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Original article

Measurement of depth-dose of linear accelerator and simulation by use of Geant4 computer code

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ABSTRACT

Radiation therapy is an established method of cancer treatment. New technologies in cancer radiotherapy need a more accurate computation of the dose delivered in the radiotherapy treatment plan. This study presents some results of a Geant4-based application for simulation of the absorbed dose distribution given by a medical linear accelerator (LINAC). The LINAC geometry is accurately described in the Monte Carlo code with use of the accelerator manufacturer's specifications. The capability of the software for evaluating the dose distribution has been verified by comparisons with measurements in a water phantom; the comparisons were performed for percentage depth dose (PDD) and profiles for various field sizes and depths, for a 6-MV electron beam. Experimental and calculated dose values were in good agreement both in PDD and in transverse sections of the water phantom.

1. Introduction

In recent years, the accuracy of dose calculation has improved together with the computing power available for radiotherapy. The Monte Carlo method has been considered as an alternative to analytical methods for treatment planning in cancer radiotherapy.[1,2]

The feasibility of beam modelling for radiotherapy planning has to be demonstrated by calculation of dose distributions and their comparison to measurements. Simple beam models are used as an effective and rapid way of calculating dose distributions in an irradiated medium.

In the present work, the depth-dose distribution was reproduced based on a Geant4 (Geometry And Tracking, Version 4) Monte Carlo method. The Geant4 Simulation Toolkit[3,4] was first used in 1994 in a research project for a new general purpose simulation code for high energy physics. As one of the first large object-oriented software applications in physics, Geant4 has become the standard simulation package for most HEP experiments, including three of the four experiments at the Large Hadron Collider (LHC).

However, the use of Geant4 is increasing rapidly. For medical physics applications, this code has some advantages over other codes such as EGSNRC, XVMC, MCNP, PENELOPE, and FLUKA.[4]

Geant4 can handle all types of particles, and it is able to handle complex geometries. Geant4 offers the most flexible geometry description among all Monte Carlo codes. Another appealing characteristic of Geant4 is its use of modern programming techniques (object-oriented, C++); all other codes currently in use are in FORTRAN. Another unique aspect of

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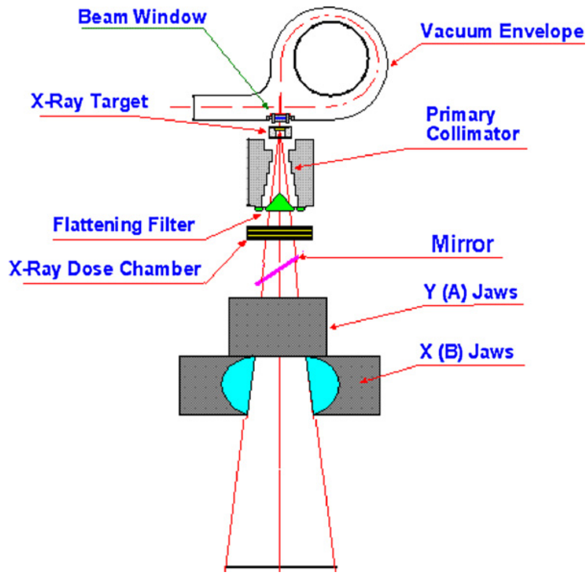

Fig. 1 – Structure of gantry in Siemens Primus linear accelerator, for 6-MV beam.

Geant4 is that it can model sources and geometries in motion, such as the rotating parts of an IMRT (intensity modulated radiation therapy) beam line, dynamic MLCs (multi-leaf collimators), a brachytherapy source moving through a catheter, moving parts of imaging systems, and even the motion of patient organs due to respiration, etc.[5]

Geant4 has the ability to handle both electric and magnetic fields. This can be helpful in simulation of novel, real-time imaging and treatment modalities where the treatment is performed in the presence of a magnetic field. Finally, Geant4 is open access and the source code is freely available.[6] It is distributed to the user who is welcome not only to add a user code, but to modify the source code and even to repackage, redistribute or sell the modified source code.

2. Materials and methods

In this study, we simulated the head of a clinical linear accelerator (Siemens Primus) based on the manufacturer's detailed information by use of Geant4 Monte Carlo code.

