The influence of linac spot size on scatter factors

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Abstract
The use of small photon fields in modern radiotherapy requires the determination of total scatter factors $S_{cp}$ or field factors $\Omega$ with high precision. Therefore, chamber-dependent correction factors for dose measurements in small fields are necessary. In this study Monte Carlo simulations were used to calculate the field factor $\Omega$ and chamber response-related correction factors for four different types of detectors in a clinical 6 MV photon beam for a square field size of 1 cm $\times$ 1 cm. As a beam source a Monte Carlo-based model of a Siemens KD linear accelerator was applied. The calculations aimed at the investigation of the influence of electron beam spot size on correction factors for small field dosimetry. The results confirm that accurate Monte Carlo calculations of the field factor $\Omega$ can only be carried out when the exact electron spot size is known. On the other hand no dependence of the electron beam spot size on the correction factors for the field size of 1 cm $\times$ 1 cm was observed.

1. Introduction

The application of modern techniques in radiotherapy such as IMRT and stereotactic radiosurgery requires the determination of total scatter factors $S_{cp}$ in small photon fields with high precision [1–3]. The accuracy in experimental determination of $S_{cp}$ is limited due to non-negligible detector volumes and response variations of the detectors used in small photon fields. Therefore, correction factors for dose measurements in small fields are necessary. Beyond this background Alfonso et al. [4] proposed a new formalism for small and non-standard field dosimetry, introducing new chamber-dependent correction factors, which may be determined by Monte Carlo simulations only.

Following this formalism, the field factor $\Omega$ and correction factors $k$ were calculated within this study for four different types of detectors in a clinical 6 MV photon beam for a field size of 1 cm $\times$ 1 cm. As a beam source a Monte Carlo-based model of a Siemens KD linear accelerator was applied. Calculating the correction factors, special attention was paid to the influence of the accelerators’ electron beam spot size on these new dosimetric quantities.

2. Material and methods

2.1. Background theory

According to Alfonso et al. [4], the absorbed dose to water $D_{w,Q_{clin}}^{f_{clin}}$ at a reference point in a water phantom for a clinical field $f_{clin}$ of beam quality $Q_{clin}$ is given by

$$D_{w,Q_{clin}}^{f_{clin}} = D_{w,Q_{msr}}^{f_{msr}} \cdot \Omega_{Q_{clin}}^{f_{msr}}$$

(1)

where $f_{msr}$ is the machine-specific reference field and $Q_{msr}$ the corresponding beam quality. The field factor $\Omega_{Q_{clin}}^{f_{msr}}$ converts the dose to water in the reference field into the dose to water in the clinical field. This dose ratio is usually not directly measurable but may be calculated by Monte Carlo simulations. If the field factor should be determined experimentally an additionally correction factor $k_{Q_{msr}}$ has to be applied, which corrects for the different detector response in different field sizes, for example due to the detector’s volume effect:

$$\Omega_{Q_{clin}}^{f_{msr}} = M_{Q_{clin}}^{f_{msr}} \cdot k_{Q_{msr}}^{f_{msr}}.$$

(2)
In equation (2) \( M \) denotes the dosimeter reading. In the case of ionization chambers the correction factor \( k_{\text{f,mon}}^{\text{f,mon}} \) can further be traced back to the ratio of stopping power ratios \( s_{\text{w,a}} \) and perturbation corrections \( p \):

\[
k_{\text{f,mon}}^{\text{f,mon}} = \frac{(s_{\text{w,a}})_{\text{f,mon}}}{(s_{\text{w,a}})_{\text{mon}}} \cdot \frac{(p)_{\text{f,mon}}}{(p)_{\text{mon}}}. \tag{3}
\]

As can be seen from equations (2) and (3), the field factor \( \Omega_{\text{f,mon}}^{\text{f,mon}} \) corresponds to the total scatter factor \( S_{\text{f}} \) as defined for example in the IPEM report on small photon field dosimetry [5]. Applying Monte Carlo simulations, the correction factor \( k_{\text{f,mon}}^{\text{f,mon}} \) may be calculated as follows:

\[
k_{\text{f,mon}}^{\text{f,mon}} = \frac{D_{\text{f,mon}}^{\text{f,mon}} / D_{\text{mon}}^{\text{f,mon}}}{D_{\text{f,mon}}^{\text{det}} / D_{\text{mon}}^{\text{det}}}. \tag{4}
\]

In equation (4) \( D_{\text{det}} \) is the dose within the active volume of the detector which is proportional to the energy deposition within the active volume, hence proportional to the generated charge or the chamber reading \( M \).

2.2. Monte Carlo calculations

All Monte Carlo simulations were performed with the EGSnrc code system [6]. The particle transport within the linear accelerator (Siemens KD2, 6 MV-X) was simulated with the user code BEAMnrc [7]. For these simulations a transport and particle production threshold energy of \( \text{ECUT} = \text{AE} = 700 \text{keV} \) for electrons and \( \text{PCUT} = \text{AP} = 10 \text{keV} \) for photons was used. The variance reduction method of directional bremsstrahlung splitting (DBS) with a splitting number of 3000 was applied, which was selected for best simulation efficiency. As recommended by Kawrakow et al [8], a splitting field radius of 10 cm at a distance of 100 cm from the source was chosen for the 10 cm \( \times \) 10 cm reference field. For the field size 1 cm \( \times \) 1 cm the splitting field radius was reduced to 1 cm. The accelerator was modelled according to the information given by the manufacturer. The commissioning of the linac model is described in [9].

