Automatic determination of primary electron beam parameters in Monte Carlo simulation

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(Received 14 September 2006; revised 4 January 2007; accepted for publication 12 January 2007; published 26 February 2007)

In order to obtain realistic and reliable Monte Carlo simulations of medical linac photon beams, an accurate determination of the parameters that define the primary electron beam that hits the target is a fundamental step. In this work we propose a new methodology to commission photon beams in Monte Carlo simulations that ensures the reproducibility of a wide range of clinically useful fields. For such purpose accelerated Monte Carlo simulations of 2×2, 10×10, and 20×20 cm^2 fields at SSD=100 cm are carried out for several combinations of the primary electron beam mean energy and radial FWHM. Then, by performing a simultaneous comparison with the correspondent measurements for these same fields, the best combination is selected. This methodology has been employed to determine the characteristics of the primary electron beams that best reproduce a Siemens PRIMUS and a Varian 2100 CD machine in the Monte Carlo simulations. Excellent agreements were obtained between simulations and measurements for a wide range of field sizes. Because precalculated profiles are stored in databases, the whole commissioning process can be fully automated, avoiding manual fine-tunings. These databases can also be used to characterize any accelerators of the same model from different sites. [DOI: 10.1118/1.2514155]

Key words: Monte Carlo, linac simulation, FWHM determination

I. INTRODUCTION

The Monte Carlo method has been thoroughly applied to many tasks in the medical physics field because of its proven capability of predicting the dose deposition in conditions where other algorithms fail. Among the most popular applications are treatment planning and verification and ionization chamber simulation.[1] Nevertheless, the accuracy of a Monte Carlo simulation relies heavily on an appropriate selection of the parameters that define the radiation source.

The process of commissioning a medical linac in the simulations starts by getting the geometry and composition of a generic accelerator (head and collimators) of the model to be simulated, preferably from its manufacturer. Only in very few occasions the user may be provided with very detailed knowledge of the actual geometry of its accelerator. It has been shown[2] that small changes in the geometry and its composition alter the simulation results. The commissioning process should then be able to deal with this problem and still provide a description of the radiation source that leads to an accurate linac reproduction of those fields according to the user interests.

For a photon beam produced by a medical linac the primary radiation source is the electron beam that impinges on the target. Its actual shape and spectra are rarely known and, except for very specific measurements conducted, impossible to be determined experimentally. As a first approximation, it is modeled in the simulations by a source with Gaussian spatial distribution and with monoenergetic spectra (except in those cases where the manufacturer provides information on the actual shape of the spectra). This turns out to be a problem of modeling a complicated, rather unknown, radiation source by means of two degrees of freedom, namely, the mean electron energy and the radial distribution σ (or FWHM). In the work from Jaffray *et al.*[3] the shape of the primary electron beam of certain linacs was determined. Despite a Gaussian with different FWHMs for the *X* and *Y* axis, it is a good initial approximation; the actual shape can be more irregular. This difference can lead to discrepancies between simulations and measurements when small fields are involved, but in general they will be rather small.

The objective of the present article is to propose a new method to standardize the process of commissioning a photon beam produced by a medical linac in Monte Carlo simulations in those cases where a generic machine geometry and composition are employed. The advantage of this last assumption is that the profiles employed in the commissioning can be stored and later employed to characterize machines from other sites. The process can then be automated, avoiding the need of an expert user controlling the process.

Traditionally, the commissioning procedure is conducted by comparing a small set of measurements to their correspondent simulations, usually employing a single field size [generally 10 cm, 20 cm,[4] or 40 cm (Ref. 5) side square fields]. This method of commissioning is acceptable provided the exact geometry and composition of the linac are well known and the primary radiation source is well characterized.[6] However, this may not be the best approach when a generic linac description is employed because of several known limitations of this procedure, namely the following.

- Depth dose curves have been proven to be quite insensitive to changes in the primary electron beam mean energy.[7] Lateral profiles of wide fields are more sensitive to this parameter, but they depend at the same time on the chosen beam radius.
- By employing very wide fields (i.e., 40×40 cm^2) the photon fluence can be accurately matched, avoiding collimator scatter contributions. However, the reproducibility of small fields cannot be assured with this procedure (see Sec. III B).
- The measurement uncertainty and the simulation noise (a combination of the statistical uncertainty and the effects of the latent variance[8]) may favor an incorrect energy/radius combination when very few profiles are employed in the commissioning procedure (see Sec. III B).

To overcome all these drawbacks we have developed a new automated Monte Carlo (MC) commissioning scheme that considers a generic linac geometry. By employing an accelerated MC simulation method, depth doses and lateral profiles of square 2, 10, and 20 cm side fields are calculated for different primary electron beam energy/FWHM combinations and later stored in a database. Among this pool of possible primary beam configurations the best one is selected by constructing a figure of merit that considers simultaneously all measured depth doses and lateral profiles from these three field sizes.

Previous works have employed the 10×10 and 20×20 cm^2 fields for beam characterization (although not simultaneously). The inclusion of the 2×2 cm^2 field in the process assures the reproducibility of small fields, which is of special importance in intensity modulated (IMRT) or radiosurgery treatments. In such cases the size of the primary radiation beam affects both the shape of the radiation field and, more noticeably, its output factor. As it will be discussed in Sec. III A, employing the 2×2 cm^2 field in the commissioning leads to a reduction in the uncertainty of the FWHM.