Geant4 was developed at CERN for use with the LHC and is an object-oriented[7,8] Monte Carlo simulation toolkit. Geant4 was developed to simulate the passage of particles through matter. It contains a large variety of physics models, covering the interactions of electrons, muons, hadrons, and ions with matter from 250 eV up to several peta-electron volts (1 PeV = 10^{15} eV).[8,9]

In the present study we developed a dedicated program in C++ language using Geant4 libraries that enables us to simulate the gantry of a Siemens Primus LINAC.

2.1. *Simulation of the Siemens Primus accelerator gantry*

The components of a linear accelerator for a 6-MV photon beam are shown in Fig. 1. In external radiotherapy, the X-ray treatment fields are usually delivered by a medical linear accelerator. Electrons are accelerated inside a waveguide up to the desired treatment energy, in this case approximately 6 MeV.

Target: The target creates Bremsstrahlung X-rays with a thin tungsten disk of approximately 1 mm height. The remaining primary electrons are absorbed in a graphite absorber inside the target. The target is of cylindrical design with a height of about 1.5 cm and a diameter of approximately 3 cm. The parameters of the primary electron beam hitting the target, including its energy, angular distribution, and spatial distribution, were chosen in order to minimize the discrepancies between simulation results and measured data. For the Geant4 code, we chose a parallel electron beam hitting the target with a Gaussian energy distribution with variance σ = 0.127 MeV.

Primary collimator: The primary collimator was made of tungsten. Basically it is a cylinder with cylindrical holes drilled into it. The primary collimator absorbs photons that are

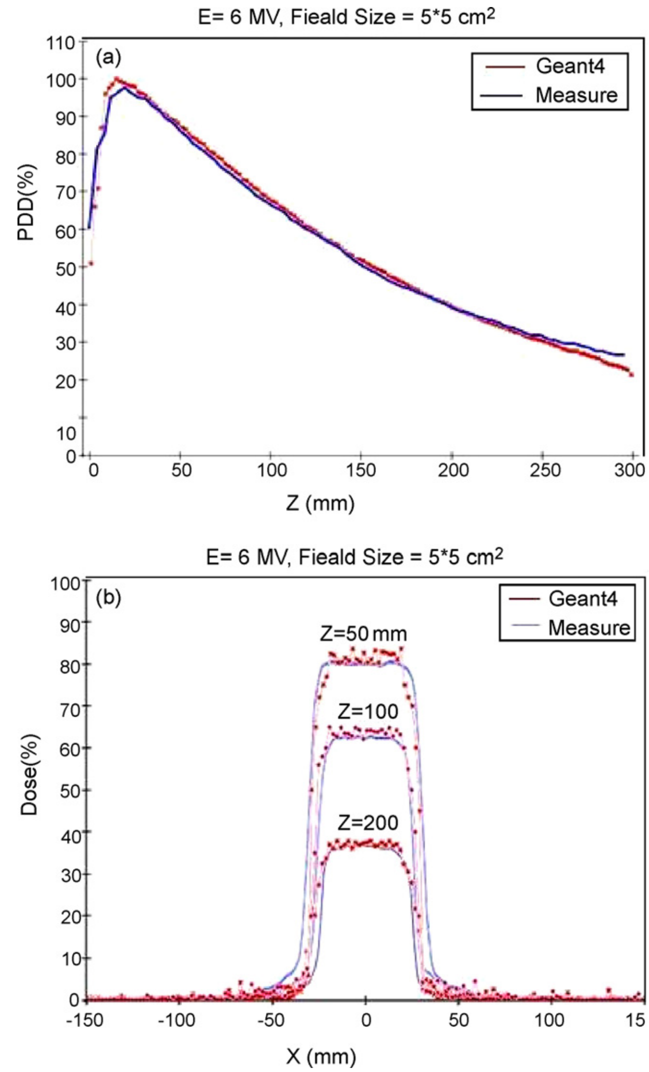

Fig. 2 – (a) Depth-dose profile. (b) Lateral dose profiles at 50, 100, and 200 mm depth for the 5 cm × 5 cm field, with the 6-MV beam. The blue lines refer to measured data; red dots refer to Geant4 Monte Carlo results.