REPORTS OF PRACTICAL ONCOLOGY AND RADIOTHERAPY 24 (2019) 331–337

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/rpor

Original research article

Determination of initial electron parameters by means of Monte Carlo simulations for the Siemens Artiste Linac 6 MV photon beam

Taylan Tuğrul [a,*], *Osman Eroğul* [b]

[a] *Department of Radiation Oncology, Medicine Faculty of Van Yüzüncü Yıl University, Van, Turkey*
[b] *Department of Biomedical Engineering, TOBB University of Economics and Technology, Ankara, Turkey*

ARTICLE INFO

Article history:
Received 19 February 2018
Received in revised form
1 March 2019
Accepted 11 May 2019
Available online 31 May 2019

Keywords:
Monte Carlo
Simulation
BEAMnrc
DOSXYZnrc
Artiste

ABSTRACT

Aim: In this study, we investigated initial electron parameters of Siemens Artiste Linac with 6 MV photon beam using the Monte Carlo method.
Background: It is essential to define all the characteristics of initial electrons hitting the target, i.e. mean energy and full width of half maximum (FWHM) of the spatial distribution intensity, which is needed to run Monte Carlo simulations. The Monte Carlo is the most accurate method for simulation of radiotherapy treatments.
Materials and methods: Linac head geometry was modeled using the BEAMnrc code. The phase space files were used as input file to DOSXYZnrc simulation to determine the dose distribution in a water phantom. We obtained percent depth dose curves and the lateral dose profile. All the results were obtained at 100 cm of SSD and for a $10 \times 10\,cm^2$ field.
Results: We concluded that there existed a good conformity between Monte Carlo simulation and measurement data when we used electron mean energy of 6.3 MeV and 0.30 cm FWHM value as initial parameters. We observed that FWHM values had very little effect on PDD and we found that the electron mean energy and FWHM values affected the lateral dose profile. However, these effects are between tolerance values.
Conclusions: The initial parameters especially depend on components of a linac head. The phase space file which was obtained from Monte Carlo Simulation for a linac can be used as calculation of scattering, MLC leakage, to compare dose distribution on patients and in various studies.

1. Background

The main purpose of radiotherapy is to give the highest dose to the tumor and to deliver minimum dose to healthy tissues which surround tumor.[1] To achieve this purpose, the dose distribution must be compared and verified with a high accuracy method. The Monte Carlo method simulates interaction possibilities for various physical processes and to solve the problem by using random numbers.[6] This method uses reliable

* *Corresponding author.*
E-mail addresses: taylantugrul@gmail.com (T. Tuğrul), erogul@etu.edu.tr (O. Eroğul).
https://doi.org/10.1016/j.rpor.2019.05.002

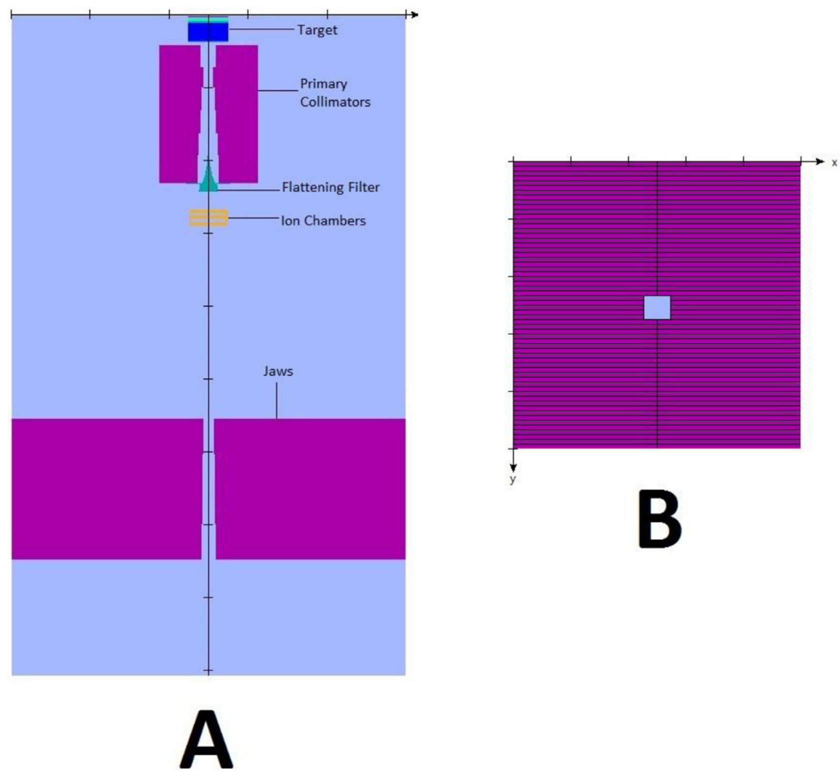

Fig. 1 – (A) Linac preview on BEAMnrc. (B) Modeled MLC.