Following this approach (described in Secs. II A and II B) we have determined the E/FWHM combinations that best reproduce the Deutsches Krebsforschungszentrum (DKFZ) Siemens PRIMUS and the Hospital Universitario Central de Asturias (HUCA) Varian 2100 CD (Sec. III B). Several considerations on the robustness of this method and its associated uncertainty are also discussed in Sec. II C. The profile database generated in this work will also serve in the eIMRT project[9] to characterize other medical accelerators of the same type.

TABLE I. Energies and FWHMs simulated (every FWHMs for each energy) to construct the datasets.

Accelerator	Mean energies (MeV)	Energy FWHM (%)	Radial FWHMs (mm)
Siemens PRIMUS	5.5,5.75,6.0, 6.25,6.5	14	0.5,1.0,1.5, 2.5,4
Varian 2100 CD	5.5,5.75,6.0, 6.25,6.5	0	0.5,1.0,1.5, 2.0,4

II. METHODS

A. Monte Carlo simulations

The commissioning strategy used in this paper aims to the standardization of the procedure. For every accelerator studied in this work a depth dose and lateral profile dataset was constructed by simulating 2×2, 10×10, and 20×20 cm^2 fields for each member of a representative collection of mean energy/FWHM combinations (see Table I). The energy and FWHM steps were chosen according to the sensitivity and uncertainty of the commissioning figure of merit relative to these parameters (see Sec. II C).

Treatment head simulations were performed employing the BEAMnrc[10] Monte Carlo code. For the 10×10 and 20×20 cm^2 fields generation a primary phase space was scored just behind the flattening filter after running 3×10^6 primary histories. Then this phase space was propagated in two different simulations (one for each field), scoring the fluence at a SSD=100 cm. A separate accelerator head simulation, conducted in a single step, was performed for the 2×2 cm^2 field for the same number of primary histories. This ensured that its phase space had a sufficient amount of statistically independent particles. Variance reduction techniques employed in these simulations were range rejection with an energy cutoff of 2.0 MeV and directive bremsstrahlung splitting with a radius of 14.2 cm for the 10×10 and 20×20 cm^2 primary phase space and 3.5 cm for the 2×2 cm^2 primary phase space.

This procedure was employed to generate datasets for a Siemens PRIMUS 6 MV accelerator and a Varian 2100 CD 6 MV accelerator. The energy/FWHM combinations simulated are summarized in Table I. For the Varian simulations the primary electron beam was considered monoenergetic. Siemens PRIMUS simulations employed a Gaussian primary electron beam spectra with a FWHM of 14% of the mean energy. In all the accelerator head simulations (including the collimator simulations) the energy cutoffs (kinetic + rest mass) were 0.7 MeV for electrons and 0.01 MeV for photons. The EGSnrc transport parameters were taken as BCA =EXACT, e^- step algoritm=PRESTA-II, Koch and Motz cross sections for bremsstrahlung angular sampling and pair angular sampling, and NIST cross section for bremsstrah-

lung. Bound Compton scattering, photoelectron angular sampling, Rayleigh scattering, and atomic relaxations were switched on.

The time required for the 10×10 and 20×20 cm^2 primary phase space calculation was about 3 h in a single Xeon 3.0 Ghz machine, while the simulation through the collimators required only about 0.7 h. The 2×2 cm^2 field required 12 h for the whole treatment head simulation.

In order to speed up the dose deposition in the water phantom a Monte Carlo convolution/superposition code[11] was employed to calculated the depth doses and lateral profiles. This dose calculation code follows the interaction of each particle in the phase space all along a rectangular voxelized phantom, storing the dose in each voxel according to Monte Carlo calculated kernels. Because only water phantoms are considered, the dose calculated employing this code is completely equivalent to a full Monte Carlo simulation.

Water phantom simulation times ranged from less than 1 h for the 2×2 cm^2 field up to 20 h for the 20×20 cm^2 field. In this work we followed the same values in the dose calculation parameters as those in the paper of Naqvi *et al.*[11] A rectangular phantom was employed with a voxel size in the directions perpendicular to the beam axis of 1, 3, and 3 mm for the 2×2, 10×10, and 20×20 cm^2 fields, respectively. Voxel size was 3 mm in the beam direction for all field sizes. Phantom outer dimensions in the directions perpendicular to the beam were 10, 30, and 50 cm for the 2×2, 10×10, and 20×20 cm^2 fields, respectively. In all cases the phantom total depth in the beam direction was 35 cm. In order to avoid simulation noise a 2D median filter (the value of a point was calculated using the statistical median of a 3×3 neighborhood) was applied to the dose distributions at each depth before extracting the lateral profiles.

B. Cost functions and comparison of profiles

The automatic commissioning process begins by loading the measured depth doses and lateral profiles of the three fields. The user is requested to provide lateral profiles of these same fields at any arbitrary depths, provided they are measured deeper than the buildup maximum and shallower than 30 cm depth. Profiles are then centered (according to the locations in the profile falloff corresponding to a 50% of the central dose) and symmetrized.

Then, for every measured lateral profile its associated simulated profile is obtained by linear interpolation between the profiles of the two nearest depths. In order to correct for small deviations in the size of the measured profiles from the nominal field size, the width of the simulated profile is adjusted to that of the measurement. This procedure is performed by adjusting the width of 50% of the central axis dose region.

Measured and simulated depth doses are also corrected for small relative displacements by calculating the position of 80% and 90% of the PDD maximum in both curves.

During the construction of the figure of merit for a certain machine, two different cost functions have been employed for different purposes, namely, the following.

