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Measurements of the relative backscatter contribution to the monitor chamber for modern medical linear accelerators; a multi-center study

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HIGHLIGHTS

- Target charge was measured for determination of backscatter to the monitor chamber.
- Jaw settings had greater impact on backscatter for iX than for the four TB linacs.
- Field size dependence of backscatter was clear for flattened beams on iX and TB.
- No field size dependence of the backscatter on the ES linac or for FFF beams on TB.
- Comparison with MC simulations indicated the target charge method to be reliable.

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ABSTRACT

Conversion to absolute dose in Monte Carlo (MC) simulations of MV radiotherapy beams needs correct modeling of backscatter (BS) to the linear accelerator (linac) monitor chamber. For some linacs the BS depends largely on jaw settings. The backscattered fraction (BSF) of radiation can be determined experimentally by measuring ratios of target charge for a given number of monitor units as a function of jaw settings. This was done using the in-house developed ME40 dosimetry system, which is able to determine the target charge for each radiation pulse from the linac. The BSF measurements were performed for different linac models at five Danish radiotherapy clinics. The investigated linacs were four Varian TrueBeams (TB), one Varian iX (iX) and one Elekta Synergy (ES). BSF measurements were performed for square field side lengths ranging from 1 to 40 cm, using the 10×10 cm^2 field as reference. The impact of the flattening filter on the BSF was investigated through measurements in flattened as well as flattening filter free (FFF) beams. Furthermore, to investigate the contribution from the upper and lower jaws separately, measurements at one of the clinics also included asymmetric fields. For the iX, the obtained BSF measurements were compared with MC simulations performed using the BEAMnrc user code. For flattened beams on the Varian linacs, the measured BSF exhibited a clear linear correlation with square jaw settings (correlation coefficient $r > 0.9$ with $p < 0.001$ in all cases). For the ES, however, no correlation between BSF and jaw settings was found ($r = 0.04$, $p = 0.92$). The change in BSF with jaw settings was also found to be negligible for FFF beams on the TB linacs, indicating that the flattening filter has a substantial influence on the BSF. Furthermore, the backscatter effect was found to be more pronounced (up to a factor of 7) for the iX compared to the TB. MC simulations on the iX agreed within 0.4% with BSF measurements, indicating that the target charge measurement method used for determination of BSF is accurate. Furthermore, the similar BSF observed for the four TB linacs included in the study also indicates that the method used for target charge measurements is reproducible. The reproducibility lies mainly in the fact that the method basically has no set-up errors and therefore is user independent.

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1. Introduction

Delivery of radiotherapy utilizing medical linear accelerators (linacs) is performed by delivering a number of monitor units (MU). A certain number of MU is calibrated to correspond to a certain response in the monitor ionization chamber in the linac head. The charge collected by the monitor chamber originates from interactions with particles moving forward through the chamber and particles being backscattered from downstream linac components. The components contributing to the major part of the backscatter (BS) are in particular the upper jaws and to a lesser extent the lower jaws. It has previously been reported that the BS component from the lower jaws amounts to about 10% of that from the upper jaws (Liu et al., 2000). The change in monitor chamber signal due to variation of the amount of BS with changing field size will result in a too early termination of the irradiation of the patient, if not accounted for (Nilsson and Landberg, 1994). Therefore, the backscattered fraction (BSF) of the charge collected in the monitor chamber as function of field size has to be considered when for example converting to absolute dose in Monte Carlo (MC) simulations (Popescu et al., 2005). In contrast to MC simulations, BS is not handled explicitly in most commercial treatment planning systems. Instead it is simply accounted for as part of the output factors. It has been shown that the BS for a given number of MU increases by about 2%–3% when moving from a 0.5×0.5 cm^2 field to a 40×40 cm^2 field on Varian 2100 accelerators (Duzenli et al., 1993; Liu et al., 1997; Verhaegen et al., 2000; Yu et al., 1996).

For small field sizes the amount of backscattered particles is higher, thus implicating that BS can have a higher impact on the dosimetric precision, for small fields as compared to larger fields. Thus, the need to compensate for BS is especially important when considering small fields. The complexity of dose measurements as well as dose calculations for small fields is also justifying the need for MC techniques for dose calculations in e.g. stereotactic radiotherapy (Taylor et al., 2011). At least for some linac vendors the recent developments of modern linacs (e.g. the Varian TrueBeam (TB) and Elekta Synergy (ES)) includes increased shielding of the monitor chamber, giving an expected decrease in the BSF. This has recently been proven for the TB linac (Zavgorodni et al., 2014). However, linac head geometry is not made available for all modern linear accelerators (e.g. TB linacs), which makes it impossible to explicitly model the backscatter to the monitor chamber. In the cases where the vendors do not provide clinics with the geometry of the linac head, it is therefore highly motivated to perform measurements of the backscatter to the monitor chamber.

