ORIGINAL ARTICLE

The Estimation of Radiation Dose to Out-of-Field Points of Organs at Risk in Block and MLC Shielded Fields in Lung Cancer Radiation Therapy

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Abstract

Purpose: Photon-field shaping in radiation therapy with cerrobend block or Multi-Leaf Collimator (MLC) leads to an increase in the scattered dose to the out-of-field Organ At Risk (OAR). This study aimed to measure and compare the healthy organs absorbed dose outside the cerrobend block and MLC shielded field.

Materials and Methods: Computed Tomography (CT) images were taken of a heterogeneous Thorax phantom while the target volume and organ at risk, including the spinal cord, contralateral lung, and heart were contoured. Conformal Treatment planning was performed (POP fields, total dose 40 Gy, 5 fx/week, and 2 Gy/fx) on the Prowess Panter Treatment Planning System (TPS). Irradiation was performed with 6 and 18 Mv X-ray of Siemens Oncor medical linear accelerator, once for the block-shielded field and again for the MLC-shielded field. At each energy, the radiation dose to the contoured out-of-field organs was measured by an ionization chamber and compared.

Results: At both 6 and 18 MV energies, the out-of-field dose in the MLC-shielded fields was significantly lower than in the block-shielded ones ($P < 0.001$). The out-of-filed dose for contoured organ at risk was not significantly different at 18 MV compared with 6 MV. The dose calculated by the treatment planning system showed that the healthy organs absorbed doses in all conditions were significantly lower than the dosimetry results.

Conclusion: The use of MLC to shield the lung cancer treatment filed reduces the out-of-field OARs dose compared to cerrobend block. This reduction is greater at 18 MV photon beam but this difference is not statistically significant.

Keywords: Out Of Field Organs; Multi Leaf Collimator; Block; Lung Cancer; Radiation Therapy.

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1. Introduction

In 2018, 2.1 million new cases of cancer were reported worldwide, and reports showed that lung cancer is the most widely diagnosed cancer and the leading cause of cancer deaths for both males and females. For these patients, Three-Dimensional Conformal Radiation Therapy (3D-CRT) is a standard treatment approach [1]. For this purpose, it is necessary to know the dose distribution in tumors and organs at risk (OARs) before irradiation, which is now achieved using Treatment Planning Systems (TPSs) [2].

Regarding this, TPS has been developed by companies in such a way that it simulates the treatment fields with various modulating factors such as energy, wedge, angle, etc. before treatment and provides the desired dose distribution in the patient's body [3]. The aim of treatment planning is to optimize the therapeutic efficacy, meaning that the maximum and the minimum doses reach the surrounding healthy tissues and OARs [4]. But there are many reasons that hinder achieving this goal, and this causes the dose to reach the healthy organs around the tumor, which is called the out-of-field dose or the peripheral dose [5-7].

The organs at risk during lung cancer treatment planning are the adjacent lung, heart, and spinal cord [8]. Out-of-field doses delivered to these organs can damage these tissues and cause side effects. Even small radiation doses can damage such organs [9, 10]. Accurate knowledge of out-of-field dose in radiotherapy is essential to assess multiple situations; For example, in the treatment of pregnant patients, the out-of-field dose is very important and there is a risk of damage to the fetus for small doses of 0.05 Gy [9]. More broadly, low doses of radiation therapy may cause late effects such as cataracts, heart disease, stroke, gastrointestinal and respiratory diseases, and secondary cancers [6] and generally reduces the quality of life for patients during and after treatment [11, 12].

Out-of-field dose in radiotherapy generally has three main sources; The first is leakage from the head of the treatment unit, second, leakage from the secondary collimator and beam modifiers such as wedges and blocks, and third, internal scattering that originates from inside of the patient [5]. The first two sources depend on the shape of the treatment unit head and may therefore be affected by changes in the design of the accelerator head or additional beam modifiers that enter the beam path [6, 7].

Beam blocking is an important and widely used technique for adapting treatment and target volume, or more simply, protecting vital organs [12]. Treatment fields are primarily determined by the tumor distribution. Not only the dose received by vital organs should not exceed their tolerance, but the dose received by healthy tissues in general should be minimized [3]. Creating and locating protective blocks is a time-consuming process that may lead to treatment errors. This has led to the development of Multi-Leaf Collimator (MLC) systems [12]. However, scattered radiations from field-shaping blocks as well as MLCs increase the dose to healthy organs, especially outside the treatment field [7, 13]. According to a study by Allahverdi *et al.*, the dose under a block consists of 3 components; First, the transmitted primary dose, which depends on the energy and block thickness, second, the external scattering depends on the field size, geometry of head and proximity of the patient to the blocking tray and third the phantom scatter depends on the shape and size of the unshielded area, energy, depth of point of interest and its proximity to the edge of the unshielded area [14].

