Evaluation of Single-Field Electron Beams for Postmastectomy Radiotherapy

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Abstract: *Introduction*: electron beams have been extensively used in postmastectomy radiotherapy due to its homogenous dose at the surface followed by sharp fall-off sparing the underlying tissue. Multiple electron fields or electron photon mix were the techniques commonly used. An old study reported the successful use of single-field electron beams with beam energy of 20 MeV. Yet the potential risks of the organs at risk were not clearly shown.

Objectives: the objectives of this study were to assess the possibility of applying single-field electron beams in postmastectomy radiotherapy in terms of: the dose distribution in the target, the volume of organs that receive a certain threshold dose and the volume of organs that receive low doses of radiation.

Materials and Methods: the Monte Carlo codes of EGSnrc were used to simulate electron beams of different energies and gantry angles. The resulting dose files were used by XSTING to generate dose volume histograms, which were used for evaluation.

Results and Discussions: the target coverage was quite poor in most of the studied scenarios. Improving the target coverage was at the expense of irradiating the lung and heart with unacceptable dose values.

Conclusion and Recommendations: Single field electron beams cannot be used for postmastectomy radiotherapy. Multiple electron fields or photon electron mix are necessary and need to be assessed.

Keywords: Electron irradiation, chest wall, postmastectomy, radiotherapy, Monte Carlo, EGSnrc, DICOM, CT-scans, XSTING, dose-volume histograms.

INTRODUCTION

For over 50 years, electron beam therapy has been an important radiation therapy modality. A single electron beam delivers a uniform ‘plateau’ of dose ranging from 90% to 100%, of maximum central-axis dose with the dose distribution steeply falling off both laterally and distally. This allows superficial cancers and disease to be irradiated with little dose to underlying normal tissues and structures, something usually not possible with x-ray therapy. Due to their deep penetration photon beams are widely used in treatment of deep-seated tumors, which reduces the dose to the skin. Moreover, electron radiotherapy is by far cheaper than the more confined regimes such as proton radiotherapy and intensity modulated radiotherapy.

Breast cancer has recently become a major health problem affecting as many as one in eight women during their lifetime [1]. Mastectomy and postmastectomy radiotherapy are amongst the most important treatment regimes of breast cancer. Irradiation, whether of the postmastectomy chest wall or in the setting of breast conserving surgery or reconstruction, is complex, because of the large, curved target volume and its proximity to heart and lung. Pierce *et al.* intensively studied and compared the different techniques that are commonly used in post mastectomy radiotherapy [2].

The risks and benefits of postmastectomy radiation treatment for breast cancer patients has been one of the most comprehensively studied topics in all of oncology. Multiple studies have indicated that radiation reduces the relative risk of local-regional recurrence by 65%-75%. Unfortunately, the harmful effects of radiation on healthy organs counterbalance this reduction. The lung and the heart are important dose limiting organs for radiation therapy of tumors in the thoracic region. The risks of pulmonary and cardiac toxicities depend on many factors amongst which are the volumes of organ irradiated by a certain threshold dose. The concept of the volume effect is observed when large volumes of organ tissue are irradiate

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resulting in a decline in the functional ability of an organ, where as the tissue sensitivity per unit volume is not affected. The radio-sensitivity of each individual cell in a tissue is not increased if the irradiated volume increases but the overall functionality or clinical tolerance is strongly affected [3].

MATERIALS AND METHODS

Different treatment planning systems are available in radiotherapy centers, the most accurate of which are based on Monte Carlo calculations. Clinical sites which involve tissue inhomogeneities or interfaces between regions of different densities such as the thoracic region are likely to benefit from the accuracy of Monte Carlo calculations. The bench-marked EGSnrc [4] set of codes were used to simulate electron beams of different energies, using the largest applicator size: 20x20 cm^2. The simulated beams were used to irradiate CT data imported using ctcreate, and the three-dimensional dose distribution (3ddose) files were generated.