Furthermore, the use of flattening filter free (FFF) beams is increasing and when removing the flattening filter, the amount of backscatter might be altered in comparison to the case with a conventional unflattened beam. In the case of FFF beams it is, however, not expected to see any significant difference in the BSF from that of a conventional beam (Titt et al., 2006; Zavgorodni et al., 2014).

Utilizing target charge measurements, the main purpose of this study was to i) investigate the BSF as a function of jaw settings for modern medical linear accelerators currently in use at five Danish radiotherapy clinics, ii) study the impact of removing the flattening filter on BSF and furthermore to iii) investigate the consistency of target charge measurements for determination of BSF. The inter-comparison between clinics is partly based on measurements performed during a comparative dosimetry study in Denmark (to be published soon).

2. Material and methods

2.1. Target charge measurements

As the response of the monitor chamber is affected by both the forward and backscattered particles, an alternative measurand is needed in order to separate the two components. AAPM Task Group 74 presents a review of experimental methods previously utilized for determination of the backscatter to the monitor chamber (Zhu et al., 2009). The methods of digitized target-current-pulse analysis (Suzuki et al., 2013) as well as different versions of the telescopic technique introduced by Kubo have been utilized for estimating the BS to the monitor chamber in the past (Duzenli et al., 1993; Kubo, 1989; Sanz et al., 2007; Yu et al., 1996). Target charge measuring techniques, however, are non-invasive techniques that are considered more reliable than for example pulse counting techniques (Zhu et al., 2009). It is also less cumbersome than the telescopic technique introduced by Kubo (Kubo, 1989) and has a lower uncertainty due to its user independence and the absence of positioning uncertainties. A formalism to calculate the BSF from measurements of the target current, I_{target}, required to keep the linac gun target electrically neutral during irradiation, has previously been presented (Lam et al., 1998) and further developed (Verhaegen et al., 2000). As the BS is field size dependent, I_{target} is not constant over all field sizes. Integration of the target current allow for determination of the collected target charge per pulse. The BSF can therefore simply be obtained by target charge ratios as

$$\mathrm{BSF}(Y,X) = \langle \int I_{\text{target}}(Y,X)\mathrm{d}t\rangle \Big/ \langle \int I_{\text{target}}\left(Y_{\text{ref}},X_{\text{ref}}\right)\mathrm{d}t\rangle, \quad (1)$$

where $\langle \int I_{\text{target}}(Y,X)\mathrm{d}t\rangle$ and $\langle \int I_{\text{target}}(Y_{\text{ref}},X_{\text{ref}})\mathrm{d}t\rangle$ is the average target charge per pulse for a field with jaw openings defined by Y,X and a reference field, respectively.

I_{target} was measured for a range of jaw settings using the in-house developed ME40 Scintillator Dosimetry System (DTU Nutech, Roskilde, Denmark). The system functions by connecting Burr-Brown ACF2101 switched integrator circuits to the I_{target} BNC contact of the linac (Mountford et al., 2008). The incoming signal from the I_{target} BNC goes through a 100 kΩ resistor, resulting in a charge that is built up in a 100 pF capacitor. The charge built up in the capacitor is held, integrated and read out as a voltage before it is reset at the onset of the next synchronization pulse. In this way, a voltage signal proportional to the target charge is acquired for each linac pulse. The target signal over all gun pulses for an irradiation with collimator settings (Y,X) is collected and averaged to yield $\langle \int I_{\text{target}}(Y,X)\mathrm{d}t\rangle$ (Fig. 1). A detailed description of the methodology is given by Beierholm et al. (Beierholm et al., 2011).

Measurements were performed at five Danish radiotherapy clinics (A to E) equipped with modern linear accelerators from multiple manufacturers (Table 1). Target charge was measured over an irradiation of 50 MU (600 MU/min) for square field side lengths ranging from 1 to 40 cm, using the 10×10 cm^2 field as a reference. Measurements were performed for both flattened and unflattened 6 MV beams and unflattened 10 MV beams on four TB linacs as well as for flattened 6 MV beams on one ES linac. Additionally, square field measurements were also carried out for 6 MV and 15 MV beams on an iX (Sjostrom et al., 2009) and a TB (Beierholm et al., 2013). Furthermore, to investigate the contribution from the upper and lower jaws separately, measurements included asymmetric fields, where one jaw opening was fixed at 40 cm while the other jaw opening was varied from 1 cm up to 40 cm, and vice versa. Each measurement was repeated 10 times.