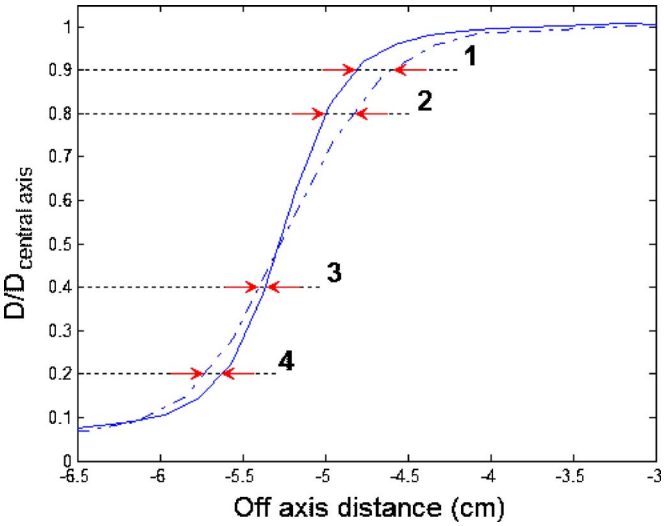

FIG. 1. Points employed for the calculation of the DBFE cost function, which is constructed as the sum of distances between simulated and measured profiles in points 1,2,3, and 4 (20%, 40%, 80%, and 90% of the central axis dose, respectively).

- The median of 1D gamma[12] profiles (MGP), which have been applied for PDD comparison at depth higher than buildup maximum and in the comparison of the flat part of the profiles (regions of dose greater than 90% of the central dose). Dose tolerance in the gamma calculations was 0.5% of the maximum dose in the PDDs and 0.5% of the central dose in the lateral profiles for all field sizes. The distance tolerance was 1 mm for the PDDs and 0.5, 2, and 3 mm for the 2×2, 10×10, and 20×20 cm^2 fields lateral profiles, respectively.
- The distance between field edges (DBFEs), which are defined as the sum of the squared distance between several dose values in the falloff region of the measured profile and these same values in the simulated one. It is calculated as $\mathrm{DBFE}=\Sigma_{i=1}^{4}d_i^2$, where points 1,2,3, and 4 correspond to 20%, 40%, 80%, and 90% of the central dose in the lateral profiles, as shown in Fig. 1.

The commissioning process is conducted calculating for each energy E_i the DBFE cost function for the different FWHMs, determining the best one for each field size:

$$\mathrm{Min}\{\mathrm{DBFE}_{2\times2}(E_i,\mathrm{FWHM}_j)\}=\mathrm{FWHM}_{2\times2}(E_i),$$

$$\mathrm{Min}\{\mathrm{DBFE}_{10\times10}(E_i,\mathrm{FWHM}_j)\}=\mathrm{FWHM}_{10\times10}(E_i),$$

$$\mathrm{Min}\{\mathrm{DBFE}_{20\times20}(E_i,\mathrm{FWHM}_j)\}=\mathrm{FWHM}_{20\times20}(E_i).$$

Then a weighted average is obtained for each energy E_i as

$$\langle\mathrm{FWHM}_i\rangle=w_{2\times2}\mathrm{FWHM}_{2\times2}+w_{10\times10}\mathrm{FWHM}_{10\times10}+w_{20\times20}\mathrm{FWHM}_{20\times20}$$

with $w_{2\times2}$, $w_{10\times10}$, and $w_{20\times20}$ user-selectable weights. In this way we obtain a series of pairs $(E_1,\langle\mathrm{FWHM}_1\rangle)$, $(E2,\langle\mathrm{FWHM}_2\rangle),\ldots,(E_n,\langle\mathrm{FWHM}_n\rangle)$ from which a median