distribution functions that control each interaction of photons and electrons in air and matter. As the Monte Carlo method tracks each particle throughout its lifetime and takes into account all the interactions it does, this method is the most accurate one for simulation of radiotherapy treatments.[7,8,15,16,18] In parallel with fast developments in computer technology, the Monte Carlo method is becoming increasingly widespread. This method is already in use in radiation oncology centers. The difficult stage that users encounter in radiation therapy is to specify initial electron parameters.[3–11] Errors in the radiation source description are directly caused through dose calculation.[17] For to run Monte Carlo code It is essential to define all the characteristics of photon beam such as: initial electron mean energy and full width of half maximum (FWHM) of the intensity distribution of these primary electrons that stimulate the target of a Linear accelerator.[4–12]

2. Aim

The purpose of this study is to investigate initial electron parameters of Siemens Artiste Linac with 160 Multi leaf collimator (MLC) and 6 MV photon beam using the Monte Carlo method. In study, the BEAMnrc and DOSXYZnrc codes were used to model 6 MV Siemens Artiste Linac head and to measure the PDD and lateral dose profile in the modeled water phantom. All the dose distribution results were compared with measurement data which was taken from an ion chamber using gamma index criteria.

3. Materials and methods

Measurement data of percent depth dose (PDD) and off-axis lateral dose profile were obtained in water by a farmer ion chamber (PTW, Freiburg Germany). BEAMnrc and DOSXYZnrc, based on the EGS nrc Monte Carlo method which is under license to the National Research Council of Canada, were used to simulate a linac head and measure respectively.[9,10–16] At the first step, Siemens Artiste Linac head geometry was modeled using the BEAMnrc code after the specifications of the linac obtained from the manufacturer. The BEAMnrc of linac head components include the exit window, target, primary collimator, flattening filter, monitor chamber, Y Jaws and X MLC. Linac modeled on BEAMnrc Fig. 1 is the model taken for the simulation.

PEGS4 (EGS preprocessor) cross-section data for specific materials in the accelerator were obtained from 700icru.pegs4data file. This data file contains cross-section data for particles with kinetic energy as low as 0.01 MeV and physical density such as mass density, atomic number and electron density for all the different materials used in the accelerator.[1] In BEAMnrc, the number of history of Monte Carlo calculation was 6×10^8 particles (Total particles in phase space file are nearly 25 million). ISOURC19 was used (Elliptical Beam

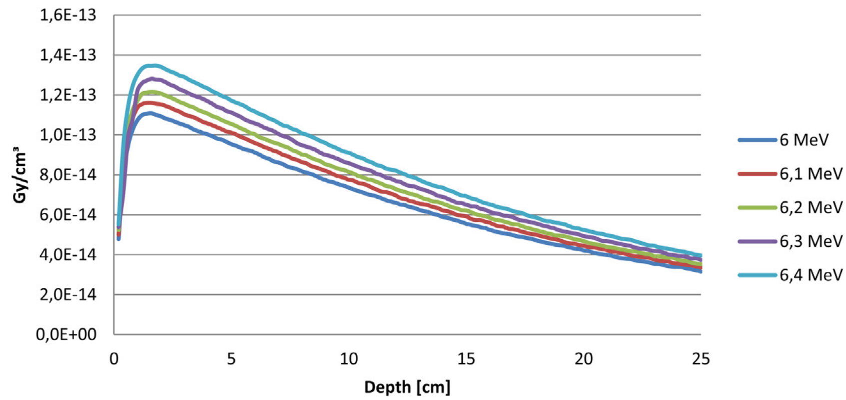

Fig. 2 – PDD curves for five different electrons mean energy.

