Hindawi Publishing Corporation
Journal of Radiotherapy
Volume 2014, Article ID 343979, 7 pages
http://dx.doi.org/10.1155/2014/343979

Research Article

FLUKA Monte Carlo for Basic Dosimetric Studies of Dual Energy Medical Linear Accelerator

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Received 29 January 2014; Revised 9 July 2014; Accepted 9 July 2014; Published 24 July 2014

Academic Editor: Tibor Major

General purpose Monte Carlo code for simulation of particle transport is used to study the basic dosimetric parameters like percentage depth dose and dose profiles and compared with the experimental measurements from commercial dual energy medical linear accelerator. Varian Clinac iX medical linear accelerator with dual energy photon beams (6 and 15 MV) is simulated using FLUKA. FLAIR is used to visualize and edit the geometry. Experimental measurements are taken for 100 cm source-to-surface (SSD) in $50 \times 50 \times 50\ cm^3$ PTW water phantom using 0.12 cc cylindrical ionization chamber. Percentage depth dose for standard square field sizes and dose profiles for various depths are studied in detail. The analysis was carried out using ROOT (a DATA analysis frame work developed at CERN) system. Simulation result shows good agreement in percentage depth dose and beam profiles with the experimental measurements for Varian Clinac iX dual energy medical linear accelerator.

1. Introduction

Monte Carlo (MC) method has become a powerful tool in radiation therapy for studying the dosimetric parameters. It is a common objective of medical physics to achieve an accuracy of better than ±5% for the delivery of dose. But this can be realized only if the dose calculation accuracy is better than ±2%. Therefore, in the future, Monte Carlo algorithms will have a clear preference compared with all other methods of dose calculation. At present, different Monte Carlo codes are used widely for modeling medical linear accelerators [1–4].

Monte Carlo methods are applied in radiation therapy to analyze the adequacy of linac head components, to benchmark dose calculation models, and to study the beam characteristics [5, 6]. Modeling of medical linear accelerator in clinical environments using any Monte Carlo models is quite complex to address source definition and collimator materials definitions. Commercial manufactures of medical linear accelerators are distributing limited versions with confidence of agreements. Different approaches are suggested in many literatures to quantify this limited knowledge for modeling [7, 8]. Percentage depth dose (PDD) and beam profiles are the basic parameters to ensure the adequacy of Monte Carlo modeling [9].

Monte Carlo for treatment planning is practically impossible in Indian scenarios, where there are a large number of patients with limited facilities. A Monte Carlo model takes considerable time to optimize individual treatment plans. However, the beam characteristic and other parameters can be tuned using any available Monte Carlo codes for all clinical institutions [10]. Time consuming process for Monte Carlo calculations is greatly influenced in our study to make simple and reliable model to mimic the clinical scenario.

In this study, we modeled a commercial medical linear accelerator, Varian Clinac iX, using FLUKA [11, 12] Monte Carlo code by using FLAIR [13] (FLUKA Advanced Interface) as per the manufactures recommendations. Percentage depth dose (PDD) values and lateral profiles of dose deposition were evaluated for standard square field sizes. Our results are compared with the experimental data taken from Varian Clinac iX machine. CERN developed ROOT v5-34 [14] software is used for analysis.

2. Materials and Methods

2.1. FLUKA Monte Carlo Calculations. Dual energy photon beam from Varian Clinac iX (Varian Medical Systems, Palo Alto, CA, USA) is modeled using FLUKA Monte Carlo. We simplified this model without altering any components in the linac head as per manufactures description. Version 2011.2b.4 (updated in 11 September 2013) of FLUKA code was utilized in the present research. This code is a multipurpose Monte Carlo code which has been developed for accurate simulation of the interaction and propagation in matter of about 60 different particles, including photons and electrons from 1 keV to thousands of TeV, neutrinos, muons of any energy, hadrons of energies up to 20 TeV and all the corresponding antiparticles, neutrons down to thermal energies, and heavy ions. A well-described physical phenomenon in our energy range is the power of this tool.