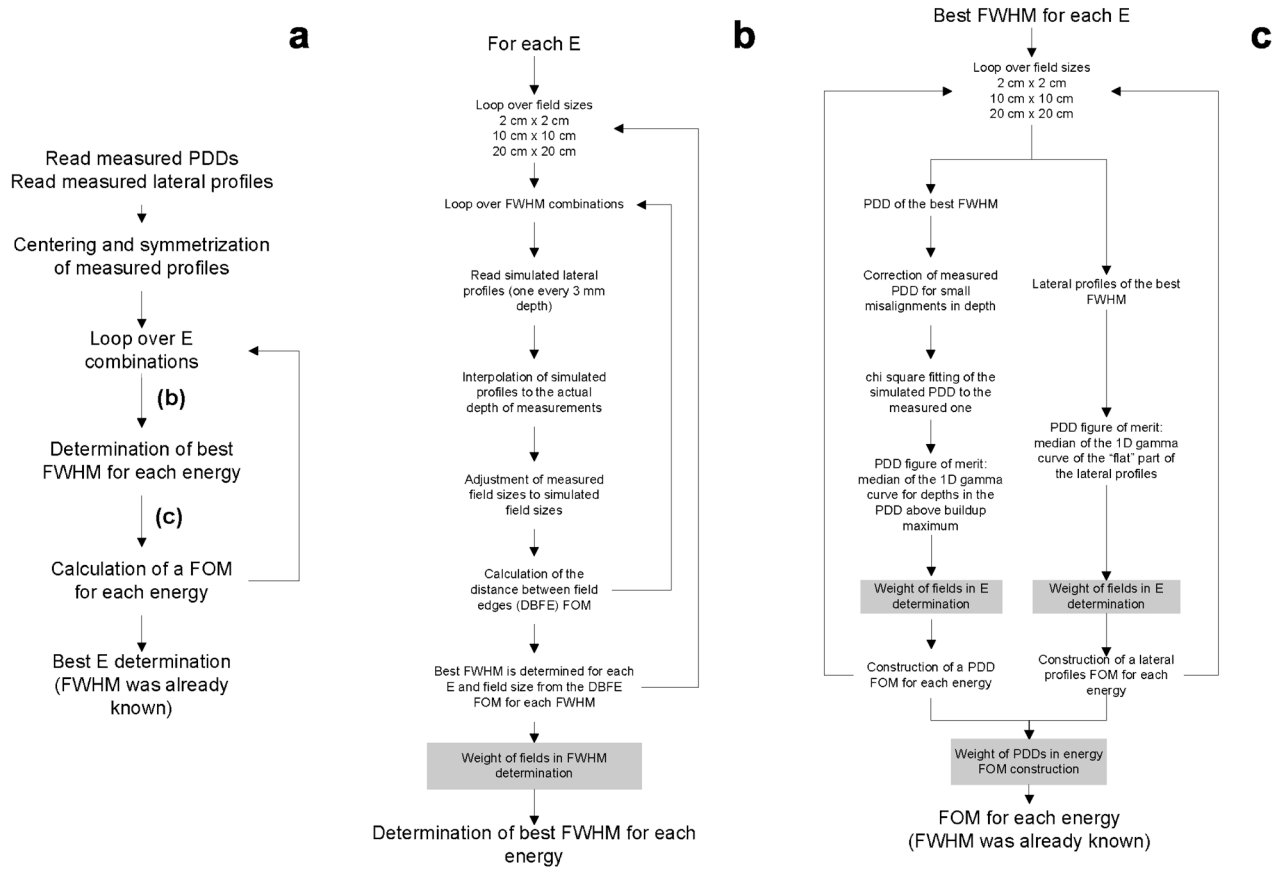

FIG. 2. Diagram illustrating the determination of the best energy and FWHM (a) and partial diagrams of best FWHM determination for each energy (b) and energy FOM calculation for the determined best FWHM (c). The different user-defined weights that control the relevance of the different fields in the process and also the importance of the depth doses in the energy determination are marked in gray.

of the gamma distribution for each profile and PDD is calculated:

$$\begin{aligned}\mu_1 = {} & W_{2\times2}\mu_{\text{profiles}_{2\times2},E_1} + W_{10\times10}\mu_{\text{profiles}_{10\times10},E_1} \\ & + W_{20\times20}\mu_{\text{profiles}_{20\times20},E_1} + W_{\text{PDD}_{2\times2}}\mu_{\text{PDD}_{2\times2},E_1} \\ & + W_{\text{PDD}_{10\times10}}\mu_{\text{PDD}_{10\times10},E_1} + W_{\text{PDD}_{20\times20}}\mu_{\text{PDD}_{20\times20},E_1} \\ & \vdots \\ \mu_n = {} & W_{2\times2}\mu_{\text{profiles}_{2\times2},E_n} + W_{10\times10}\mu_{\text{profiles}_{10\times10},E_n} \\ & + W_{20\times20}\mu_{\text{profiles}_{20\times20},E_n} + W_{\text{PDD}_{2\times2}}\mu_{\text{PDD}_{2\times2},E_n} \\ & + W_{\text{PDD}_{10\times10}}\mu_{\text{PDD}_{10\times10},E_n} + W_{\text{PDD}_{20\times20}}\mu_{\text{PDD}_{20\times20},E_n},\end{aligned}$$

where $W_{2\times2}$, $W_{10\times10}$, $W_{20\times20}$, $W_{\text{PDD}_{2\times2}}$, $W_{\text{PDD}_{10\times10}}$, and $W_{\text{PDD}_{20\times20}}$ are user-selectable constants to weight differently the different field sizes and the PDDs and lateral profiles. The optimum combination (E,FWHM) is obtained from the minimum μ_i. A detailed description of the commissioning process workflow can be seen in Fig. 2.

C. Uncertainty of the primary electron beam parameters

The sources of uncertainty in the whole commissioning process are the measurement and simulation uncertainty and the approximations in the geometry and in the shape and spectra of the radiation source. Several of this uncertainties cannot be determined directly.

We have estimated the A type uncertainty of the commissioning procedure by inserting a random Gaussian noise with a typical relative uncertainty of 1% both in the measurements and in the MC simulated depth doses and lateral profiles. This noise represents a maximum boundary of the uncertainties actually present in this procedure. By running the commissioning process several times the standard deviation of the mean energy and radial FWHM can be estimated.

On the other hand, the B type uncertainty of the mean energy and radial FWHM was modeled as the typical uncertainty from a square distribution whose width was taken to be the sampling intervals (0.25 MeV and 0.5 mm, respectively).