with Gaussian Distributions in X and Y) in photon beam simulation. In all simulations the electron cut-off energy (ECUT) was defined at 0.7 MeV and the photon cut-off energy (PCUT) was defined at 0.01 MeV. UBS was used (Splitting factor is 20 and Russian Roulette is off) as the variance reduction parameters. The primary output of the simulation for the linac head is a file called phase space file which has all the information of the particles leaving the linac head. The file was created in a plane which is perpendicular to the beam axis at 100 cm distance from the target and the field size is $10 \times 10\,cm^2$. Monte Carlo simulations were performed for monoenergetic beams ranging from 6 to 6.4 MeV and FWHM varied from 0.28 to 0.32 cm for 6 MV beam. At the second step, the phase space files were used as an input file to DOSXYZnrc simulation to determine the dose distribution in water phantom which was created by DOSXYZnrc program. The dose distributions for PDD and beam lateral dose profile were calculated in a $30 \times 30 \times 30\,cm^3$ water phantom which was located at a source to surface distance (SSD) of 100 cm. The voxel size was $0.2 \times 0.2 \times 0.2\,cm^3$. DOSXYZnrc parameters such as ECUT and PCUT were 0.7 MeV and 0.01 MeV, respectively. 8×10^9 histories were run in the phantom simulation. Recycle and split parameters were used as options. The particle recycling can lead to better accuracy in simulation.[19] The PDD curves were calculated along the central axis of the water phantom and all depth dose curves were normalized to the maximum dose. The PDD curves were used to define the electron mean energy and the lateral dose profile was examined to find FWHM of beam.[13–15] The lateral dose profiles were calculated at depths of 1.6 cm (Maximum dose depth). The lateral dose profiles were normalized to dose at the central axis. According to Tzedakis et al.[20] and Mihailescu et al.[15] studies, the depth dose curves were unaffected by the radial spread of electron beam. The lateral dose profile was considered because the influence of electron beam width was investigated on the dose distribution. According to Chang et al. study,[2] for optimal FWHM values, difference comparisons should be taken from the flat regions of the off-axis dose profile. Therefore; the measurements were taken at off-axis. All the results were obtained at 100 cm of SSD and for a $10 \times 10\,cm^2$ field. The PDD and lateral dose profile results obtained from DOSXYZnrc were compared with measurement data. To examine the effect of FWHM values on the PDD, different values of FWHM were calculated at an energy value. Additionally, different energy values were calculated at a FWHM value to examine the effect of energy on the lateral dose profile. The gamma index criteria were used to test the difference between Monte Carlo calculation and measurement data. The tolerance of acceptability was set to 0.5% for calculated dose and 0.5 mm for the position. For correct PDD and lateral dose profile; Quality Index (QI), gamma index criteria and maximum dose depth were considered.[3–14]

4. Results

We calculated five different modes to obtain the accurate PDD values and lateral dose profiles. The statistical uncertainty of the simulations which contain PDD and the lateral dose profile was kept less than 0.4% in all dose points. The target and flattening filter components have an important effect on PDD. The PDD curves help us to define accurate initial electron mean energy. For five different energies, the percent depth dose curves obtained at 100 cm of SSD for 6 MV photon beam and $10 \times 10\,cm^2$ are shown in Fig. 2.

Fig. 2 shows the influence of electron mean energy on depth dose distributions. It is clear that when the energy

Table 1 – Quality index and D_{max} values for five electron mean energy.

Energy (MeV)	$QI_{(D20/D10)}$ (measurement value = 0.57488)	D_{max} (maximum dose depth) (cm) (measurement value = 1.6)
6	0.57350	1.6
6.1	0.57385	1.6
6.2	0.57423	1.6
6.3	0.57474	1.6
6.4	0.57528	1.8

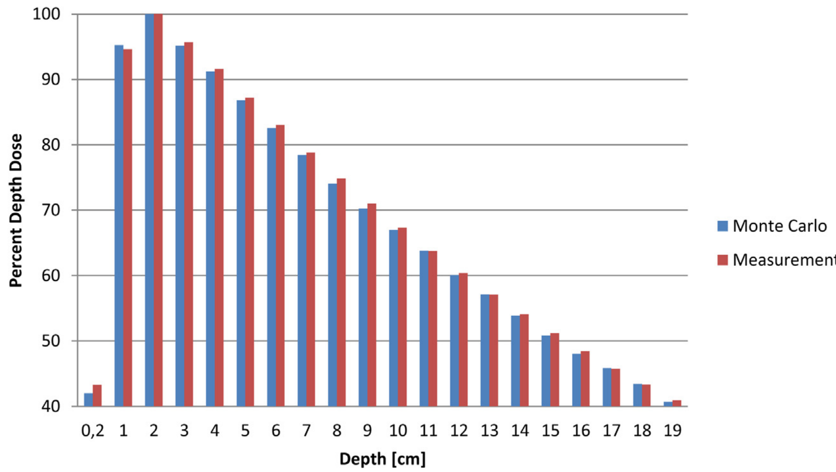

Fig. 3 – For 6.3 MeV, Monte Carlo result and measurement data.