Figure 1 shows major components including target, primary collimator, fattening filter, and secondary collimator jaws. Actual components combination is not shown in the figure, because of confidence of agreement signed with the manufacturer. Target with tungsten coupled with copper is defined in the simulation. Primary and secondary collimators are defined using tungsten. Water phantom of 50 × 50 × 50 cm^3 cube is defined at 100 cm from the target with 1 cm plastic outer covering layer except in beam entrance plane.

FLAIR gives wide options to choose desired FLUKA input cards (the type of interaction and transport thresholds can be set in the physics and transport section of the cards). EMCASCA card is used as a default in both cases. Number of primary photons for this study was set at 5×10^7 for 6 MV and 8×10^7 for 15 MV histories in 5 cycles. Electromagnetic intersection input file was carried out in electromagnetic FLUKA cascade mode [12]. A production threshold of 10 keV is used for EMF and 50 keV for delta ray production.

2.2. Dose Measurements. All the measurements were carried out by Scanditronix automatic water phantom (Blue Phantom, Scanditronix Wellhofer AB, Sweden) and a cylindrical ionization chamber of 0.12 cm^3 active volume. Both PDD curves and beam profiles were taken using 1 mm step size for measurements. For comparison 2 mm readings were considered to obtain better illustration in PDD and 1 mm binning for profile plots. Beam quality measurements were carried out using TPS 20/10 on both energies before the data taking. Room lasers and standard scalars are used for accurate position of water phantom.

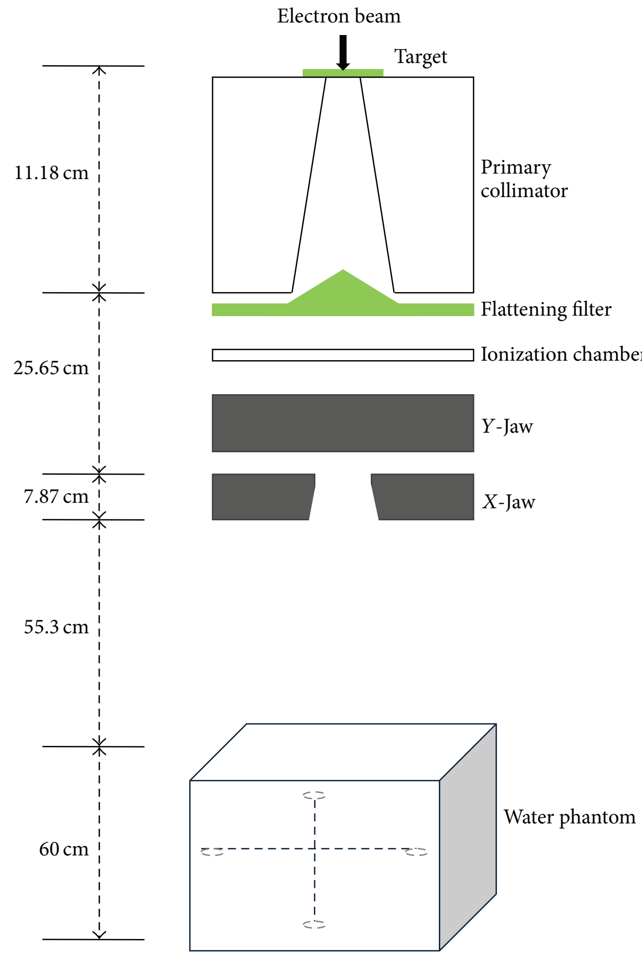


Figure 1: The schematic representation of Varian Clinac iX medical linear accelerator and water phantom simulated in our study.

2.3. Beam Energy Optimization. Standard 10 × 10 cm^2 field size is used to obtain the beam energy for both photon energies. Percentage depth dose for this field size is compared between Monte Carlo calculated and the measurements. This is a common approach by many authors [1, 9] for beam energy optimization.

