Validation of GEANT4 Monte Carlo Simulation Code for 6 MV Varian Linac Photon Beam

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ABSTRACT

The head of a clinical linear accelerator based on the manufacturer’s detailed information is simulated by using GEANT4. Percentage Depth Dose (PDD) and flatness symmetry (lateral dose profiles) in water phantom were evaluated. Comparisons between experimental and simulated data were carried out for two field sizes; 5 × 5, and 10 × 10 cm\textsuperscript{2}. The obtained results indicated that GEANT4 code is a promising and validated Monte Carlo program for using in radiotherapy applications.

Key Words: Monte Carlo Simulation; GEANT4; 6 MV Varian Linac

1. INTRODUCTION

Radiotherapy is the treatment of cancer and other diseases with ionizing radiation by damaging their genetic material, with no possibility to grow. Ionizing radiation deposits its energy that injures or destroys cells in the region of the target tissue being treated. The overall estimate for radiotherapy utilization is about 52\%, based upon the best available evidence \cite{1}.

Evaluation of dose distribution in oncological radiotherapy treatments is a salient problem that requires developed computing technologies to optimize the clinical results. This could be accomplished by increasing the dose to the cancerous tissues and reducing the dose to the healthy tissues. In recent years, the accuracy of dose calculation has improved together with the computing power available in radiotherapy departments. New mathematical approaches to dose calculation and optimization have been introduced in the clinical practice. Dose calculation algorithms, based on the Monte Carlo method, are generally regarded as one of the most accurate tools among the sophisticated algorithms \cite{1,2}. Most of the commercial Treatment Planning Systems (TPS) use analytic calculations and errors near the inhomogeneities for patients can be from 10 to 20\%. Such methods are less accurate for practical complex situations. Small irradiated volumes, limited in lateral and/or forward directions and interface regions are examples for this complex situation\cite{4}.

Alternatively, Monte Carlo calculations using GEANT4 (Geometry and Tracking, Version 4), can be used for accurate dose calculations. This technique represents a powerful tool for simulation of complex geometrical shapes and material composition by using different GEANT4 physics models.
GEANT4 is an object-oriented toolkit developed to simulate the passage of particles through matter\(^5\). It has several physics models, including the interactions of electrons, muons, hadrons and ions within matter from 250 eV up to several PeV. Moreover, GEANT4 applications are developed, not only in particle physics, but also in many other fields; where high accuracy and precision of simulations are required. Some of these applications are: high energy physics, astrophysics, medical physics, radiation protection\(^6\) and radiotherapy dosimetry\(^7,8,9\). In GEANT4, we have three models of electromagnetic (EM) Physics packages, namely: Standard, Low Energy and Penelope. The Low Energy Package is developed to extend electromagnetic interaction of particles with matter down to very low energy; 250 eV for electrons and photons\(^10\).

The comprehensive validation of the physics models is essential in order to guarantee the accuracy and reliability of GEANT4-based simulations. Statistical GEANT4 photon models are validated with the NIST datasets\(^12\). In the present work, a Monte Carlo simulation for medical linear accelerator (Linac) VARIAN type, using GEANT4 is introduced.

2. MATERIALS AND SIMULATION METHOD

In this study, the head of a clinical linear accelerator (VARIAN 600C) based on the manufacturer’s detailed information is simulated by using the GEANT4 Monte Carlo code. Simulation of percentage depth dose distribution (PDD) and flatness symmetry in water phantom were performed. Comparison between experimental and simulated data was executed for three field sizes 5 × 5, 10 × 10 and 15 × 15 cm\(^2\).

The simulation processes were performed on two stages: the first stage was the simulation of the accelerator gantry resulting in phase space file formation. The second stage was the interaction simulation of the recorded phase space particles with a water phantom resulting in dose distribution for two different field sizes: 5 × 5 and 10 × 10 cm\(^2\) at the isocenter.

2.1. Simulation of the Linac Gantry (Phase Space Formation):

The head of a 6MV-VARIAN-clinical linear accelerator based on the manufacturer’s detailed information was simulated by using the Low-Energy GEANT4 physics model of GEANT4_9_5 Monte Carlo code. The developed program in C++ language using GEANT4 libraries was built to simulate the gantry of a VARIAN 600C LINAC. During the physics setting construction, the geometry specification of the accelerator and the beam energy were taken into consideration. A schematic diagram of the simulated linear accelerator gantry is shown in Fig.1. The figure shows that the Linac components are: an electron gun, collimator, ion chamber, mirror, flattening filter, jaws, and multi-leaf collimator.