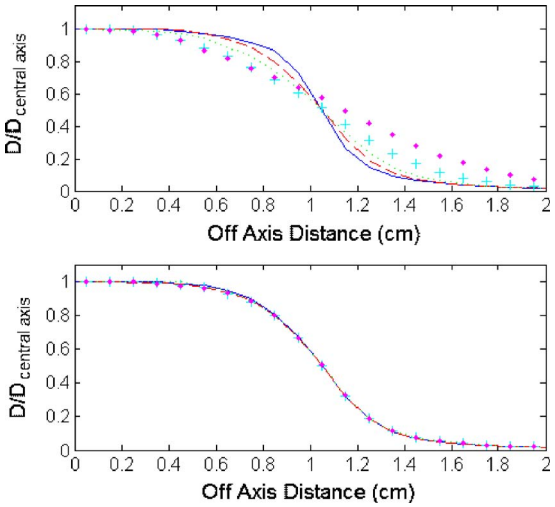

FIG. 3. Dependence of the simulated lateral profiles of a 2×2 cm^2 field (SSD=100 cm) from a 6 MV Siemens PRIMUS on the radial FWHM for a fixed mean energy (upper plot) and on the mean energy for a fixed radial FWHM (lower plot) at 5 cm depth. Simulated FWHMs for a fixed 6.0 MeV mean energy were, from higher to lower horns in the profiles, 0.5 mm (solid line), 1 mm (dashed line), 1.5 mm (dotted line), 2.5 mm (+), and 4 mm (dots). Simulated energies for a fixed FWHM of 1.0 mm were, from higher to lower horns in the profiles, 5.5 MeV (solid line), 5.75 MeV (dashed line), 6.0 MeV (dotted line), 6.25 MeV (+), and 6.5 MeV (dots).

III. RESULTS AND DISCUSSION

A. Dependence of 2×2 cm^2 field on primary beam parameters

The field sizes considered in the present work have been selected because of their marked dependence on the beam parameters or their representativity of typical beam sizes employed in radiotherapy treatments. Because 10 and 20 cm square fields have been employed in other works in the commissioning of medical linacs, in this section we will only discuss the advantages of employing a 2×2 cm^2 field in this process. Two issues have to be considered when a small field has to be employed in the commissioning process, namely, its dependence on the primary beam mean energy and FWHM and that the actual beam measurements are accurate and will not lead to an erroneous primary beam parameter determination.

Except in the vicinity of the penumbra, a 20×20 cm^2 field cannot separate the effect of a change in radius from the effect of a change in the mean energy. On the contrary, it can be seen in Fig. 3 that the 2×2 cm^2 is roughly independent on a change in energy for a fixed FWHM. Changing this parameter, however, leads to a sharp change in the shape of the lateral profiles. Then, the inclusion of the 2×2 cm^2 field in the commissioning process decreases the uncertainty associated to the FWHM determination.

Despite the lateral profiles of the 2×2 cm^2 field being very sensitive to the primary beam FWHM and insensitive to its mean energy, the FWHM determined employing only this field should be considered only as a first approximation to the best value. Lateral profiles of 10×10 and 20×20 cm^2 fields should also be taken into account in order to ensure the reproducibility of the accelerator fluence, which becomes more important as the field becomes wider.

The 2×2 cm^2 profiles of the 6 MV Siemens PRIMUS at the Deutsches Krebsforschungszentrum (DKFZ) were mea-

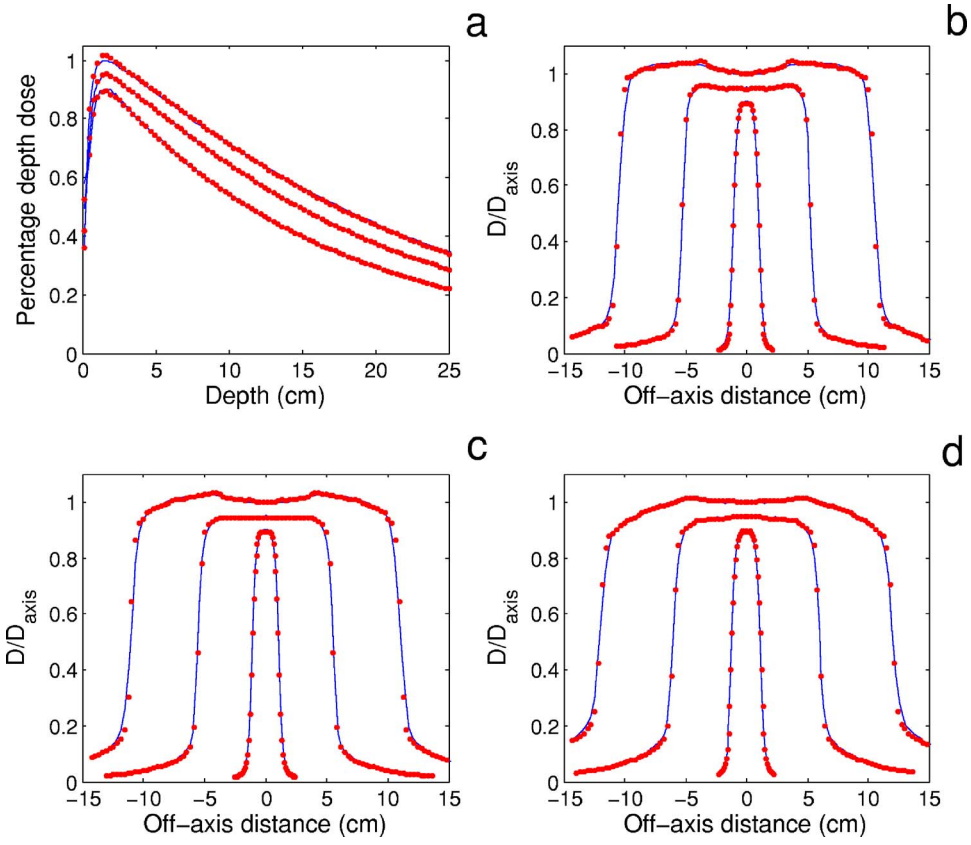

FIG. 4. Measured depth doses (a) and lateral profiles at 5 cm (b), 10 cm (c), and 20 cm (d) depth of the three field sizes: 2×2, 10×10, and 20×20 cm^2 employed in the commissioning of the DKFZ Siemens PRIMUS 6 MV accelerator. Dots correspond to the simulations for the best energy/FWHM combination (6.0 MeV/1 mm). Depth doses and lateral profiles have been normalized to different maximum and central axis dose values, respectively. Lowest curves correspond to lowest field sizes.

sured by a pinpoint chamber (PTW model 31014) and a diamond detector (PTW model 60003), with good agreement with both detectors. The commissioning process will not be affected then by ionization chamber volume-averaging effects provided suitable detectors are employed for measuring the 2×2 cm^2 field. However, the actual field size delivered by the machine differs somehow from the nominal field size and was taken into account in this article by scaling accordingly the measured profiles.