Three independent measurements were taken to reduce the uncertainties in maximum dose point and the comparison is performed to this normalized point. Initial energy value of photon beam is taken as the default value as set by the manufacturer. Further, the value was increased or decreased according to the result of the first comparison between calculations and measurements. In 6 MV photon beam, the energies of 6.0, 6.2, 6.3, and 6.4 MeV were simulated and for 15 MV photon beam, the energies of 15.0, 15.2, 15.3, and 15.4 MeV were simulated. Local differences

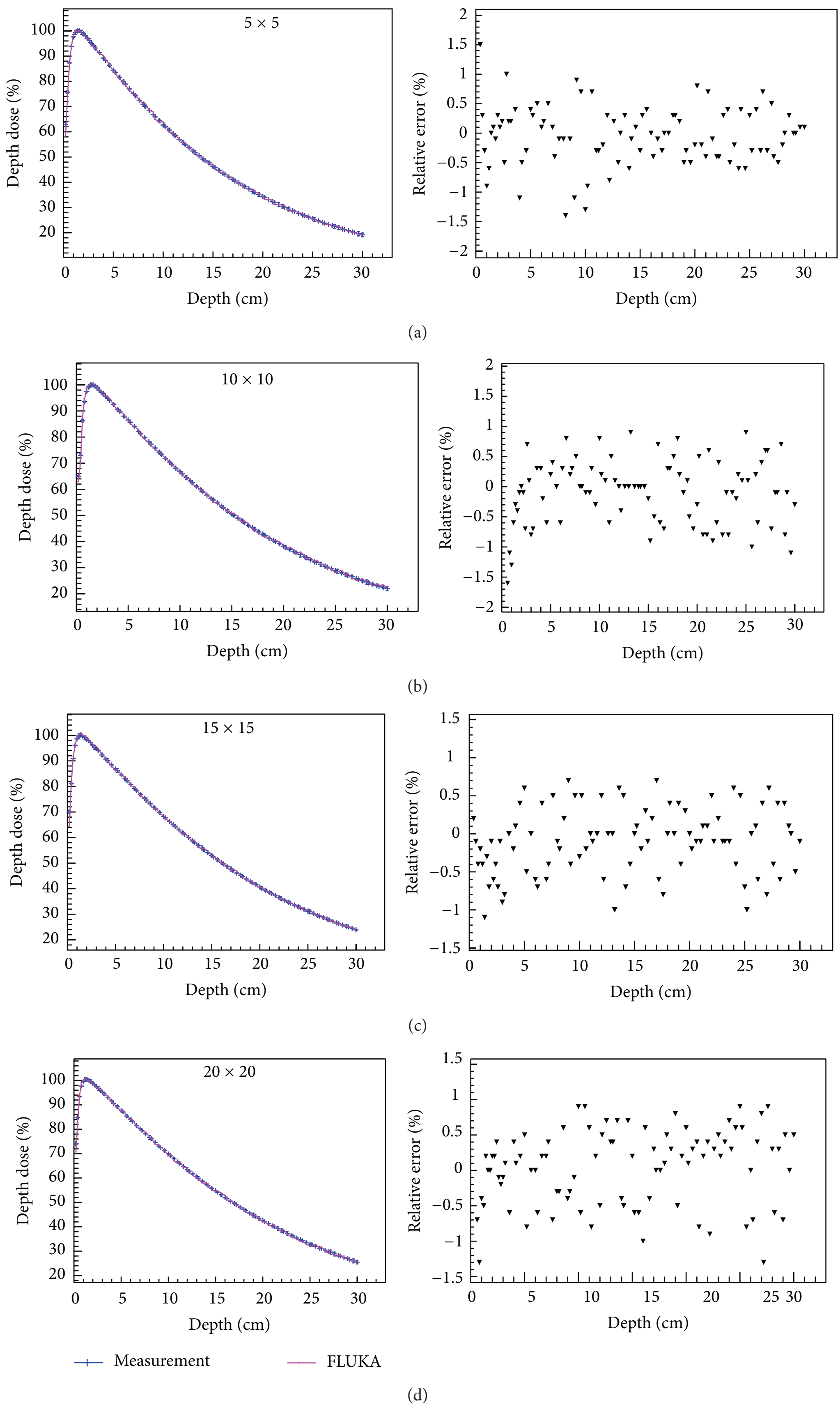


Figure 2: Comparison of calculated and measured percentage depth dose for 6 MV photon beam for field sizes $5 \times 5\,cm^2$ (a), $10 \times 10\,cm^2$ (b), $15 \times 15\,cm^2$ (c), and $20 \times 20\,cm^2$ (d). Relative error is shown on right side.