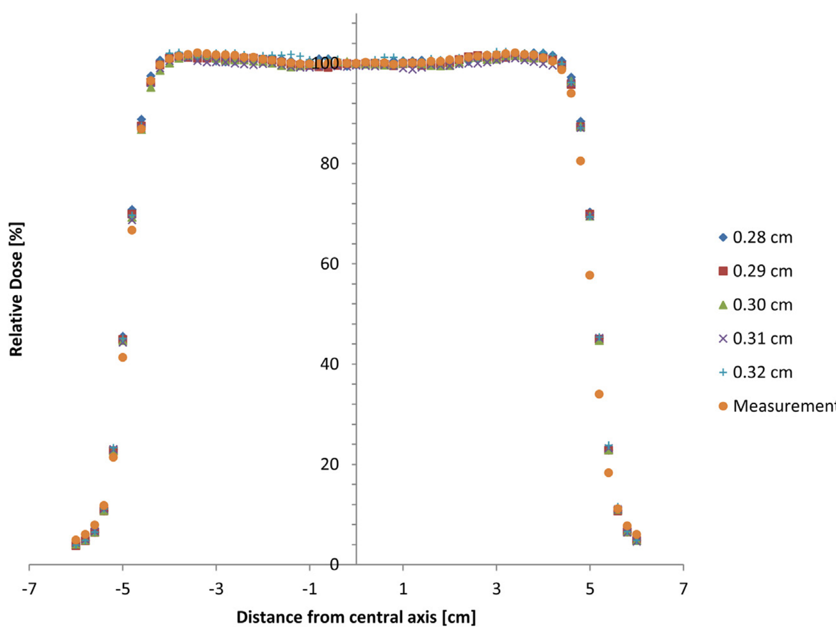

Fig. 4 – Lateral dose profiles for measurement and 0.28, 0.29, 0.30, 0.31, 0.32 cm FWHM.

increases, the absorbed dose increases at all depths. We observed that the doses of surface and build-up regions were the most sensitive when the electron mean energy changed. After normalization, the measurement data and Monte Carlo simulation were compared. Results obtained from comparing Monte Carlo simulation and measurement data by using gamma index criteria are shown in Table 1.

QI represents D20/D10. D20 is the dose at 20 cm depth. D10 is the dose at 10 cm depth. For 6.3 MeV electron mean energy, the comparison demonstrated good conformity between Monte Carlo simulation and measurement data. PDD curves for 6.3 MeV are shown in Fig. 3.

The important components that have a major influence on lateral dose profiles are flattening filter, JAW and MLC components. The lateral dose profile is very significant to confirm Monte Carlo simulation because it gives information about the accuracy of building of each component. For five different FWHM values, the lateral dose profiles were obtained at 100 cm of SSD for 6 MV photon beam, $10 \times 10\,cm^2$ and 1.6 cm depth. After normalization, the measurement data and Monte Carlo simulation were compared in Fig. 4.

For all FWHM values, symmetry and flatness can be seen well in the profiles. FWHM is connected with the spatial distribution of the electron beam hitting the target. This