In an aim to study the dose-volume effects XSTING, home-built software written in Borland C++, utilizing Kitware's Visualization Toolkit (VTK) and running on Windows XP was used. As a research platform XSTING was adapted to work with the DOSXYZ CT data and dose formats. It has the capability of exporting CT data in DICOM format and allows contouring of the different volumes and then superimposes the 3dd dose files produced by DOSXYZnrc to create isodose lines and DVHs. Organs' delineation of the external contour, target, epsilateral and contralateral lung and heart, were performed manually. The 3ddose files for the different energies and gantry angles were imported and DVHS for the organs at risk are computed and used to study:

- The dose distribution in the target
- The volume of organs that receive a certain threshold dose
- The volume of organs that receive low doses of radiation.

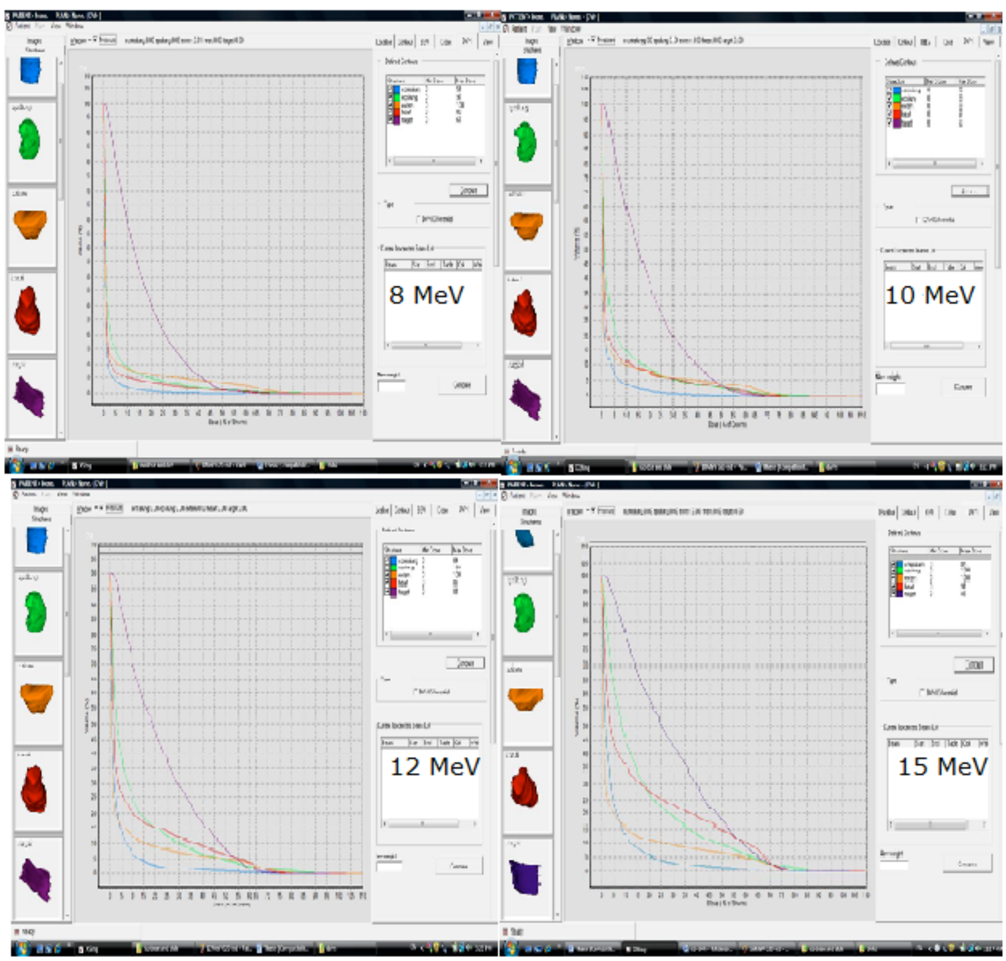

Figure 1: Gantry 20^0: 8 MeV, 10 MeV, 12 MeV and 15 MeV.