B. Automatic commissioning of a Siemens PRIMUS and a Varian 2100 CD

Following the procedure described in the previous section, we have characterized the 6 MV beam of the DKFZ Siemens PRIMUS accelerator. The best energy/FWHM combination was determined to be 6.0 MeV/1 mm (see FOM in Fig. 5). The comparison of the measured curves employed for its commissioning and the correspondent simulations is shown in Fig. 4. The agreement in the depth doses and lateral profiles is excellent, except in the 20×20 cm^2 field PDD where the measurements would be more accurately fitted with a higher mean energy. Depth doses of the fields employed for commissioning are reproduced at depth higher than buildup maximum with a mean gamma value below 1 for 1 mm, 0.5% tolerances. Gamma values below unity are also obtained in all PDD buildups except in that of the 20×20 cm^2 field, where a 1.9 value of average gamma is obtained for these same tolerances. This slight disagreement illustrates the concept that the best commissioning is one that matches most of the relevant fields at the cost of not matching perfectly any of them. If in this work we had chosen to tune the primary beam parameters relying only on the 20×20 cm^2 field, the final energy would be higher, decreasing then the quality with which smaller fields are reproduced. Lateral profiles of these same fields are all reproduced with a mean gamma value below one for a dose tolerance of 0.5% and a spatial tolerance of 0.5, 2, and 3 mm for the 2×2, 10×10, and 20×20 cm^2 fields, respectively.

By running the Siemens PRIMUS commissioning process 300 times we have obtained the histogram of best energies plotted in Fig. 5. The standard deviations of the mean energy and FWHM determined employing the method of A type uncertainty estimation described in Sec. II C were 0.15 MeV and 0.04 mm, respectively. The overall uncertainty of the commissioning process after including the B type component was $\sigma_E=0.15$ MeV for the mean energy and $\sigma_{\mathrm{FWHM}}=0.2$ mm for the radial FWHM. From these results it is clear that decreasing the energy and radial FWHM sampling intervals below their typical commissioning uncertainty will not yield more accurate simulations.

The method, however, may deteriorate for measurements performed with an unsuitable ionization chamber (such as a big active volume chamber measuring 2×2 cm^2 lateral profiles) or simulations with a relative uncertainty larger than 2%.

In order to test the capability of the commissioned beam parameters to predict the dose deposition in other field sizes

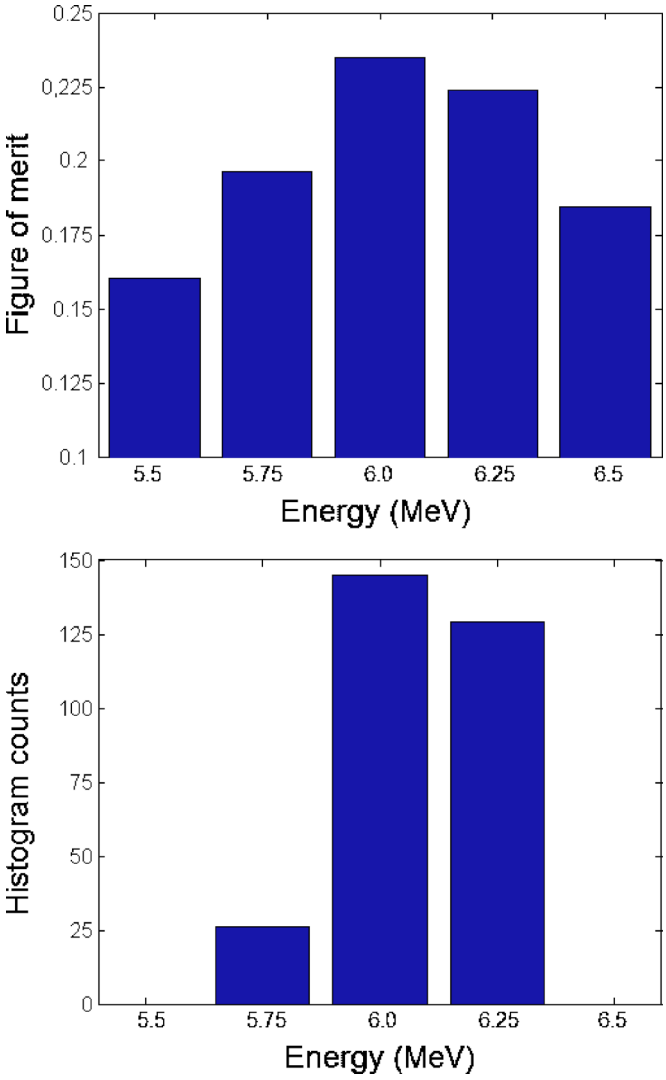

FIG. 5. Upper plot: figure of merit of the energies in the commissioning of the DKFZ Siemens Primus accelerator commissioning. Lower plot: histogram of best energies in this commissioning obtained by running the process 300 times inserting a random gaussian noise with a typical relative uncertainty of 1% both in the measurements and in the MC simulations.

we have simulated a 5×5 and a 15×15 cm^2 field from the same accelerator. For this purpose the dose to water was calculated employing the DOSXYZnrc[13] code in order to assure that the MC convolution/superposition code introduced no bias in the commissioning process. The comparison of the predicted profiles with the actual measurements is shown in Fig. 6. It can be seen that there is an excellent agreement between simulations and measurements, confirming the accuracy of the determined parameters. For gamma tolerances of 1 mm, 1% PDDs and lateral profiles of these two field sizes were reproduced with average gammas of less than 0.52.

