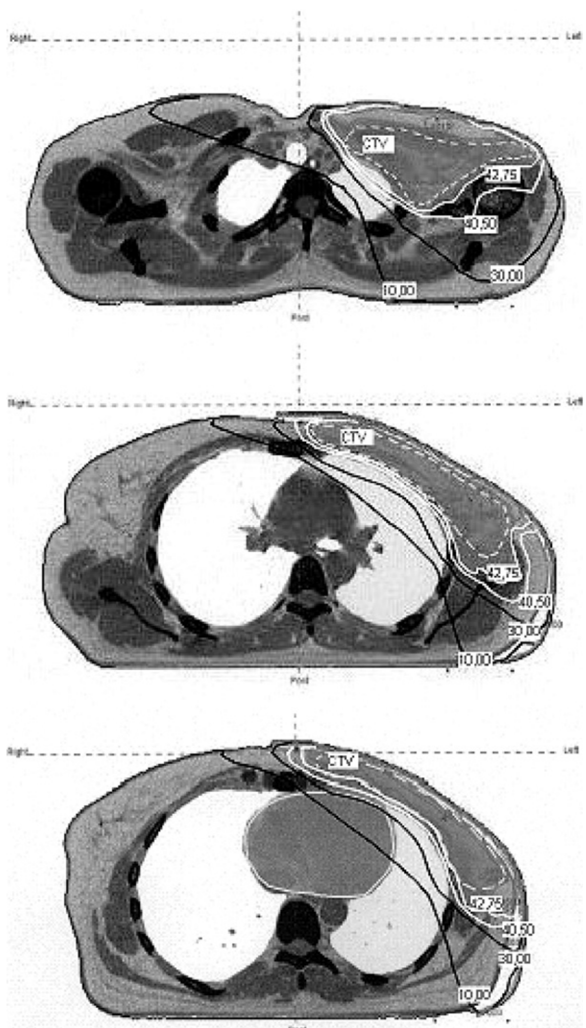

Fig. 3 – Dose distribution for one of the postmastectomy patients treated with segmented beam technique.

Maximum doses to the contralateral breast exceeded 35 Gy for more than 50% of patients. On average, $V_{5\,Gy}$ to the contralateral breast was about 17%.

The average volume of tissues that received dose larger than 20 Gy was 2600 cm^3.

In Table 3, parameters of dose distribution for the targets, lung and heart are presented for reference plan and after simulation of isocenter displacement by 2 mm, 3 mm, 5 mm, by 5 mm and by 2 mm, 5 mm laterally, vertically and longitudinally, respectively.

Only displacements of the isocenter of 5 mm decreased noticeably the volume of the CTV receiving dose in the range of 95–107% of the MD. The mean dose to the lung and heart as well as $V20\%$ for the lung and $V40\%$ for the heart were sensitive to lateral and vertical downward shifts of the isocenter.

5. Discussion

Several studies show a significant improvement in survival in postmastectomy patients who received systematic therapy.[5–7,9,10] No single technique is accepted as a "gold standard." In different radiotherapy departments, different techniques are used. Since 2007, the segmented photon beams technique (SPB technique) is used at our department. The technique has several advantages over many other techniques. The target is treated as a whole, which is not a common policy in almost all other techniques. In many techniques the chest wall and internal mammary nodes are treated with one arrangement of fields and the supraclavicular fossa region with another. This leads to well-known problems of obtaining the homogenous dose distribution at match line of these two regions. In our technique, only a few segments have a common match line, which almost eliminates the match line problem. The homogeneity of dose distribution in the PTV depends on patient's body habitus but in almost all cases the standard deviation of dose distribution is smaller than 4.0%. According to the Nordic Association for Clinical Physics, this satisfies the requirements of a good treatment plan. It is difficult to compare this indices with those obtained with other techniques because they are indicated for the chest wall region only. Pierce in dosimetric comparison of common techniques showed that in the chest wall region the mean value of standard deviation calculated for 20 patients was never smaller than 3.5%. However, the SPB technique does not comply with the ICRU requirements. The minimum dose is smaller than 95% and the maximum dose is larger than 107% of the prescribed dose. On average, 96.3% of the CTV volume received doses within 95–107%. The dose distribution in the PTV is slightly worse but mainly because a part of the PTV can

