A multi-centre analytical study of small field output factor calculations in radiotherapy

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ABSTRACT

An audit methodology was developed and applied for output factor (OF) calculations in radiotherapy. The auditees were asked to calculate OFs for field sizes from 10 × 10 cm² to 2 × 2 cm². Sixty five beams were audited; missing reference OFs were interpolated. The calculated OFs were in 73% of cases higher than the reference data. The smaller the field size, the higher the overestimations which were observed in the higher fraction of cases. Treatment planning systems generally overestimated OFs for small fields. The reference dataset helped radiotherapy centres to identify discrepancies which were higher than typical.

1. Introduction

Appropriate calculation of output factors for small fields shaped by a multileaf collimator (MLC), performed in treatment planning systems (TPS), is essential for intensity-modulated radiation therapy (IMRT). Therefore, proper configuration of beam data and precise modelling of the MLC in the treatment planning system (TPS) are key factors that have to be verified prior to clinical use. Dosimetry for fields smaller than 3 × 3 cm² is very difficult and has a high degree of uncertainty. This is caused both by the relatively large penumbra size, as well as by the changes in the energy spectrum [1–5]. The significant role of external dosimetry audits [6–8], including small field tests, in radiation therapy clinical trials, is often evoked [9]. Methodologies of audits of small field output performance were formerly proposed [8,10,11]. The Radiological Physics Center (RPC) at the MD Anderson Cancer Center (presently IROC-Houston QA Center) has prepared a set of data containing output factors depending on nominal beam energy, field sizes and accelerator models [12–14]. However, the published data do not cover all beam energies from the mega-voltage range used in photon-based radiotherapy. The RPC dataset and the interpolation functions proposed in this work were used to carry out a nationwide audit of small field OF calculations.

2. Material and methods

Participants were asked to calculate the output factors for beams formed by the multi-leaf collimator (MLC), using their planning software. The results of their calculations were compared with the reference published data. All 35 Polish radiotherapy departments were invited to take part in the study, and 32 of them responded and provided their results. The TPS calculations for medical accelerators of three vendors were evaluated: Elekta, Siemens and Varian, further denoted throughout the text as type A, B and C. In total, 65 beams were audited: 20 of type A, 15 of type B and 30 of type C accelerators. In seven centres the calculations were repeated for the same beams with two or three different TPSs or with alternative calculation algorithms. In total, 76 beam&TPS combinations were evaluated. Most of the results (90%) were obtained for beams with a nominal energy of either 6 MV (62%) or 15 MV (28%) (see Supplementary Tables S1–S3). The most commonly used beam energies (excluding FFF) for each of the vendors were used in the calculations. The participants had to calculate the number of monitor units (MU) for the delivery a dose of 10 Gy to water with five square, MLC-shaped fields (10 × 10 cm², 6 × 6 cm², 4 × 4 cm², 3 × 3 cm² and 2 × 2 cm²), to a reference point at a depth of 10 cm on the central axis at a source-to-photon distance (SPD) of 100 cm. The dose rates \( DR(f,E) \) [Gy/MU] were calculated for a specific field size \( f \) [cm²] and beam energy \( E \) [MV], and then divided by the \( DR(10\times10,E) \) calculated for a field size of 10 × 10 cm² and for the same beam energy, thus providing a normalized output factor \( OF(f,E) \) (see Eq. (1)).

\[
OF(f,E) = \frac{DR(f,E)}{DR(10\times10,E)}
\]

The discrepancies between the reference RPC data and the institution OF were analysed and compared with the criteria of acceptability provided by other authors [15,16]. Thus, when the 3% level of disagreement was exceeded, the authors expected institutions to consider
this as problematic. The values of the OFs for beam energies $E [\text{MV}]$, not present in the RPC data set, have been interpolated with a second degree polynomial (see Eq. (2))

$$\text{OF}_{SSR} = a(f) \cdot E^2 + b(f) \cdot E + c(f)$$  \hspace{1cm} (2)

using the non-linear least-squares (NLLS) Marquardt-Levenberg algorithm [17–19]. Interpolated values of the reference OFs had to be used in 18% of cases. The clinically used TPSs and related calculation algorithms were examined (see Table 1).

The audit results for individual participants were grouped for accelerator types A, B and C.