Phase space files (PHSP) were generated with BEAMnrc for the accelerator for the field sizes 10 cm \( \times \) 10 cm and 1 cm \( \times \) 1 cm for different electron beam spot sizes varying from 1.4 mm to 2.6 mm. The PHSP files were also used as a particle source in the user code egs_chamber [10]. Within the egs_chamber code the threshold/cut-off energies for the particle transport have been \( \text{ECUT} = \text{AE} = 521 \text{keV} \) and \( \text{PCUT} = \text{AP} = 10 \text{keV} \).

Four different types of detectors (see table 1) were modelled in detail according to the information given by the manufacturer (PTW-Freiburg) using the egs++ geometry package [11].

<table>
<thead>
<tr>
<th>Type</th>
<th>Sensitive volume</th>
<th>Type</th>
<th>Sensitive volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionization chambers</td>
<td></td>
<td>Diodes</td>
<td></td>
</tr>
<tr>
<td>PTW31010</td>
<td>125 mm³</td>
<td>PTW60016</td>
<td>0.03 mm³</td>
</tr>
<tr>
<td>PTW31016</td>
<td>16 mm³</td>
<td>PTW60017</td>
<td>0.03 mm³</td>
</tr>
<tr>
<td>PinPoint</td>
<td>0.03 mm³</td>
<td>Unshielded diode P</td>
<td>0.03 mm³</td>
</tr>
</tbody>
</table>

In preliminary Monte Carlo calculations the backscatter from the accelerator head into the monitor chamber was investigated for both field sizes. The results showed that the dose variation within the monitor chamber as a function of field size is below 0.1%. Therefore, the effect of backscattering was neglected for all field size-dependent Monte Carlo calculations within this study. This is in accordance with results recently published by Francescon et al [12] for two different types of linear accelerators.

3. Results

The calculated ratio of the detector readings for the different detectors as a function of the spot size of the primary electrons hitting the accelerator’s target is given in figure 1. As can
be seen, this ratio strongly depends on the volume of the detector as well as on the electron spot size of the accelerator. The comparison of the calculated and measured ratios can be used for the determination of the true spot size [3]. The figure also contains the calculated field factor \( k_{\Omega_{\text{clin}},Q_{\text{msr}}}^{1\times1,10^{10}} \), i.e. the ratio of the dose to water for different spot sizes. This ratio is free from all detector perturbations. Due to its large volume, the PTW 31010 chamber strongly underestimates the dose within the 1 cm × 1 cm field, i.e. the correction factor \( k_{Q_{\text{clin}},Q_{\text{msr}}}^{10^{10},10^{10}} \) is largest. The deviation for the PinPoint chamber is much smaller because of the smaller chamber volume. As is to be expected, the deviations are smallest for the diodes. Comparing both diodes, the unshielded one shows slightly smaller perturbations and should be the ideal detector for small field dosimetry measurements as already reported by Eklund and Ahnesjö [13].

The ratio of the detector readings \( M_{Q_{\text{clin}}}^{1\times1}/M_{Q_{\text{msr}}}^{10^{10},10^{10}} \) for the diodes is somewhat larger than the field factor \( \Omega \), i.e. the detector response increases with decreasing field size. This is due to the changes in photon and electron fluence; further investigations are necessary for clarification.

The relative dependence of the ratio \( M_{Q_{\text{clin}}}^{Q_{\text{msr}}}/M_{Q_{\text{msr}}}^{\Omega} \) on electron spot size is the same for all detectors and equals the spot size dependence of the field factor \( \Omega \). This dependence is due to the source occlusion effect [14]. According to this, the correction factors \( k_{Q_{\text{clin}},Q_{\text{msr}}}^{1\times1,10^{10}} \) for the different detectors are independent of beam spot size within 1% for the ionization chambers and 0.5% for the diodes (see figure 2). Similar results for different accelerators have recently been published by Francescon et al [12]. However, it has to be remarked that these authors further studied field sizes down to 0.5 cm × 0.5 cm and demonstrated a clear dependence of the correction factor \( k \) on beam spot size for field sizes below 1 cm × 1 cm. However, it has to be kept in mind that the calculation of \( k \) without any bias at these field sizes is questionable since the finite water volume itself might show a volume effect [15].

4. Conclusion

For small field dosimetry the field factor \( \Omega \) and the correction factor \( k_{Q_{\text{clin}},Q_{\text{msr}}}^{Q_{\text{msr}}} \) according to the formalism of Alfonso et al were calculated as a function of the primary electron beam spot size of the linear accelerator. Both dosimetric quantities were calculated for different detectors in a 6 MV photon field sized 1 cm × 1 cm of a Siemens KD linear accelerator using the EGSnrc Monte Carlo code. The resulting correction factors \( k_{Q_{\text{clin}},Q_{\text{msr}}}^{Q_{\text{msr}}} \) vary by as much as 20% between different detectors, but for the chosen field size they are independent of the spot size of the primary electrons hitting the target. This is an important fact when Monte Carlo calculated values will eventually be used for clinical measurements, where the exact spot sizes of the linear accelerator used are usually unknown. For the unshielded diode the correction factor is close to unity (\( k_{Q_{\text{clin}},Q_{\text{msr}}}^{1\times1,10^{10}} = 0.98 \)). Further investigations are necessary to calculate the correction factor \( k_{Q_{\text{clin}},Q_{\text{msr}}}^{Q_{\text{msr}}} \) for the full range of clinical field sizes.

References

[12] Francescon P, Cora S and Satarianno N 2011 Calculation of \( k_{Q_{\text{clin}},Q_{\text{msr}}}^{1\times1,10^{10}} \) for several small detectors and for two linear accelerators using Monte Carlo simulations Med. Phys. 38 6513–27
