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Original Research Article

Surface doses of flattening filter free beams with volumetric modulated arc therapy dose delivery for breast cancer

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ABSTRACT

Background and purpose: Flattening filter free (FFF) beams enable high-dose rate irradiations and have the potential to speed up breast cancer radiotherapy (RT) treatments. In this work the surface doses of FFF beams were studied with various treatment plans for breast cancer RT. The near surface dose distributions were compared to the ones delivered with conventional flattening filter (FF) beams and to the calculated dose distributions.

Materials and methods: The study was executed with radiochromic films. In addition to one open field, four techniques were investigated: tangential open field, tangential IMRT (IMRT), tangential VMAT (tVMAT) and continuous VMAT (cVMAT) techniques, respectively. The dose distributions were calculated with commercial Monte Carlo (MC) algorithm with energies of 6 and 10 MV with both FF and FFF. The surface areas investigated were divided into depths of 0–2, 2–5 and 5–8 mm.

Results: The largest deviations (on average 5.9%) between the measured and calculated doses were recorded at the most shallowest depths (0–2 mm). At deeper depths, the differences were on average 1.4% and always less than 6%. The measured near surface doses were slightly lower (4.6%) with modulated 6MVFFF beams than with the corresponding flattened beams and on the contrary with 10 MV the surface doses by FFF were slightly higher (2.8%).

Conclusions: The studied MC calculation algorithm was accurate in determine the near surface doses. There was no significant difference in measured or calculated surface doses between FFF and FF beams. With respect to surface dose uniformity the VMAT techniques overall resulted in the most uniform dose distributions.

1. Introduction

Radiotherapy (RT) after breast conserving surgery is associated with significant improvement in local control and is at least equivalent to mastectomy with respect to overall survival [1]. Unfortunately, RT can also cause heart, pulmonary and skin toxicity [2–4]. Traditionally whole breast RT is delivered by using two opposing tangential treatment fields. Recently it has been shown that the use of volumetric modulated arc therapy (VMAT) technique in left-sided breast cancer treatments is able to decrease the high-dose volumes to heart, left anterior descending (LAD) artery and ipsilateral lung compared to traditional tangential or intensity modulated radiotherapy (IMRT) techniques, thus decreasing the probability of radiation induced toxicities [5,6]. The use of deep-inspiration breath hold (DIBH) treatments has been reported to further decrease the dose to the cardiac structures [7]. Furthermore, there is evidence that the use of flattening filter free (FFF) beams can decrease treatment duration which can have clinical significance, especially in the DIBH treatments [8,9]. In addition, the absence of the flattening filter can decrease the out-of-field doses to the patient decreasing the possibility of inducing secondary cancer [10]. However, one of the disadvantages of using FFF beams in breast RT is the higher degree of modulation needed when uniform dose distribution is required, thus requiring more monitor units (MUs) to achieve the uniform dose distribution [8,9]. As a result the percentage of dose coming from leaf transmission and scatter increases highlighting the need of accurate surface dose determination.

In RT the surface doses have to be estimated with high accuracy to avoid underdosing near the surface target volumes and

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simultaneously to avoid radiation related skin reactions. For skin reactions induced by ionizing radiation, such as erythema and fibrosis, the depths between 0.1 and 2 mm have been considered to be most relevant [11,12]. In external beam RT the dose in the near surface areas is accumulated from primary photon beam, scattered radiation from treatment head (including electron contamination) and backscattered radiation from the patient. Further, the surface doses depend heavily on the angle of beam incidence, field size, source-skin distance and beam energy [13]. As a result, accurate calculation of the near surface doses is challenging and larger than 15% deviations have been reported between calculated and measured doses [14,15]. In addition, the FFF energies have different photon energy spectrum and different head-scatter properties than conventional flattened beams.

The use of beam modulation by IMRT or VMAT no longer require having a flat beam for achieving uniform dose distribution in the target volume. On the other hand, the accurate determination of near surface doses of the unflattened beams has been addressed and reported to require further study [20]. Near surface dose (ranging from 0 to 5 mm) measurements of several breast cancer treatment techniques including IMRT have already been performed [15–17]. However, the surface doses delivered by either VMAT techniques or modulated FFF energies for breast cancer treatments have not been studied. The purpose of this study was to investigate the superficial doses of VMAT beams with and without flattening filter (FF) with respect to conventional open field irradiations for breast cancer. In addition, the accuracy of the X-ray Voxel Monte Carlo (XVMC) calculation algorithm to predict the superficial doses for various treatment techniques with FFF and FF beams was investigated.