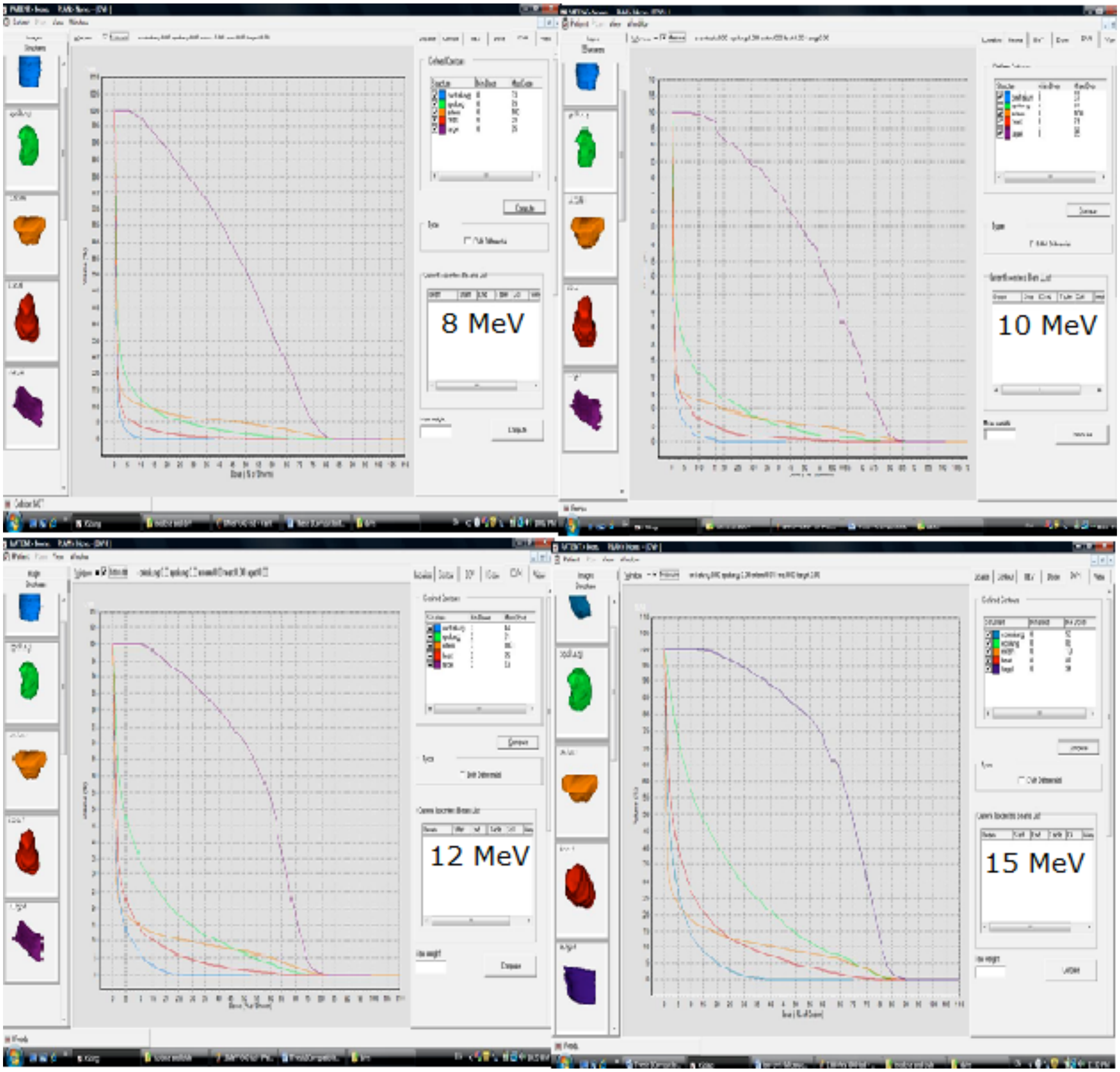

Figure 2: Gantry 40^{0}: 8 MeV, 10 MeV, 12 MeV and 15 MeV.

RESULTS

In the following figures the mean cumulative dose volume histograms are shown for different energies and gantry angles. The horizontal axis represents the percentage of the dose normalized to the maximum dose, while the vertical axis represents the percentage of the volume of the different organs; target, epsilateral lung, heart, contralateral lung and external contour of the patient's body.