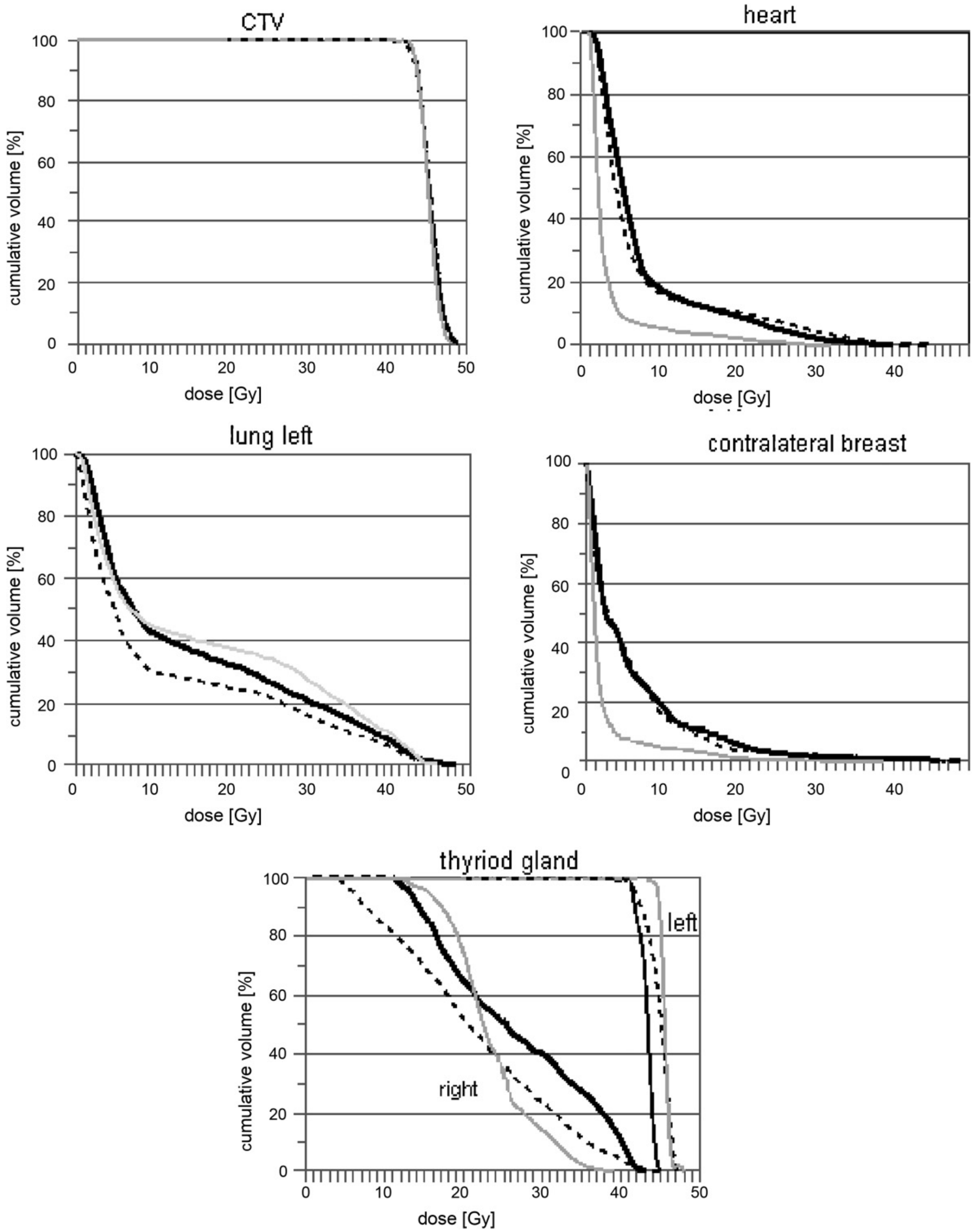

Fig. 4 – Dose volume histograms for three selected patients with the left-sided cancer for CTV and OARs.

be either in the build-up region or in the air between skin and bolus.

The homogeneity of dose distribution is not the most important issue in radiotherapy of postmastectomy patients. In case of patients treated for a left side cancer, the aim of treatment planning is to deliver as low a dose to the heart as possible. In the current study, for patients of this group, *V*5, *V*20 and *V*30 for the heart were 27.6%, 8.4% and 1.7%, respectively. In Pierce study only for partially wide tangent fields were the *V*30% indices smaller than 1.7%. For the SBP technique, a smaller dose to the heart might be obtained but at the price of much worse homogeneity of dose distribution in the PTV. The risk of the postradiation impairment of the heart is essential if life expectancy is long. Impairment of coronary vessels occurs in 5–10%.[20] Therefore, in all clinical cases, the individual decisions concerning the final requirements of dose

Table 3 – Parameters of dose distribution for the targets, lung and heart are presented for reference plan and after simulation of isocenter displacement.