### 3. Results

The $a(f)$, $b(f)$ and $c(f)$ parameters of the Eq. (2) were obtained in the procedure of fitting to the experimental data (see Supplementary Table S4 and Supplementary Figs. S1–S3). In any case of fitting, the final sum of the square residuals (WSSR) was not larger than $2.6 \times 10^{-4}$. The OFs calculated with TPSs were in 73% of cases higher than the published reference data. The smaller the field size, the higher the over-estimations which were observed. Overestimations of OFs were observed in 69% calculations for $6 \times 6 \text{ cm}^2$ fields, in 70% for $4 \times 4 \text{ cm}^2$, in 75% for $3 \times 3 \text{ cm}^2$, and in 77% for $2 \times 2 \text{ cm}^2$ fields. The mean values ($\pm \sigma$) of the fraction of OFs calculated with TPS to the reference data were: $1.001 (\pm 0.007)$ for $6 \times 6 \text{ cm}^2$, $1.004 (\pm 0.010)$ for $4 \times 4 \text{ cm}^2$, $1.008 (\pm 0.012)$ for $4 \times 4 \text{ cm}^2$, and $1.014 (\pm 0.024)$ for $2 \times 2 \text{ cm}^2$ fields (see Supplementary Figs. S4–S7). For smaller field sizes, wider distributions and higher modal values of ratios of the institution OF to the reference OF were observed (see Fig. 1). The ratios of the audited institution mean OFs to the corresponding values reported by RPC, in our opinion, there is no need to repeat the measurements in future routine clinical audit programmes unless unresolved high discrepancies are observed by the auditee.

The simple interpolation formula presented by the authors of this work needs further validation through carrying out and juxtaposing additional measurements and by means of Monte Carlo simulations. Similar work has been performed for electron and photon beams [21–23]. Reports presenting the ratios of the OF to the reference values calculated in institutions were sent back to the participants. Recalculated OFs showing improved results for five beams were obtained from four centres. In the first center (A/MO), the auditee performed new measurements and changed the beam modelling in the most advanced TPS used in the institution. In the second institution (C/EC), the PB calculation algorithm was replaced with an AA one. In the third institution (A/PC), the second alternative “small” beam model was created for the same beam, which was optimized and used only for field sizes from $1.5 \times 1.5 \text{ cm}^2$ up to $10 \times 10 \text{ cm}^2$. In the fourth institution, misunderstanding of the geometrical set-up from the audit instruction was reported. In one institution (B/PR), the OF factor value for field size $2 \times 2 \text{ cm}^2$ was set in TPS, as the same as for the $3 \times 3 \text{ cm}^2$ field. The institution did not change the TPS configuration, because $2 \times 2 \text{ cm}^2$ fields were not clinically used there. The results presented here include the corrected values of the OFs. It seems that there is a correlation between the results of the OF calculations and the type of the TPS calculation algorithm. For type B accelerators and ON/PB TPS, all results for the $2 \times 2 \text{ cm}^2$ field differ more than 5% from the reference data. For type C accelerators, upgrading TPS from EC/PB to EC/
AA decreased the difference for the $2 \times 2 \text{cm}^2$ field from 8.5% to 2.2%, relative to the reference data. The authors believe that the reference dataset is an easily available data source which can help users of linacs equipped with MLCs to detect potential problems in IMRT delivery. The audit aims were to verify the quality of the TPS calculations in the case of IMRT-style small fields, using the postal method, and to popularize the method of TPS QA, which does not require time-consuming and difficult measurements. In general, Eq. (2) can probably be used also for FFF beams, but the coefficients presented in the Supplementary Table S4 are valid only for filtered beams.

The set of measured small field output factors provided by the RPC, together with the parameters of the analytical functions published here, is a very good tool for TPS QA. Follow-up actions have been performed in the four audited centres with issues, yielding improved results. This audit already has had substantial impact for clinical practice but more reference data sets, which are anticipated for small field OFs for FFF beams, could also be used in a future audit of this type.

**Conflict of Interest**

Krzysztof Chełmiński and Wojciech Bulski have no conflict of interest to declare.

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**Appendix A. Supplementary data**

Supplementary data associated with this article can be found, in the online version, at [http://dx.doi.org/10.1016/j.phro.2018.03.001](http://dx.doi.org/10.1016/j.phro.2018.03.001).
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