DISCUSSION

Electron beams are clinically utilized in the treatment of several malignant conditions including; total skin (replacing Grenz x rays), head and neck (where the proximity of critical organs e.g. the eyes, spinal cord and brainstem, to the majority of the primary lesions and lymph nodes require great care in treatment planning) and the chest wall especially in postmastectomy radiotherapy. In an early work, Zackirson *et al*. (1996) [5] reported successfully using a single electron field or postmastectomy radiotherapy. The energy used was very high, 20 MeV, but a bolus was used to shape the beam and reduce the dose to the organs at risk. Nevertheless accurate means for estimating the risks were not available at that time. This work aims to assess the possibility of applying a single electron field to treat the chest wall during

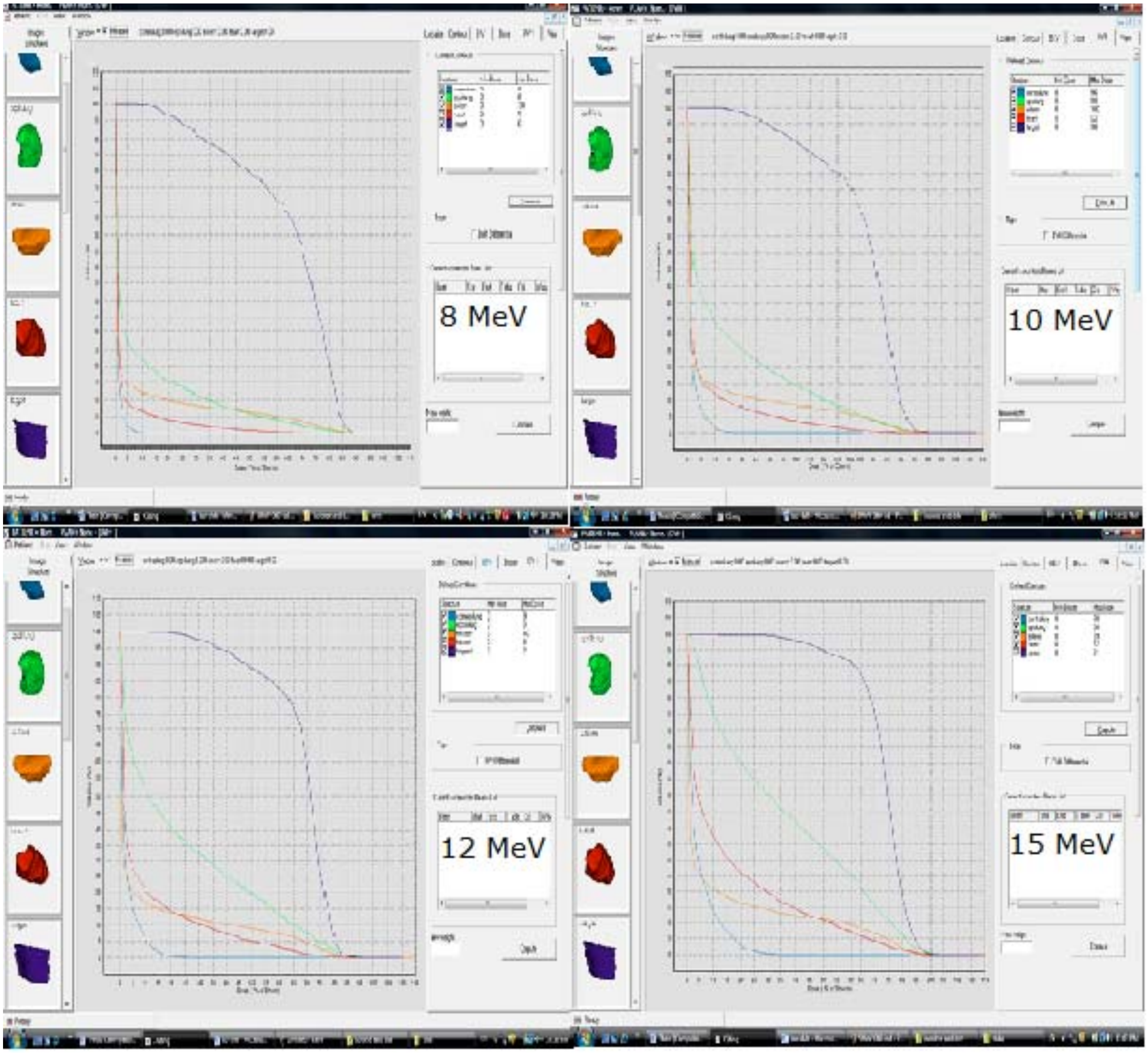

Figure 3: Gantry 60^0: 8 MeV, 10 MeV, 12 MeV and 15 MeV.

postmastectomy radiotherapy in terms of: the dose distribution in the target, the volume of organs that receive a certain threshold dose and the volume of organs that receive low doses of radiation.