A better understanding of the radiotherapy side effects not only requires improved control over high doses delivered to the target volumes, but also a better understanding of lower doses that inadvertently and unavoidably reach outside the target volume [15]. Therefore, the aim of the present study was to measure the radiation dose to out-of-field organs (heart, spinal cord, and contralateral lung) in radiation therapy of lung cancer at 6 and 18 MV energies while the treatment field is shielded with cerrobend blocks and MLCs.

2. Materials and Methods

2.1. Heterogeneous Thorax Phantom

Thorax phantom was used for irradiation (Figure 1). This phantom is elliptical (width 356 mm, height 210 mm, and length 240 mm) and in terms of density and two-dimensional structure, it represents a torso that fits a normal human. The phantom is made of several well-defined electron densities sections that simulate soft tissue, spinal cord, lung, and bone, and contains eight holes to hold the interchangeable rod with the ionization chamber.

Figure 1. Heterogeneous Thorax phantom

2.2. Treatment Planning

At first, CT scan images (Sumatom, Siemens, Germany) were taken of the heterogeneous Thorax phantom (Behyar Sanaat Sepahan, Iran) (Figure 2). CT images were obtained at 130 kVp and 100 mAs with 5mm slice thickness, and then CT dicom images were transferred to TPS (Prowess Panter , Version 2.0, USA). Irradiation was performed with 6 and 18 MV X-ray linear accelerators (Oncor, Siemens, Germany), and for dose calculations, the structures were contoured with isocentric settings. Treatment planning was performed with the parallel-opposed field technique and an isocenter inside the lung. The prescription dose was set at 200 cGy/fx in the isocenter (L-R: 9.00, L-A: -6.00, A-P: 0.00) and the contra-lateral lung, heart, and spinal cord were contoured.

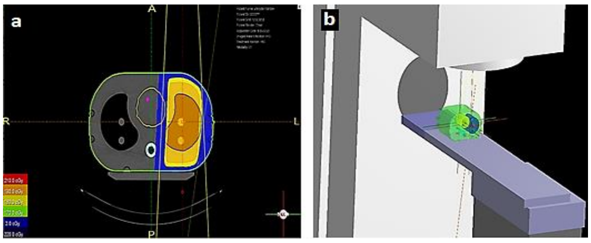

Figure 2. a: View of the Thorax phantom in the Prowess Panter treatment planning system. The center of the contralateral lung, heart, and spinal cord was contoured as out-of-field organs. b: View of the room from the Thorax phantom

2.3. Field Shielding

Field shielding was performed once by MLC (82 leaves with a maximum field size of 40 cm) (Siemens Optifocus MLC, Germany) and again by cerrobend block. The cerrobend block (7.5 cm thickness for 18 MV and 6.5 cm for 6 MV with density equals to 9.4 gr/cm^2) was prepared with a mold shielding that used an auto cutter (PAR Scientific model ACD-4MK4, Denmark). To perform the molding, the required shield area was transferred to the molding system and the required mold was cut using the block cutter system and then the required shield was made using the cerrobend alloy.

2.4. Experimental Measurements

After treatment planning, irradiation of heterogeneous Thorax phantom was performed at two-photon beams energies of 6 and 18 MV, once with block and again with MLC-shielded fields. Each time the absorbed dose of the contoured organs was measured using the FC65 P farmer ionization chamber (IBA Dosimetry GmbH, Schwarzenbruck, Germany). Absolute dose values are obtained according to the TRS-398 protocol (v2006) using correction coefficients (temperature, pressure, etc.) [16].

2.5. Statistical Analysis

All analyses were performed in SPSS software version 24 with a significance level of 5%. A two-sample independent student t-test was used to analyze the obtained values between the two groups.

