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STUDIES ON THE RADIAL DOSE DISTRIBUTION FOR CLINICAL ELECTRON BEAMS OF 9 AND 16 MEV USING MONTE CARLO SIMULATION

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ABSTRACT

Radial dose distributions have been obtained for several electron beam field sizes through the Monte Carlo simulation. Measurements were performed by an ionization chamber in a 50x50x50 cm^3 water phantom which is routinely used for calibration. Calculated and measured values were compared to adjust the input energy spectra used for the Monte Carlo simulation. The methodology presented here is part of the “tuning procedure” for the construction of electron beam sources typically used for radiotherapy.

1. INTRODUCTION

Clinical utilization of electron beams in radiotherapy needs a careful analysis of some parameters and characteristics that are observed, either by experimental measurements or by simulation calculations. Parameters like R_{100}, the depth of 100% dose, R_{50} the depth of 50% dose and R_t the therapeutic range are some clinical parameters, which characterize dose profiles for the treatment planning elaboration. One important aspect is also the behavior of the radial dose distribution and its dependence on the field size. Theoretical analysis of absorbed doses is usually done through Monte Carlo codes in which the radiation transport simulation is performed in order to obtain the energy deposition in specific target volumes.

Nowadays the most accurate method for radiation transport simulation in calculating absorbed dose distribution in radiation therapy is the Monte Carlo method. This method can handle accurately the dose from electron beams situations such as scatter perturbations by air cavities or other heterogeneities, as well as the backscatter from high-density materials such as bone [1,2,3]. The present work has utilized the Monte Carlo codes MCNP-4C [4] to perform the radiation transport simulations. The radial dose profiles have been obtained in a water phantom for a typical electron beam sources of 9 and 16 MeV from a Varian Clinac

2100C linear accelerator. Calculated and measured values are compared to correct the input energy spectra built by the “source tuning” procedure.

2. MATERIAL AND METHODS

2.1. Simulation

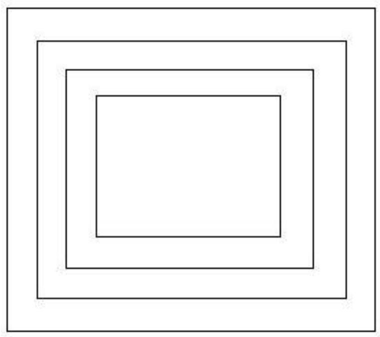
The accelerator output energy spectra used in these simulations were taken from the previous works [5,6] which were based on a “source tuning” procedure. This procedure consists of an iterative process to match simulated results with experimental data and it is ended when an agreement between both results is gotten. In addition, this method is advantageous because it is not necessary the complete knowledge of the accelerator head, introducing a significant reduction in computing time and storage memory with respect to full accelerator simulation.

For all cases studied in this present work, the electron source in the Monte Carlo simulation is geometrically considered as a square surface positioned 5 cm above the phantom surface where the electrons are emitted in the normal direction toward the phantom surface. This configuration simulates the electron energy spectrum which exits the last applicator window.

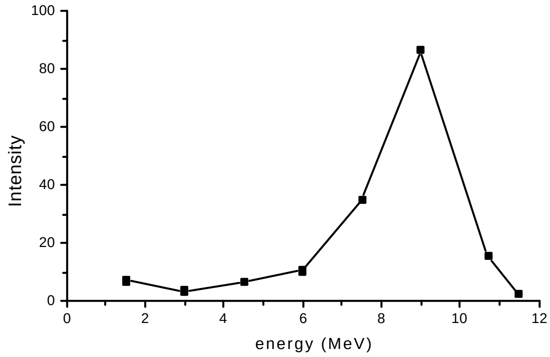
The clinical field size considered in the present study is 10x10 cm^2. Measurements were performed by an ionization chamber in a 50x50x50 cm^3 water phantom, which is routinely used for calibration. Simulation of these experiments was performed by the Monte Carlo code MCNP-4C for dose determination. The geometrical modeling of the phantom consisted of a 50x50x50 cm^3 of water cube which was divided into slices of 2 mm thick where the energy deposition is computed. As these slices stand perpendicular to the beam incident direction, they were further divided into a 4 mm square grid, so that, each target volume for energy deposition is a parallelepiped of 4 x 4 x 2 mm^3. Axial and radial dose distributions were obtained for 9 and 16 MeV electrons beams.

