Fluence and energy espectra for photon beams: A Monte Carlo study

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Introduction

Much of the algorithms used to calculate dose distributions for photon beams generated by clinical electron linacs (Zhou et al. 2010, Sikora and Alber 2009, Tillikainen 2009) consider three particle sources: a photon source corresponding to Bremsstrahlung in the target (primary source), a second photon source that takes into account those photons produced by scattering into the primary collimator, the flattening filter and the secondary collimation system (scattering source) and an contamination electron source that considers those electrons produced in the various components of the linac head and the air space between it and the patient (contamination electron source). Most of the published works in which the behavior of the particles produced in linac heads is characterized (Chaney et al. 1994, Sempau et al. 2001, Sheikh-Bagueri and Rogers 2002, Fix et al. 2005, Hirshi et al. 2007, Grevillot et al. 2011) describe the sources in terms of their characteristics at the phantom entrance. However, the calculation models take into account that these particles originate at different positions with specific values of position, movement direction and energy. In this work we aim at describing the source characteristics at the particular positions where particles originate.

Materials and Methods

Source characteristic were studied within Monte Carlo (MC) simulation. The first step was to build up the linac models for the MC simulations that where performed with two simulation codes: PENELOPE (Salvat et al. 2006) and Geant4 (Agostinelli et al. 2003) through GAMOS (Arce et al. 2008). Three linac heads were considered: Elekta Precise, Varian Clinac 2300 and Siemens Mevatron KDS. The corresponding geometries were constructed takin into account the information provided by the manufacturers. Different phase space files (PSFs) were generated at different positions in the respective geometries in order to analyze the various components of the beams. PSFs include information about the particles reaching these positions, specifically the particle type, its energy, position when reaches that were the PSF is defined, movement direction and relative weight. In addition, the position where particle suffered the last interaction before reaching the PSF position was also included.

Results

The elements that most contribute to the dose in the phantom were the target (primary source), with 70-80%, and the primary collimator and the flattening filter (scattering source), with 10-15%.

Particle fluence distributions

To describe the photon fluence of the primary source, a PSF was determined just below the target. The corresponding distribution was fitted by means of a Gaussian distribution or a Pearson distribution of order VII. The best of both distributions was selected using the information criterium of Akaike (1974), and we found that the second one permits a more precise fit of the MC fluences. A similar results was obtained experimentally by Sham et al. (2008).

The contribution of the scattering source was analyzed obtaining a PSF just below the flattening filter. The corresponding fluence distribution can be fitted by means of a Gaussian specific for each linac head. Also a Lorentzian distribution can be considered, but the Gaussian one produces more accurate fits. In the case of the Siemens Mevatron KDS, it is necessary to consider the superposition of two Lorentzian distributions to adequately fit the MC values.

The contamination electron source was analyzed by constructing a PSF at the entrance of the secondary collimators. Using the particle directions at this position, the electron distribution is characterized below the flattening filter. An energy dependent Gaussian behavior was found for this third source.

Behavior with energy

The energy spectrum of the primary source was analyzed with the PSF determined below the flattening filter. In the beam axis, it was found that this energy spectrum can be fitted with a lognormal function, as proposed by Yang et al. (2004). In addition, we studied how the average energy varies as a function of the polar angle of the particle movement direction. Results are compared with a model proposed by Fippel et al. (2003).

The photon energy for the scattering source can be obtained (Fippel et al. 2003 y Zhou et al. 2010) from that of the primary source assuming that scattered photons are generated by Compton interactions of the photons of the primary source with the head elements. This was verified using a PSF, just below the flattening filter, in which the particle direction with respect to that of the particle that produced it is also scored. We checked that the average energy in the beam axis is reproduced if the Compton inverse correction is applied to the average energy of the scattering source photons only for 6 VM configurations. For higher energies this does not happens because there pair production is the dominant photon interaction mechanism.

The energy spectrum of the electron contamination source is determined from a PSF at the phantom surface (at 100 cm of the primary source). We compared the MC results with an exponential model proposed by Sikora and Alber (2009) and a lognormal one proposed by Yang et al. (2004). We found that the first one describes in a better way the results of our simulations.

Conclusions

The particle fluence of the primary source can be fitted using a Pearson distribution of order VII. The fluence due to the scattering source can be fitted by a Gaussian distribution except for the Siemens Mevatros KDS for which the superposition of two Lorentzian distributions are needed.

The energy spectrum of the primary source in the beam axis can be fitted by a lognormal distribution. Average energy reduces as a function of the polar angle of the particle directions.

For 6 MV beams, the photon energy corresponding to the scattering source can be calculated from the energy distribution of the primary source, assuming that the photons of this last source interact via Compton scattering with the scatter elements of the linac head.

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