3. Results

The absorbed dose to out-of-field organs of the contralateral lung, heart, and spinal cord in the lung cancer treatment fields shielded by cerrobend block and MLC at 6 MV photon beam is shown in Table 1. As can be seen, the highest scattered dose of the MLC-shielded field is

Table 1. Absorbed dose to out-of-field organs in the lung cancer treatment fields shielded by cerrobend block and multi-leaf collimator (MLC) at 6 MV photon beam

Out-of-field Organ	Absorbed Dose (Gy/MU)			
	Measurement (MLC)	Measurement (Block)	TPS (Block)	TPS (MLC)
Contralateral Lung	$1.85*10^{-3}$	$4.12*10^{-3}$	0	0
Heart	$0.36*10^{-3}$	$10.58*10^{-3}$	0	0
Spinal cord	$0.58*10^{-3}$	$11.56*10^{-3}$	0	0

related to contralateral lung (18.5 cGy/MU), and the highest scattered dose of the shielded field by cerrobend block is related to the spinal cord (115.6 cGy/MU). The results showed that the absorbed dose of these organs in the block-shielded field is 2.2, 29.3, and 19.3 times higher than in the MLC-shielded field, respectively.

Table 2, illustrates the absorbed dose to out-of-field organs of lung cancer treatment fields at 18 MV photon beam. In the case of out-of-field organs of contralateral lung, heart, and spinal cord, the absorbed dose in the block-shielded field is higher than the MLC-shielded field (2.2, 24.85, and 28.85 fold, respectively). As can be seen, at 18 MV, the highest scattered dose of MLC and block shielded fields were related to the spinal cord and contralateral lung, respectively (19.8 and 98.1 cGy/MU, respectively).

As shown in Tables 1 and 2, the absorbed dose calculated by the treatment planning system is zero in all three organs and in both energies. Figure 3 shows the statistical differences in the absorbed doses of the out-of-field organs of contralateral lung, heart, and spinal cord in the lung cancer treatment fields shielded by cerrobend block and MLC at 6 and 18 MV photon beams.

4. Discussion

Increasing the dose delivered to the tumor to increase its control depends on keeping the dose of radiation-sensitive structures close to the treatment volume to a minimum level. Measuring out-of-field doses before starting a conventional treatment can be useful in the treatment planning process and reduce the side effects of ionizing radiation [17].

In the present study, the radiation dose to the organs of the heart, contralateral lung, and spinal cord was investigated during 3D-CRT of lung cancer malignancies on a heterogeneous Thorax phantom irradiated by 6 and 18 mv photon beams of Oncor linear accelerator. For this purpose, the treatment field was shielded once with MLC and again with cerrobend block.

The use of blocks complicates the treatment. These blocks are heavy, expensive, and time-consuming to prepare. It is also necessary to change their position by changing the fields [18]. The American Association of Physicists in Medicine (AAPM) report 36 states that the use of MLC can greatly reduce the ambient dose by reducing the scattering radiation of primary and

Table 2. Absorbed dose to out-of-field organs in the lung cancer treatment fields shielded by cerrobend block and Multi-Leaf Collimator (MLC) at 18 MV photon beam

Out-of-field Organ	Absorbed Dose (Gy/MU)			
	Measurement (MLC)	Measurement (Block)	TPS (Block)	TPS (MLC)
Contralateral Lung	$1.98*10^{-3}$	$4.40*10^{-3}$	0	0
Heart	$0.35*10^{-3}$	$8.70*10^{-3}$	0	0
Spinal cord	$0.34*10^{-3}$	$9.81*10^{-3}$	0	0

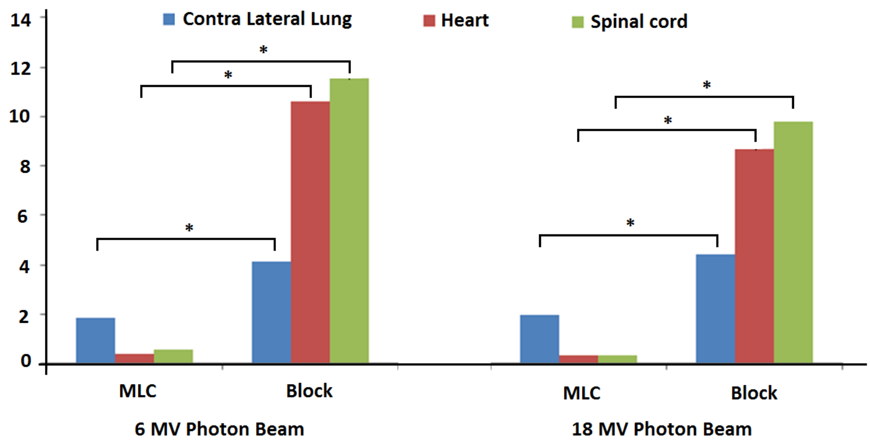

Figure 3. Statistical differences and absorbed doses to out-of-field organs of the lung cancer treatment fields shielded by cerrobend block and Multi-Leaf Collimator (MLC) at 6 and 18 MV photon beams