2. Material and methods

The superficial doses of breast cancer RT treatments were studied with Elekta Infinity (Elekta AB, Stockholm, Sweden) linear accelerator equipped with Agility MLC with flattened and unflattened photon energies of 6 and 10 MV. It should be noted that unlike with Varian Medical System's FFF beams, the corresponding Elekta beams have higher maximum energy to achieve equivalent mean energy to the flattened beams thus resulting in deeper D_{max} depths [10].

2.1. Phantom

The surface dose measurements were performed in a homogeneous cylindrical phantom (CIRS, ø16 cm) which mimics the female breast. A radiochromic film (Gafchromic EBT3; Ashland Inc., Kentucky) was placed tightly inside the phantom on an axial plane without any air gaps as illustrated in Fig. 1. The phantom was imaged with a multislice CT scanner (Toshiba Aquilion LB, Toshiba Medical Systems Co., Tochigi, Japan) with a slice thickness of 1 mm. A planning target volume (PTV) and a critical organ simulating lung were contoured on the axial slices (Fig. 1).

2.2. Treatment planning

The treatment plans were created using the Monaco® treatment planning system (TPS, version 5.00.04, Elekta AB) with a fractional dose of 2 Gy. First, only one open field was used to calculate and measure the near surface doses. Then the surface doses created by four different treatment techniques for breast cancer RT were investigated: 1) tangential open field, 2) a tangential dynamic IMRT (IMRT), 3) tangential VMAT (tVMAT) with two dual arcs of 50° and 4) continuous VMAT (cVMAT) treatment plan with one dual arc of 240°. The field arrangements are presented in Fig. 2.

To avoid overdosing the surface areas due to dose build-up effects, the PTV was retracted from the surface by 5 mm and 7 mm for the optimisation with the energies of 6 and 10 MV, respectively. This is also the clinical practice in our department. Further, the autoflash margin (an extension of the dose outside the body surface) was set to 2 cm in the plan optimisation. The treatment plan isocentres were set 4 cm off axis from the plane of the film to reduce the direct attenuation effect of the film itself. The plans were optimised and the doses were calculated with the XVMC (Elekta AB, Stockholm, Sweden, Monaco®) algorithm to water with a grid size of 1 mm and with a standard deviation of 0.5%. The cut-off energies for photons and electrons were 50 keV and 500 keV, respectively. The treatment plans were normalised to the mean dose of the edited PTV (excluding the surface areas).

2.3. Dose delivery

The phantom was aligned on the treatment table and the final positioning was based on cone beam CT (CBCT) imaging. Each treatment plan was irradiated three times to a separate film to reduce the effect of an individual film response and possible treatment plan delivery repeatability. Thus, a total of 48 irradiations were delivered to 48 films.

2.4. Film dosimetry

Films were scanned with a flatbed scanner (Epson V700, Seiko Epson Corporation, Nagano, Japan) in RGB mode. The films were scanned approximately 20 h after the irradiation with a resolution of 72dpi and a lateral response artefact correction of the scanner was taken into account [18]. The red channel data was used in analysis with OmniPro-I'mRT software (v1.7.0021, IBA Dosimetry, Germany) and the optical densities of the films were converted

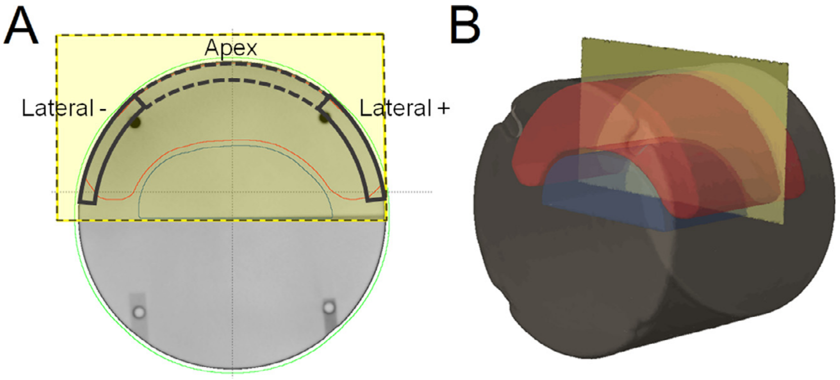

Fig. 1. Axial slice (A) and 3D-image (B) of the cylindrical phantom employed in the study. PTV (red) and critical organ (blue) were contoured on the axial slices of the CT images. The dosimetry film is shown in yellow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)