2.1.1. The “source tuning” procedure

The lack of detailed knowledge of initial electron beam parameters, in the Monte Carlo simulation of linear accelerators, LINACS, has led many researchers to use various methods to estimate them. The most common is the “source tuning” procedure, which basically consists in the adjustment of source parameters by a trial and error method to match the calculated and experimental data. For each electron beam energy it is attributed an energy spectrum which is varied to match the calculated and measured percentage depth dose. In this step it is assumed that this energy spectrum has an uniform intensity throughout the source field. Once this match is reached, experimental and simulated radial dose distributions are compared and the spectral intensity is varied through the source field to match the radial dose distribution. As a result the “tuned” source which produces simulated axial and radial dose distributions which match the measured values consists of an energy spectrum which varies its intensity throughout the source field [7], see Figure 1.



(a)



(b)

Figure 1. (a) Square regions where the energy spectra have different intensities; (b) Energy spectra for the 9 MeV electron beam.

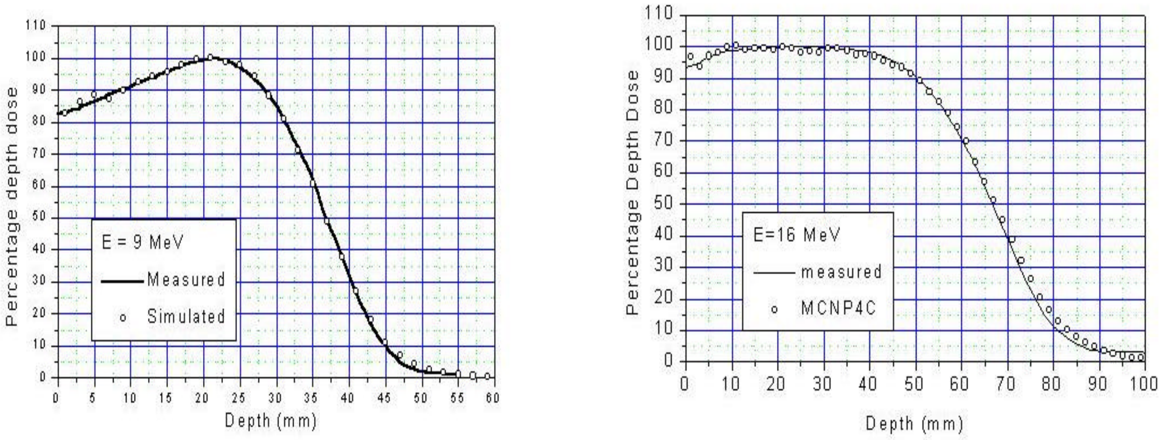
2.2. Experimental procedure

Relative dose values have been obtained using an automatic 3-D sweep system coupled to the simulator, the Blue Phantom, which consists of a 50x50x50 cm^3 acrylic box. This system is connect to a software (Omni-Pro) which controls the spatial position, allowing continuous sweeping through two ionization chambers (IC), one for field reading and the other for reference. The ratio of these readings eliminates possible fluctuations in the radiation bundle.
The Omni-Pro software controls the IC movements according to the instructions given by the operator allowing to positioning the IC automatically in any position inside the simulator and shifts the IC in any direction according to X, Y or Z axis, so that its possible to perform the percentage depth dose and radial profiles. The operator can also control the IC movement velocity and the charge collection rate. Once the data are collected several adjustments are possible as: smoothness of the curves, noise elimination, normalization, data interpolation, measured values table, ionization curves conversion to dose curves.

3. RESULTS AND DISCUSSION

3.1. Axial dose distribution

Percentage depth dose (PDD) curves are shown in Figures 2a and 2b, respectively for 9 and 16 MeV, 10x10 cm^2 field size electron beam. Energy spectra used for the simulation for both electron beam energies were built according to the procedure described in the previous section giving very good agreement between simulated and measured values. For the build-up region the discrepancies are less than 1.3 % and 2.8 %. The maximum discrepancies found are 2 % and 3.5 %, respectively for 9 and 16 MeV electron beams. These discrepancies are localized in the curves tails where the photon population predominates and are less important for clinical purposes.