secondary collimators, passing through the secondary collimator, and leakage from the gantry [19]. Mazuki *et al.* also showed that using lead blocks instead of MLCs in abdominal radiotherapy increases the gonads dose by up to 2 times [20].

In the present study, the results showed that the absorption dose to out-of-field organs was significantly reduced by using MLC instead of cerrobend blocks (p-value < 0.05 for all organs). This may be due to the fact that the block is closer to the patient's body than the MLC, and therefore, more scattered radiation is expected to reach the out-of-field organs [21]. Also, using a tray to place blocks in the beam path may be an additional factor in the generation of scattered radiation compared to MLC [22, 23]. Moreover, Basker *et al.* showed that the primary radiation passage through the MLC was less than the cerrobend block (2% vs. 3.5%, respectively) [2] and this could lead to a higher out-of-field dose when using the blocks.

In lung tumors radiation therapy, due to the presence of vital structures in the chest area, choosing the correct and accurate energy for the treatment of the tumors is important and necessary. In this regard, due to the increased lateral electron transfer in low-density tissues irradiated with high-energy photons (more than 10 MV), the use of low-energy photons is better than high-energy photons [24]. The lack of electron equilibrium also leads to a larger penumbra for high-energy photons [25]. In other words, at higher energies, more energetic secondary electrons are produced, leading to dose loss in the boundary regions [26].

Therefore, low-energy photons (less than 10 MV) are currently used in many lung cancer treatment protocols (such as RTOG 0412 and SWOG S0332), and 6 MV photon beam energy is a good choice for optimal Planning Target Volume (PTV) coverage [24]. White *et al.* showed that in some clinical geometries, energies more than 6 MV reduce the maximum peripheral dose at considerable distances from the treatment field [27]. On the other hand, Kaderka *et al.* showed that higher beam energy due to increased leakage and scattering of the primary beam at the accelerator head leads to increased out-of-field dose [28].

In the present study, with a change in energy from 6 to 18 MV, for both block and MLC shielded fields, the radiation dose to the spinal cord and heart decreased, but the radiation dose to the contralateral lung increased. Although not all of these changes were statistically significant (p-value > 0.05 for all organs), it was observed that increasing the energy decreased out-of-field doses for short distances and increased them over longer distances. These results are consistent with the results of a study by Chaffer *et al.*, who also concluded that the effect of beam energy on the peripheral dose profile of photons due to field shielding is not considerable [29].

Regarding the reason for this, it can be said that with increasing energy, the scattering angle of the photons decreases, and as a result, the probability of scattered dose to distant areas decreases, but in any case, this reduction may be compensated in some cases. For example, by increasing the probability of leakage from the accelerator head at higher energies, it is not possible to observe a significant or definite trend in the comparison between the two energies of 6 and 18 MV.

In any case, this decrease may be compensated in some way by increasing the probability of leakage from the accelerator head at higher energies, and therefore there is no significant and definite trend in comparing the two energies of 6 and 18 MV.

Cozy and Howell showed that while existing treatment planning systems accurately calculate in-field doses, they cannot be used to accurately calculate out-of-field doses [30, 31] and in most cases, these doses are estimated to be more or less than the actual amount. At present, the use of Monte Carlo simulation methods, despite being time-consuming, is the best choice for calculating out-of-field doses [32]. The treatment planning system used in this study showed zero out-of-field dose values for all organs. However, if we accept the possibility of errors in TPS modeling for the calculation of out-of-field doses, this could be a limitation of our study. Also in this study, dose estimation using simulation methods can be useful and allows the dose to be obtained at more points as well as the total organ dose.

5. Conclusion

The results of this study showed that the use of MLC for field shielding significantly reduced the out-of-field dose values compared to when the block was used for field shielding. This dose reduction is at both 6 and 18 Mv photon energies although it is more pronounced at 6 MV. In addition, the out-of-field dose did not show a significant difference between the 6 and 18 MV energies.