Izocenter shift	CTV					Ipsilateral lung		Heart	
	[mm]	$V_{95\%}$ [%]	$V_{107\%}$ [%]	SD	MD [Gy]	$V_{20\,Gy}$ [%]	MD [Gy]	$V_{40\,Gy}$ [%]	MD [Gy]
Reference	0	96.3	5.4	3.8	45.5	36.4	16.3	19.9	4.1
Laterally outside	5.0	94.7	7.7	3.8	45.53	33.1	14.6	18.1	3.6
	3.0	95.7	6.8	3.6	45.53	34.3	15.2	18.5	3.0
	2.0	96.0	6.2	3.6	45.53	35.2	15.5	19.1	3.9
Laterally Inside	−2.0	96.2	4.9	3.5	45.44	37.9	16.8	20.9	4.3
	−3.0	95.8	4.9	3.5	45.41	38.4	17.1	16.6	3.5
	−5.0	95.1	4.8	3.6	45.33	40.0	17.8	14.1	4.6
SSD	−5.0	94.9	9.5	3.8	45.62	34.0	15.2	18.2	3.6
	5.0	93.8	4.7	3.7	45.22	38.9	17.1	14.2	4.7
Cranially	5.0	95.4	7.2	3.8	45.41	33.9	15.0	19.1	3.8
	2.0	96.3	5.9	3.5	45.55	35.5	15.7	19.5	3.9
Caudally	−2.0	96.0	5.0	3.5	45.42	37.7	16.7	20.4	4.2

distribution should be made. Anterior part of the heart with left anterior descending coronary artery (LAD) are particularity exposed to radiation during postmastectomy irradiation. It should be noted that dose deposited to LAD is higher than for other parts of the heart. For our patients, LAD was not outlined as a separate OAR but we kept maximum doses to heart (LAD) at a level lower than the prescribed dose. For left breast cancer patients, maximum heart doses were always below 36 Gy.

Another important organ at risk in postmastectomy irradiation is the lung. Radiation pneumonitis is a clinical syndrome associated with lung irradiation that typically develops up to 6 months after completion of therapy. One risk factor contributing to the development of pneumonitis is volume of lung irradiated. To evaluate the risk of acute pneumonitis, the mean dose to both the lung and the *V*20 are used. In our series the mean ipsilateral lung *V*20 was 35.4%. This value is much smaller than the one obtained by Pierce for 6 different techniques. The smallest value of the *V*20 obtained by Pierce was larger than 45%. The smallest value was obtained for the standard tangent technique. In the case of the standard tangent technique, the normal tissue complication calculated by Pierce with the Lyman model[2] did not exceed 0.5%. We may expect that for our technique the risk of acute pneumonities is smaller and can be treated as negligible.

For some patients for whom due to habitus dose delivered to the heart and lung is considered too high, a gating or breath holding technique may be applied. According to Korremen et al.[21] significant reduction of dose to the heart and lung can be obtained by applying gating or breath hold at deep inspiration. The volume of heart and lung receiving dose of 50% of the target dose could be decreased by 80% and 30%, respectively.[21] In principle, gating can be applied in combination with SPBT.

According to Stovall et al.,[22] women <40 years of age who received radiation doses of more than 1 Gy to the contralateral breast have an elevated long-term risk of developing a second primary breast cancer. No excess risk of contralateral breast was observed for women >40 years of age with radiotherapy. In our study, the mean dose to the contralateral breast was 2.8 Gy. Therefore, if younger patients are to be treated with other techniques, e.g. the reverse hockey stick technique, may be considered. In our group of patients the average age was 63 years and 4% patients was younger than 40 years. For IMRT techniques, delivering low and moderate doses outside the target is a problem of concern. Dose greater than 20 Gy was delivered to the average of 18% of the tissue volume outside target within the target length. The largest bulk of such tissue was in the neighbourhood of the cranial part of CTV, posterior to the SC nodes. The dose distribution was much more conformal in the chest wall region. Especially, doses to the thyroid gland were quite high for our patients. We decided to reduce dose to the thyroid lobe on the healthy side for next patients. We accomplished this by excluding the SC region from the most horizontal beam coming from the healthy side. The SPB technique has the potential of further slight decrease of doses to some OARs at the cost of target coverage or dose increase in other OARs.

It should be emphasized that the quality of the final plan depends strongly on the habitus, which is common for all techniques, but also on the experience of the planner. For experienced planners, the planning process takes about 3 h. Daily treatment time is about 8 min. The reproducibility of the set-up is checked with two treatment portals: the first segment of the first beam and additional anterior "foto field" covering the entire bow of the chest wall. Portal analysis showed that changes of the isocenter position did not exceed 5 mm in all directions. In our QA procedures, pre-treatment plan verification is performed for each patient using 2D array of detectors. We noticed that doses to segments smaller than 4 cm^2 were overestimated. The decision was made not to use segments smaller than 4 cm^2.

6. Conclusion

The presented technique of irradiation of postmastectomy patients with six segmented, mono-isocentric photon beams complies with requirements for high dose homogeneity within the target volume and satisfactory level of sparing organs at risk. The forward IMRT planning is time consuming and requires planning experience but dose delivery/treatment is fast, easy and well reproducible.

Conflict of interest

None declared.

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