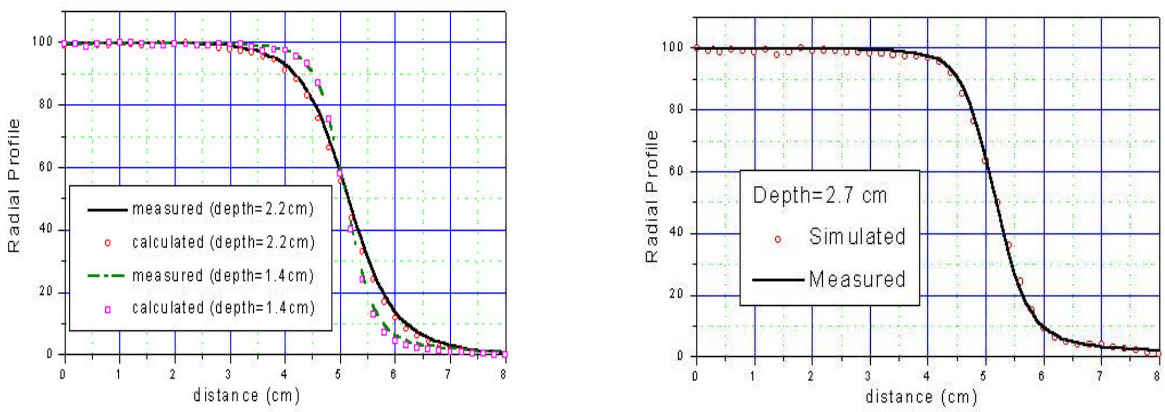


(a) (b)

Figure 2. Percentage depth dose: (a) 9 MeV; (b) 16 MeV.

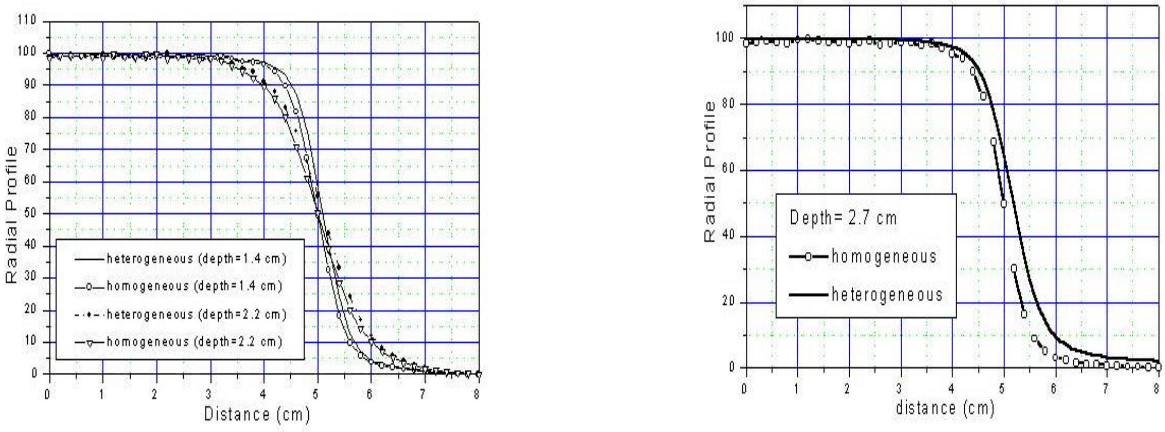
3.2. Radial dose distribution

Figure 3a and 3b show the simulated and measured radial dose profiles (RDP) at two depths 1.4 and 2.2 cm for 9 MeV and at 2.7 cm depth for 16 MeV electron beams, respectively. The maximum discrepancies, between simulated and measured values, in the range of 0 to 5 cm in radial direction, which is the range that covers from the center to the edge of the 10x10 cm^2 field size beam, are: 4.7% and 2.7 %, respectively for 9 and 16 MeV. These discrepancies are less than 2 % in the build-up region and increases along the radial distance, however, the dose levels at distances beyond 5 cm are very small and the statistical uncertainties increase. Figures 4a and 4b show the differences in the RDP at 1.4 and 2.2 cm depths for 9 MeV and at 2.7 cm depth for 16 MeV, respectively, when considering homogeneous and heterogeneous intensity spectra along the field size, as shown in figure 1a. As one can observe considerable discrepancies have been found between them, showing that homogeneous intensity spectrum doesn't provide adequate RDPs which match the measured curves, so spatially heterogeneous source intensity is needed to provide an agreement between simulated and measured RDPs.



(a) (b)

Figure 3. Simulated and measured radial profile: (a) 9 MeV; (b) 16 MeV.



(a) (b)

Figure 4. Radial profiles obtained with homogeneous and heterogeneous radial source intensity distribution: (a) 9 MeV; (b) 16 MeV.

4. CONCLUSIONS

This present work demonstrates that an adequate procedure using trial and error method can be used to model the electron beam source which matches the measured values giving very good agreement. Axial dose distribution can be achieved using homogeneous intensity spectra, but this approach is not adequate for the radial profile, so that, a heterogeneous intensity spectrum is necessary to reproduce correctly the measured profile. This procedure should be done for each clinical beam source energy and for each field size.

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