Also the treatment planning system is completely unsuccessful in estimating the out-of-field dose.

References

1- Freddie Bray, Jacques Ferlay, Isabelle Soerjomataram, Rebecca L Siegel, Lindsey A Torre, and Ahmedin Jemal, "Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries." *CA: a cancer journal for clinicians,* Vol. 68 (No. 6), pp. 394-424, (2018).

2- Rajamanickam Baskar, Kuo Ann Lee, Richard Yeo, and Kheng-Wei Yeoh, "Cancer and radiation therapy: current advances and future directions." *International journal of medical sciences,* Vol. 9 (No. 3), p. 193, (2012).

3- Edward C Halperin, Carlos A Perez, and Luther W Brady, "Perez and Brady's principles and practice of radiation oncology." (2020).

4- Faiz M Khan and John P Gibbons, Khan's the physics of radiation therapy. *Lippincott Williams & Wilkins*, (2014).

5- Gabriele Kragl *et al.*, "Flattening filter free beams in SBRT and IMRT: dosimetric assessment of peripheral doses." *Zeitschrift für medizinische Physik,* Vol. 21 (No. 2), pp. 91-101, (2011).

6- M Behmadi *et al.*, "Evaluation of breast cancer radiation therapy techniques in outfield organs of Rando phantom with thermoluminescence dosimeter." *Journal of Biomedical Physics & Engineering,* Vol. 9 (No. 2), p. 179, (2019).

7- Robin L Stern, "Peripheral dose from a linear accelerator equipped with multileaf collimation." *Medical physics,* Vol. 26 (No. 4), pp. 559-63, (1999).

8- Tim Lustberg *et al.*, "Clinical evaluation of atlas and deep learning based automatic contouring for lung cancer." *Radiotherapy and Oncology,* Vol. 126 (No. 2), pp. 312-17, (2018).

9- Marilyn Stovall *et al.*, "Fetal dose from radiotherapy with photon beams: report of AAPM Radiation Therapy Committee Task Group No. 36." *Medical physics,* Vol. 22 (No. 1), pp. 63-82, (1995).

10- C Roux, C Horvath, and R Dupuis, "Effects of pre-implantation low-dose radiation on rat embryos." *Health Phys.;(United Kingdom),* Vol. 45 (No. 5), (1983).

11- Sasa Mutic, Jacqueline Esthappan, and Eric E Klein, "Peripheral dose distributions for a linear accelerator equipped with a secondary multileaf collimator and universal wedge." *Journal of applied clinical medical physics,* Vol. 3 (No. 4), pp. 302-09, (2002).

12- A Fogliata, A Clivio, E Vanetti, G Nicolini, MF Belosi, and L Cozzi, "Dosimetric evaluation of photon dose calculation under jaw and MLC shielding." *Medical physics,* Vol. 40 (No. 10), p. 101706, (2013).

13- Ebtesam M Mohamedy, Hassan Fathy, Wafaa M Khalil, Nadia L Helal, and Ehab M Attalla, "Assessment the Photo-neutron Contamination of IMRT and 3D-Conformal Techniques Using Thermo-luminescent Dosimeter (TLD)." *Journal of Pharmaceutical Research International,* pp. 1-10, (2018).

14- MAHMOUD ALLAHVERDI, HOSSEIN KHOSRAVI, H GHARAATI, and HR KHOSRAVI, "DEPTH DOSE UNDER SHIELDING BLOCK: AN EVALUATION AND COMPARISON OF MEASURED & CALCULATED BY TREATMENT PLANNING SYSTEM (PLATO) AND SUGGESTION AN ALGORITHM FOR IT CORRECTION." (2003).

15- Mohamad M Alabdoaburas *et al.*, "Experimental assessment of out-of-field dose components in high energy electron beams used in external beam radiotherapy." *Journal of applied clinical medical physics,* Vol. 16 (No. 6), pp. 435-48, (2015).

16- M Saiful Huq, "Absorbed dose determination in external beam radiotherapy: an international code of practice for dosimetry based on standards of absorbed dose to water." (2006).

17- Paul T Finger, "Radiation therapy for orbital tumors: concepts, current use, and ophthalmic radiation side effects." *Survey of ophthalmology,* Vol. 54 (No. 5), pp. 545-68, (2009).