The general assessment of irradiation with single-field electron beam can be summarized as follows:

The Target

The target coverage was poor for the low energy electron beams (8 MeV) regardless of the gantry angle. This is because these electron energies are too weak to penetrate to the chest muscles included in the target volume. The situation is somewhat better for Gantry angle 60 degrees. The target coverage is improved with increasing energies and angles as can be seen from the above results.

The Heart

The dose-volume effect at the heart decreases with increasing the gantry angle, although the maximum dose at the heart slightly increases. It is apparent from the results that the heart dose is more influenced by the gantry angle than the energy of the beam.

The Lung

The dose at the epsilateral lung increases with energy and gantry angle. The percentage of the volume that receives above 20 Gy, on a 50Gy treatment basis V20 exceeds 20% only with 12 MeV gantry angle 60 degrees and 15 MeV gantry angles 40, 50 and 60 degrees. But if the whole lung volume, including the contralateral lung is considered, the parameter V20 =20% is not exceeded. The dose at the contralateral lung is very limited regardless of the energy or angle of inclination.

Moreover, it is realized from Figures **1-3** above that the volume of the lung that receives low dose of radiation increases with the energy and decreases with gantry angle for low energy electron beams, but is not affected by the gantry angle for high-energy electron beams. For 15 MeV electrons, almost the entire lung receives low doses. Moreover, the volume of the heart that receives low doses of radiation increases with energy and decreases with gantry angles. Large volumes of organs at risk were associated to long term effects like secondary malignancies. This is still a subject of much debate.

Ischemic heart diseases caused by irradiation of the cardiac chambers and coronary vessels are amongst the major causes of mortality in postmastectomy irradiation. This is specially the case when inclusion of internal mammary nodes that lie in close proximity of the heart is necessary [6, 7].

The probability and severity of radiation induced lung damage on the other hand, depend mainly on the radiation dose, fractionation schedule and the amount of irradiated lung volume. The irradiated lung volume is a deterministic factor because of the structural organization of the functional subunits of the lung. However, the exact tolerance dose of the normal lung tissue is not fully known in humans. An early study showed that dose effect relation for early changes in perfusion and ventilation show an almost linear increase of the reduction in local function as a function of dose. This suggests that early local pulmonary changes can occur at fairly low dose levels with progressive dysfunction for doses up to 50-80 Gy [8, 9]. In recent studies evaluating the dose-volume effect for the lung and heart, a contributing risk factor for the development of pneumonitis was found to be the volume of the lung irradiated [10, 11]. Graham *et al*. [12] showed a lung V20 (volume that received 20 Gy) to be an independent and significant predictor of GRADE2 or greater pneumonitis. The authors suggested that if V20<25% the risk of pneumonitis is low. Moreover, V30 was observed by Gagliardi *et al*. [13] to be the threshold for calculated risks of ischemic heart diseases. V45 was associated with pathologic data that suggest the development of coronary vessels stenosis [7]. It is important to mention that the values displayed above are old but are still used as reference values to estimate the risks to the heart and lung.

Nevertheless, these results are not conclusive. This is because appropriate target coverage was not fulfilled in this study, using a single electron field without an unacceptable dose to the organs at risk. Moreover, the target area is not usually a square field, which is the area irradiated in our different scenarios, with a square applicator. In addition to that, the depth of the different layers within the target is not constant and the anatomy of the target area is not homogeneous. This is especially the case if the internal mammary nodes or the supraclavicular lymph nodes are included in the delineated target. In the real life scenarios, the target area is divided into sections, each of which is considered individually.

CONCLUSIONS AND RECOMMENDATIONS

Postmastectomy radiotherapy cannot be performed with a single electron beam, because regardless of the energy, field size or angle, it is not possible to provide adequate target coverage. Multiple electron, photon or electron/photon mix fields with appropriate field shaping using cut-outs or a bolus with partitioned target area will allow better target coverage and fewer doses to the surrounding health organs. Electron boost to some areas is also common in many cases. Dose-volume assessment based on Monte Carlo calculations need to be carried out to study the different scenarios for optimized postmastectomy radiotherapy.

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