We have also employed this methodology to commission the 6 MV beam of the Varian 2100 CD accelerator of the Hospital Universitario Central de Asturias (HUCA) in Oviedo, Spain. The best matching between measurements and simulations was achieved for a mean energy of

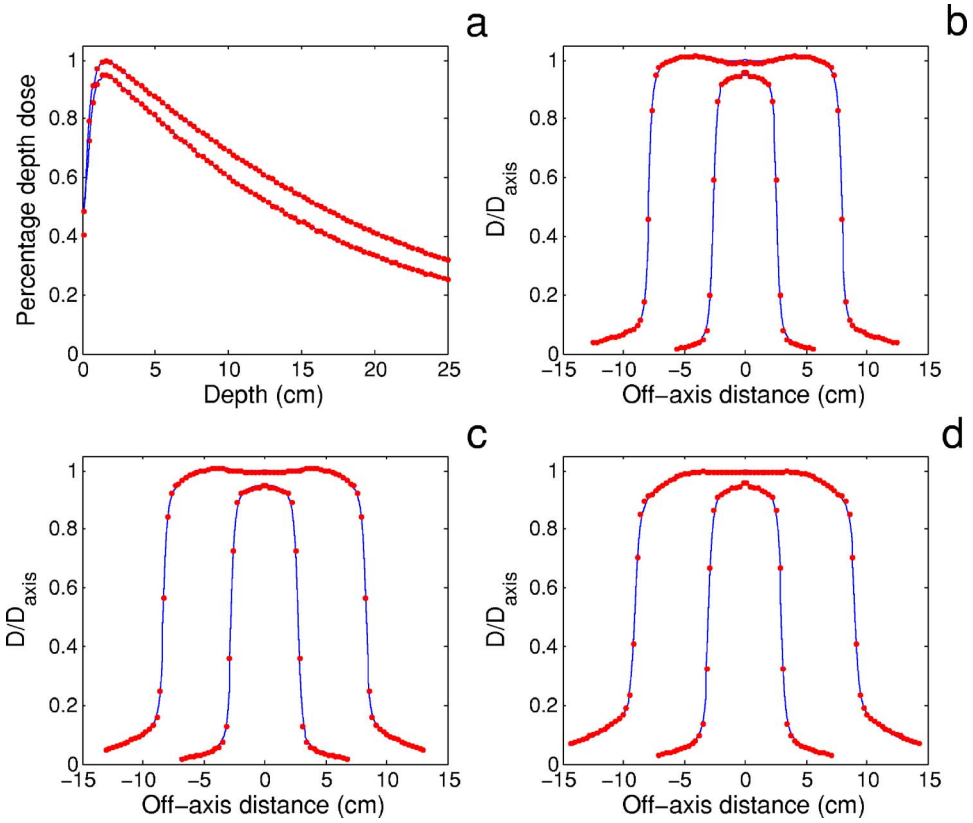

FIG. 6. Measured depth doses (a) and lateral profiles [(b), (c) and (d)] of the 5×5 and 15×15 cm^2 fields from the DKFZ Siemens PRIMUS 6 MV accelerator at several depths: 5 cm (b), 10 cm (c), and 20 cm (d). Dots correspond to correspondent simulations with a mean energy of 6.0 MeV and a radial FWHM of 1 mm, as determined by the commissioning procedure. Depth doses and lateral profiles have been normalized to different maximum and central axis dose values, respectively. Lowest curves correspond to lowest field sizes.