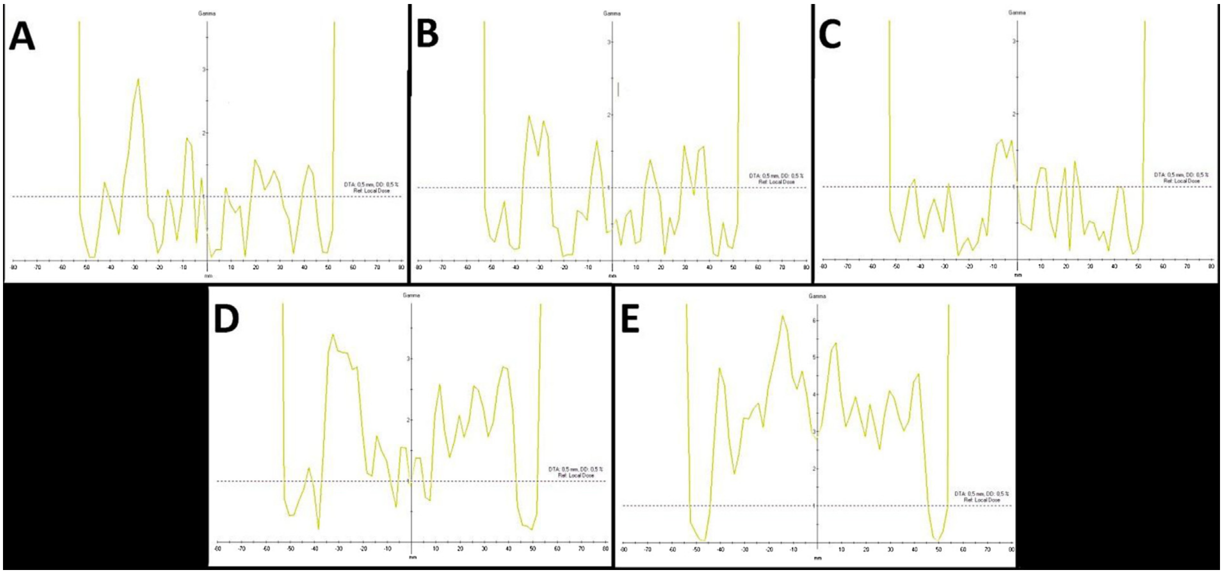

Fig. 5 – Gamma index results (A) 0.28 cm FWHM, (B) 0.29 cm FWHM, (C) 0.30 cm FWHM, (D) 0.31 cm FWHM, (E) 0.32 cm FWHM.

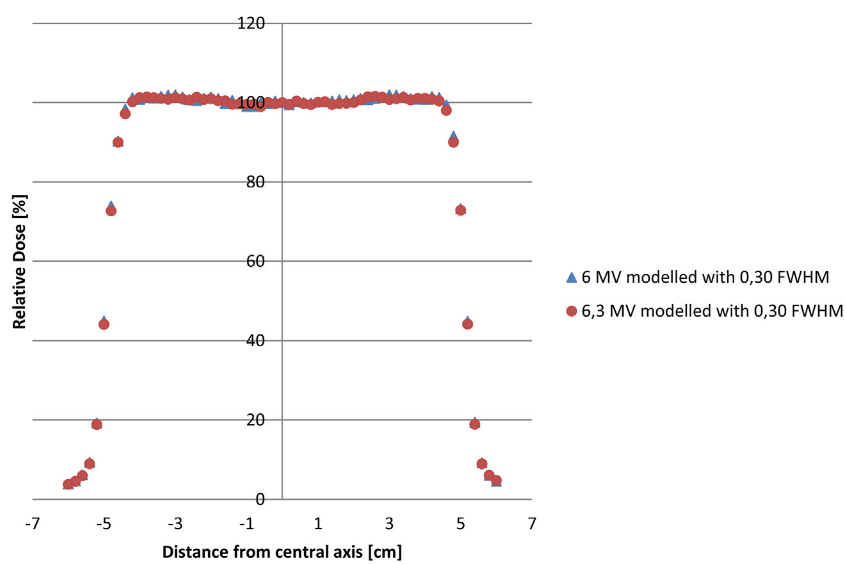

Fig. 6 – The comparison of different mean energies for the same FWHM value.

distribution is shaped as the 3D Gaussian. If we want to determine the FWHM value correctly, we have to examine the gamma index criteria. Gamma index results are shown in Fig. 5.

The gamma index criteria have a very important role to approve accurate FWHM on lateral dose profile. The tolerance values which are different between measurement and Monte Carlo are 0.5% for calculated dose and 0.5 mm for the position.

For flat and horn regions at 0.30 cm FWHM value, we obtained good conformity between Monte Carlo simulation and measurement data. This conformity in flat, horn and penumbra regions confirms that flattening filter and JAW-MLC sizes were accurately modeled using Monte Carlo.