A 6 MV circular electron beam with a radius of 0.5 mm, with a Gaussian energy distribution, is accelerated down to hit the tungsten target and bremsstrahlung photons are created. These photons and secondary particles are randomly produced: and the majority is directed towards the flattening filter, monitor chamber, mirror and a pair of Jaws.
The simulations were performed in the first stage by creating a phase-space file between the jaws and the primary collimator with ~70 million events generated by using more than $2 \times 10^9$ primary electrons. The phase-space file contains information concerning energy, orientation, type, charge and position of the particles crossing the scoring plane. Based on this created phase space file, dose depositions in a water phantom were simulated as a second stage.

2.2 Simulation of Dose Distribution in the Water Phantom:

A water phantom, with dimensions of 48cm×48cm×35cm, was simulated with a source-surface distance (SSD) whose value is 100 cm. The phantom was divided into 5x5x5 mm$^3$ voxels, where the percentage depth dose (PDD) and the flatness symmetry for different field sizes are calculated at three depth positions, namely: 15, 50 and 100 mm. The obtained data were normalized to 100% relative to the maximum dose. Using the phase space data file obtained from the first stage, the interaction of particles with the water phantom is simulated. All calculations were executed using Intel 2 quad core CPU of 3.00 GHz processor.

2.3 Comparison with Experimental Data Dose Measurements:

Dose measurements were carried out though a computerized Welhofer WP 700 water phantom (version 3.5). The phantom consists of a water-filled tank, with a scanning volume of $48 \times 48 \times 35$ cm$^3$, and two cylindrical water-proof ion chambers, each of sensitive volume 0.147 cm$^3$ and wall thickness of 0.4 mm (RFA 300 Scanditronix). For uncertainty evaluation, measurements were repeated at least two times [12]. Comparisons with experimental data were performed for all simulation results.
3. RESULTS AND DISCUSSIONS

The energy spectrum of the obtained phase space particles is illustrated in Fig. 2. It was found that the mean electron beam energy of 6.5 MeV is the best fit for the measurements after several simulation trails.

![Energy spectrum of phase space particles](image)

**Fig. (2):** Energy spectrum of phase space particles

Fig. 3(a) shows the simulated percentage depth dose (PDD) in comparison with the corresponding experimental data for 5×5 cm$^2$ field size. The lateral dose profiles at 15, 50 and 100 mm depths for the 5 ×5 cm$^2$ field are presented in Fig. 3(b).

Fig. 4(a) illustrates a comparison between simulated and corresponding experimental data for the percentage depth dose (PPD) of 10×10 cm$^2$ field size. In figure 4(b), the lateral dose profiles at 15, 50, and 100 mm are shown. The results show acceptable agreement between computed and measured PDD. Apparently, this is mainly due to the lesser number of particle hits resulting in increasing the uncertainty level at higher depths. Moreover, the lateral dose profiles at 15, 50, and 100 mm depths are compatible with the measured values.
**Fig. 3(a):** Depth-dose profile at 15, 50, and 100 mm depth for 5cm×5cm field with a 6-MV beam.

**Fig. 3(b):** Lateral dose profiles at 15, 50, and 100 mm depth for 5cm×5cm field with a 6-MV beam.
Several possible factors probably affect the level of agreement obtained in this study: the level of precision of experimental data itself, the uncertainties in component geometry and material composition, the GEANT4 physics models and the effects of actual setting of the treatment room.

**Fig. 4(a):** Depth-dose profile for 10cm×10cm field with a 6-MV beam.

**Fig. 4(b):** Lateral dose profiles at 15, 50, and 100mm depth for 10cm×10cm field with a 6-MV beam.
4. CONCLUSIONS

A 6 MV high energy photon VARIAN type Linac was simulated. The computed (PDD) and the flatness symmetry are compared with experimental measurements in water phantom for two field sizes: 5 × 5 and 10 × 10 cm². Results indicate acceptable agreement between computed and measured PDD. Moreover, the lateral dose profiles at 15, 50, and 100 mm depths are compatible with the measured values.

Accordingly, this study emphasizes that GEANT4 is capable of modeling various types of medical Linac gantries; which could enviably assist in estimating dose to patients administrated at critical positions where normal measurements are unachievable.

REFERENCES