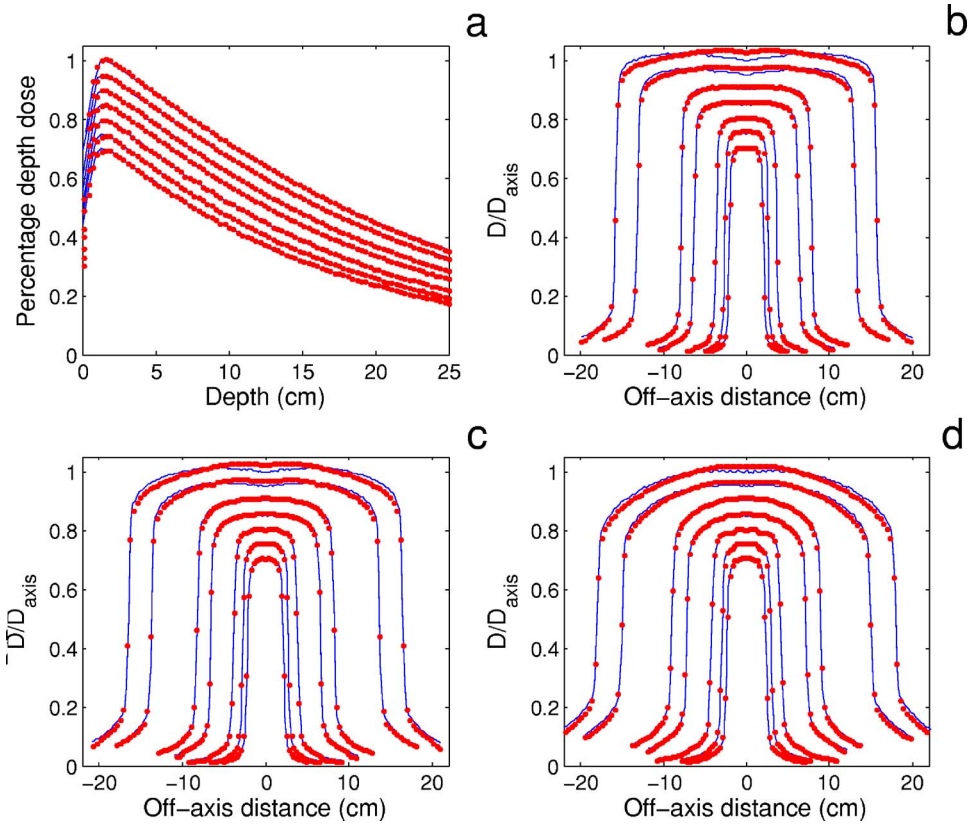

FIG. 7. Measured depth doses (a) and lateral profiles [(b), (c), and (d)] of 4×4, 5×5, 7×7, 12×12, 15×15, 25×25, and 30×30 cm^2 fields from the HUCA Varian 2100 CD 6 MV accelerator at different depths: 5 cm (b), 10 cm (c), and 20 cm (d). Simulations (dots) were performed with a mean energy of 6.25 MeV and a radial FWHM of 1.5 mm, as determined by the commissioning procedure. Depth doses and lateral profiles have been normalized to different maximum and central axis dose values, respectively. Lowest curves correspond to lowest field sizes.

6.25 MeV (monoenergetic) and a FWHM of 1.5 mm. For the primary electron beam parameters we have simulated (again employing the DOSXYZnrc code for dose calculation) several square field sizes not employed during the commissioning process. The results can be seen in Fig. 7.

It can be seen from these figures that all the depth doses and lateral profiles are accurately predicted up to a field size of 30×30 cm^2. For gamma tolerances of 1 mm, 1% PDDs and lateral profiles of all fields except 25×25 and 30×30 cm^2 were reproduced with average gammas of less than 0.7. These values rose up to a maximum average gamma of 1.4 in the lateral profiles of the 30×30 cm^2 field. However, this field size has a slight discrepancy between simulations and measurements. Due to its depth dose, a higher mean energy in the MC simulations would be necessary to produce a better match. On the other hand, to exactly match the lateral profiles of this field, the horns of the simulated curves should be raised, which can only be done by decreasing the energy. This apparent contradiction may be due to a nonmonoenergetic energy spectrum or to some geometrical or source modelation details that may differ between the simulations and the actual accelerator. This discrepancy supports the basic assumption of this work, i.e., that the Monte Carlo simulations of photon beams should be tuned by employing a measured dataset representative of the field sizes that shall be reproduced later by the simulations.

IV. CONCLUSIONS

In this work we have presented a new method for commissioning photon beams that employs depth doses and lateral profiles from three different square fields. By simultaneously comparing measurements and simulations from these field sizes for several mean energy/radial FWHM combinations we can determine the values that yield the best matching.

In Sec. III B this procedure was applied to a Siemens PRIMUS and a Varian 2100 CD machine. The DKFZ machine is accurately reproduced employing a mean energy of 6.0 MeV and a radial FWHM of 1 mm. The agreement between measurements and simulations in Figs. 4, 6, and 7 is mostly well below a gamma value of 1 calculated with different strict tolerances, showing the validity of the proposed commissioning method.

Only the 30×30 cm^2 field of the Varian 2100 CD showed a slight disagreement between simulations and measurements. If only the average electron primary beam energy is considered, the disagreement in the depth dose profile would be reduced increasing this energy, while the lateral profiles would improve with a lower one. These kinds of mismatches can appear due to some geometrical details not included in the simulation for a particular machine or due to the difference between the actual electron energy spectrum and that used in Monte Carlo.

In TPS commissioning the most relevant fields are reproduced by employing many free parameters that are adjusted by matching the measurements from these same fields. We have translated this approach to MC commissioning by matching only the most relevant fields with a more limited set of free parameters. The differences in broad fields supports the use of field sizes more similar to those commonly found in clinical routine for beam commissioning.

The proposed method relies in precalculated MC simulations of generic medical accelerators and provides a figure of merit to obtain the best combination of energy and FWHM of the primary electron beam. The implementation has followed a user-friendly approach to provide an automatic commissioning tool inside the verification web platform of the eIMRT project.[9]

ACKNOWLEDGMENTS

This work was financed by the Xunta de Galicia through Project No. GIDT05SIN00101CT. The authors would like to express their gratitude to Dr. A. Rodríguez and Dr. J. Vivanco from the Radiophysics Unit of the Hospital Universitario Central de Asturias for providing us with the measurements of the Varian 2100 CD and Dr. S. Naqvi for providing us with the Monte Carlo C/S dose calculation code. Javier Pena wants to acknowledge the Ramón Areces foundation for its financial support. Finally, the authors want to express their gratitude to the International Atomic Energy Agency (IAEA Research Agreement No. 13662) for the Co-ordinated Research Project in Dosimetry carried out under its sponsorship.

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