When we wanted to examine the effect of FWHM values on the PDD and effect of energy on the lateral dose profile, we observed that FWHM values had very little effect on PDD. We found that the electron mean energy and FWHM values affected the lateral dose profile. However, these effects are between tolerance values. The effects are shown in Figs. 6 and 7.

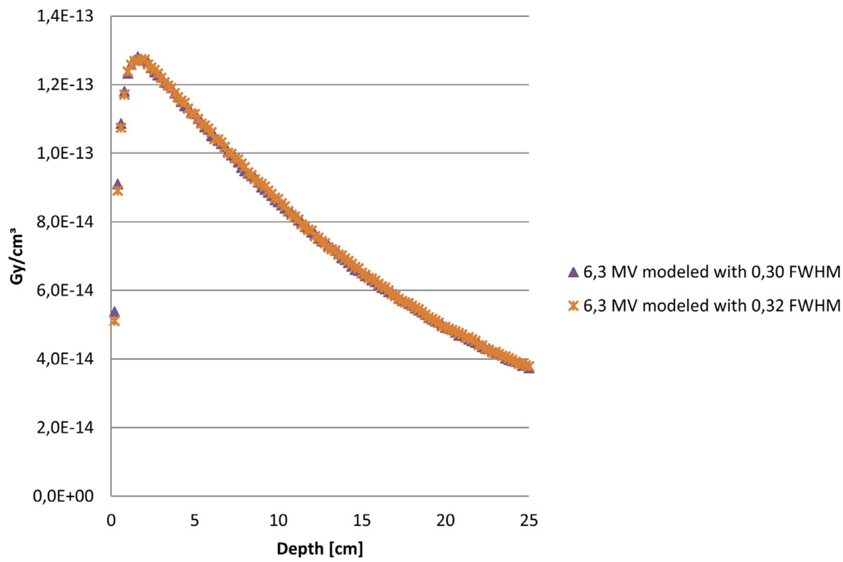

Fig. 7 – The comparison of different FWHM values for the 6.3 MeV electron energy on PDD.

5. Conclusions

The determination of the initial electron parameters is an important part of simulating radiation transfer using Monte Carlo methods. The initial parameters give some parameters of exit beam which include real mean energy and FWHM of beam. For Siemens Artiste Linac, PDD curves were obtained from Monte Carlo simulation at the field size of $10 \times 10\,cm^2$ for 6 MV beam with initial electron energy of 6, 6.1, 6.2, 6.3, 6.4 MeV with FWHM of 0.28, 0.29, 0.30, 0.31, 0.32 cm. Sheikh-Bagheri et al.[21] specified that the PDD curves were sensitive to varied mean energy but the lateral beam dose curves are sensitive both to mean energy and FWHM. We found the same result in this study. We also noted that different FHWM values did not show significant effect on PDD. Mohammed et al.[3] utilized IQ and gamma index criteria to find initial electron mean energy and FWHM value. In this study, we used these criteria to find initial electron parameters. Jabbari et al.[5] found the electron mean energy and FWHM values as 6.5 MeV and 0.31 cm, respectively. In another study, Chang et al.[2] found that the electron mean energy was 6.15 MeV and FWHM value was 0.03 cm. Bakkali et al.[14] obtained the best modeling of the incident electron source of a 6 MV by a mean energy of 5.6 MeV and a FWHM of 0.118 cm. We concluded that there existed a good conformity between Monte Carlo simulation and measurement data when we used electron mean energy of 6.3 MeV and 0.30 cm FWHM value as initial parameters. The initial parameters for 6 MV differ for each linac model. They especially depend on the target, flattening filter, size and material of components. The obtained results cannot by directly compared with other types of accelerators by different manufactures because each accelerator has specific components such as target, flattening filter, etc. The variance reduction technique helps to reduce the calculation time. Statistical uncertainty is reduced by using recycling and split parameters.

In this study, the important components were defined about Siemens Artiste Linac head. Then, the significant parameters were obtained. A small change in electron parameters creates strong effects on the dose. The phase space file which was obtained from Monte Carlo Simulation for the linac can be used as calculation of scattering, MLC leakage, to compare dose distribution on patients and in various studies.

Financial disclosure

None declared.

Conflict of interest

None declared.