18- Intensity Modulated Radiation Therapy Collaborative Working Group, "Intensity-modulated radiotherapy: current status and issues of interest." *International Journal of Radiation Oncology* Biology* Physics,* Vol. 51 (No. 4), pp. 880-914, (2001).

19- Sasa Mutic and Eric E Klein, "A reduction in the AAPM TG-36 reported peripheral dose distributions with tertiary multileaf collimation." *International Journal of Radiation Oncology* Biology* Physics,* Vol. 44 (No. 4), pp. 947-53, (1999).

20- Michalis Mazonakis, Fotini Zacharopoulou, Stefanos Kachris, Charalambos Varveris, John Damilakis, and Nicholas Gourtsoyiannis, "Scattered dose to gonads and associated risks from radiotherapy for common pediatric malignancies." *Strahlentherapie und Onkologie,* Vol. 183 (No. 6), pp. 332-37, (2007).

21- Sarah B Scarboro *et al.*, "Effect of organ size and position on out-of-field dose distributions during radiation therapy." *Physics in Medicine & Biology,* Vol. 55 (No. 23), p. 7025, (2010).

22- Stephen F Kry, Susan A Smith, Rita Weathers, and Marilyn Stovall, "Skin dose during radiotherapy: a summary and general estimation technique." *Journal of applied clinical medical physics,* Vol. 13 (No. 3), pp. 20-34, (2012).

23- W Jalbout, R Howell, W Newhauser, F Geara, N Khater, and P Taddei, "Poster—Thur Eve—36: Out-of-Field dose in craniospinal irradiation." *Medical physics,* Vol. 39 (No. 7Part3), pp. 4631-31, (2012).

24- Elisabeth Weiss, Jeffrey V Siebers, and Paul J Keall, "An analysis of 6-MV versus 18-MV photon energy plans for intensity-modulated radiation therapy (IMRT) of lung cancer." *Radiotherapy and oncology,* Vol. 82 (No. 1), pp. 55-62, (2007).

25- James S Welsh, Thomas Rockwell Mackie, and Jeffrey P Limmer, "High-energy photons in IMRT: uncertainties and risks for questionable gain." *Technology in cancer research & treatment,* Vol. 6 (No. 2), pp. 147-49, (2007).

26- Martin J Butson, KN Peter, Tsang Cheung, and Peter Metcalfe, "Radiochromic film for medical radiation dosimetry." *Materials Science and Engineering: R: Reports,* Vol. 41 (No. 3-5), pp. 61-120, (2003).

27- Pamela J White, Robert D Zwicker, and David T Huang, "Comparison of dose homogeneity effects due to electron equilibrium loss in lung for 6 MV and 18 MV photons." *International Journal of Radiation Oncology* Biology* Physics,* Vol. 34 (No. 5), pp. 1141-46, (1996).

28- R Kaderka *et al.*, "Out-of-field dose measurements in a water phantom using different radiotherapy modalities." *Physics in Medicine & Biology,* Vol. 57 (No. 16), p. 5059, (2012).

29- Ndimofor Chofor, Dietrich Harder, Antje Rühmann, Kay C Willborn, Tilo Wiezorek, and Björn Poppe, "Experimental study on photon-beam peripheral doses, their components and some possibilities for their reduction." *Physics in Medicine & Biology,* Vol. 55 (No. 14), p. 4011, (2010).

30- Luca Cozzi, Francesca M Buffa, and Antonella Fogliata, "Dosimetric features of linac head and phantom scattered radiation outside the clinical photon beam: experimental measurements and comparison with treatment planning system calculations." *Radiotherapy and Oncology,* Vol. 58 (No. 2), pp. 193-200, (2001).

31- Rebecca M Howell, Sarah B Scarboro, SF Kry, and Derek Z Yaldo, "Accuracy of out-of-field dose calculations by a commercial treatment planning system." *Physics in Medicine & Biology,* Vol. 55 (No. 23), p. 6999, (2010).

32- Andreas Joosten, Oscar Matzinger, Wendy Jeanneret-Sozzi, François Bochud, and Raphaël Moeckli, "Evaluation of organ-specific peripheral doses after 2-dimensional, 3-dimensional and hybrid intensity modulated radiation therapy for breast cancer based on Monte Carlo and convolution/superposition algorithms: implications for secondary cancer risk assessment." *Radiotherapy and Oncology,* Vol. 106 (No. 1), pp. 33-41, (2013).