REFERENCES

1. Aljamal M, Zakaria A. Monte Carlo modeling of a Siemens Primus 6 MV photon beam linear accelerator. *Aust J Basic Appl Sci* 2013;**7**(10):340–6.
2. Chang KP, Wang ZW, Shiau AC. Determining optimization of the initial parameters in Monte Carlo simulation for linear accelerator radiotherapy. *Radiat Phys Chem* 2014;**95**:161–5.
3. Mohammed M, Bardouni TE, Chakir E, Saeed M, Jamal AZ, Mohamed L. Validation of BEAMnrc Monte Carlo model for a 12 MV photon beam. *J King Saud Univ – Sci* 2017, http://dx.doi.org/10.1016/j.jksus.2017.07.001.
4. Makrani DS, Hasanzadeh H, Pourfallah TA, Ghasemi A, Jadidi M, Babapour H. Determination of primary electron beam parameters in a Siemens Primus Linac using Monte Carlo simulation. *J Paramed Sci* 2015;**6**(1). ISSN 2008-4978.
5. Jabbari K, Anvar HS, Tavakoli MB, Amouheidari A. Monte Carlo simulation of Siemens ONCOR linear accelerator with BEAMnrc and DOSXYZnrc code. *J Med Signals Sens* 2013;**3**:172–9.

6. Ayyıldız Ü. *EGSnrc Monte Carlo modeling of radiotherapy source and detectors using the multi geometry technique*. The Thesis of Celal Bayar University; 2005.
7. Kodaloğlu N. *Comparison of dose distributions of linear accelerator treatment planning system, Monte Carlo (BEAMnrc and EGSnrc) and in-vivo dosimetric measurement methods*. The Thesis of Hacettepe University; 2011.
8. Verhaegen F, Seuntjens J. Monte Carlo modelling of external radiotherapy photon beams. *Phys Med Biol* 2003;**48**:107–64.
9. Kawrakow I, Rogers DWO. *The EGSnrc code system: Monte Carlo simulations of electron and photon transport. National Research Council of Canada Report PIRS-701*. Ottawa: NRC; 2000.
10. Ma CM, Rogers DWO, Walters B. *DOSXYZnrc users manual. National Research Council of Canada Report PIRS-509*. Ottawa: NRC; 2001.
11. Chow JC, Jiang R, Owrangi AM. Dosimetry of small bone joint calculated by the analytical anisotropic algorithm: a Monte Carlo evaluation using the EGSnrc. *J Appl Clin Med Phys* 2013:15.
12. Aljarrah K, Sharp GC, Neicu T, Jiang SB. Determination of the initial beam parameters in Monte Carlo linac simulation. *Med Phys* 2006;**33**:850–8.
13. Almberg SS, Frengen J, Kylling A, Lindmo T. Monte Carlo linear accelerator simulation of megavoltage photon beams: independent determination of initial beam parameters. *Med Phys* 2012;**39**:40–7.
14. Bakkali JE, Bardouni TE. Validation of Monte Carlo Geant4 code for a 6 MV Varian linac. *J King Saud Univ – Sci* 2017;**29**:106–13.
15. Mihailescu D, Borcia C. Monte Carlo simulation of the electron beams produced by a linear accelerator for intraoperative radiation therapy. *Rom Rep Phys* 2014;**66**:61–74.
16. Rogers DWO, Walters B, Kawrako I. *BEAMnrc users manual. NRC Rep. PIRS* 509; 2017. p. 12.
17. Keall PJ, Siebers JV, Libby B, Mohan R. Determining the incident electron fluence for Monte Carlo-based photon treatment planning using a standard measured data set. *Med Phys* 2003;**30**:574–82.
18. Kawrakow I. Accurate condensed history Monte Carlo simulation of electron transport. I. EGSnrc, the new EGS4 version. *Med Phys* 2000;**27**:485–98.
19. Vazquez-Quino LA, Massingill B, Shi C, et al. Monte Carlo modeling of a Novalis Tx Varian 6 MV with HD-120 multileaf collimator. *J Appl Clin Med Phys* 2012;**13**:3960.
20. Tzedakis A, Damilakis JE, Mazonakis M, Stratakis J, Varveris H, Gourtsoyiannis N. Influence of initial electron beam parameters on Monte Carlo calculated absorbed dose distributions for radiotherapy photon beams. *Med Phys* 2004;**31**:907–13.
21. Sheikh-Bagheri D, Rogers DWO. Sensitivity of megavoltage photon beam Monte Carlo simulations to electron beam and other parameters. *Med Phys* 2002;**29**:379–90.