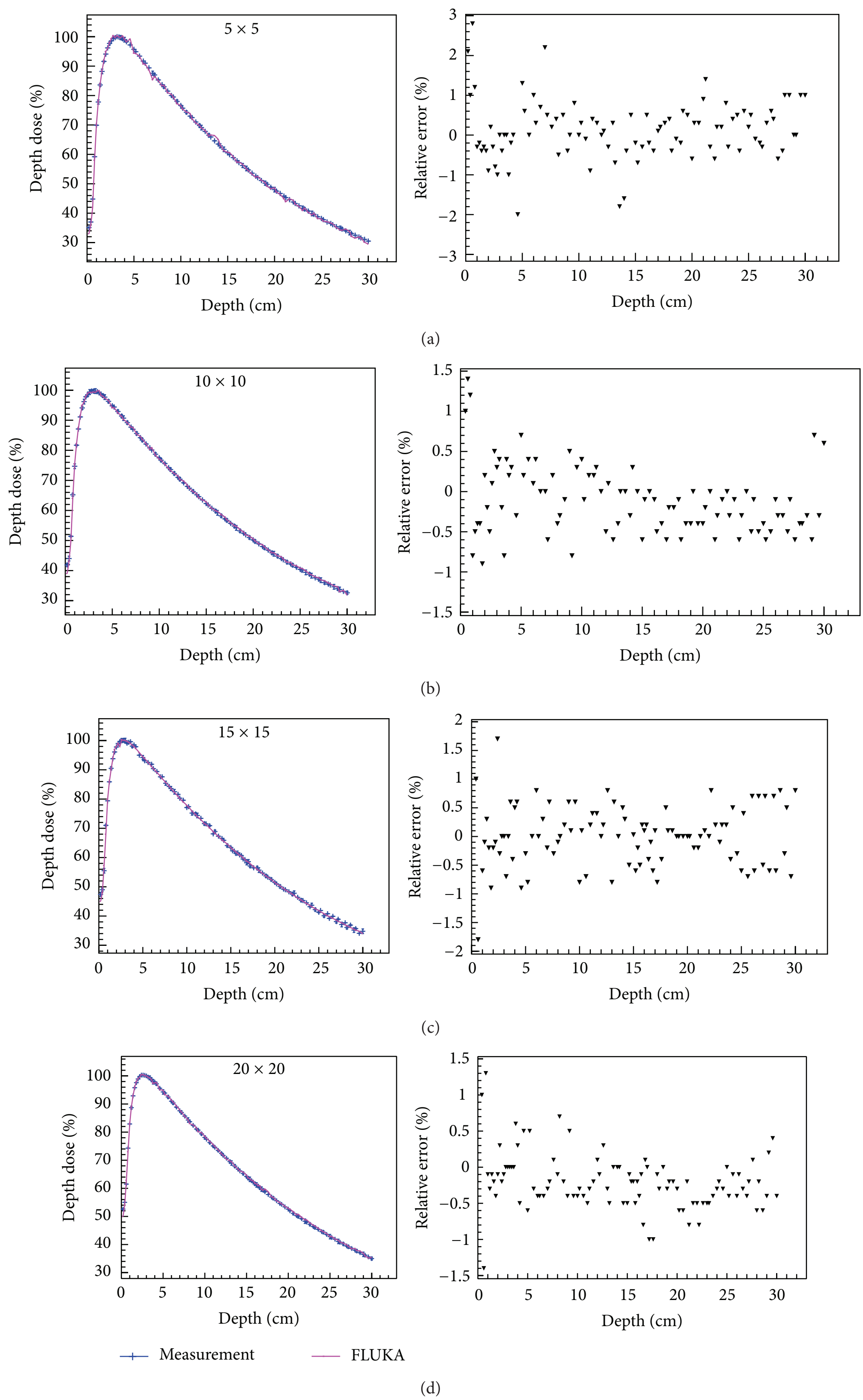
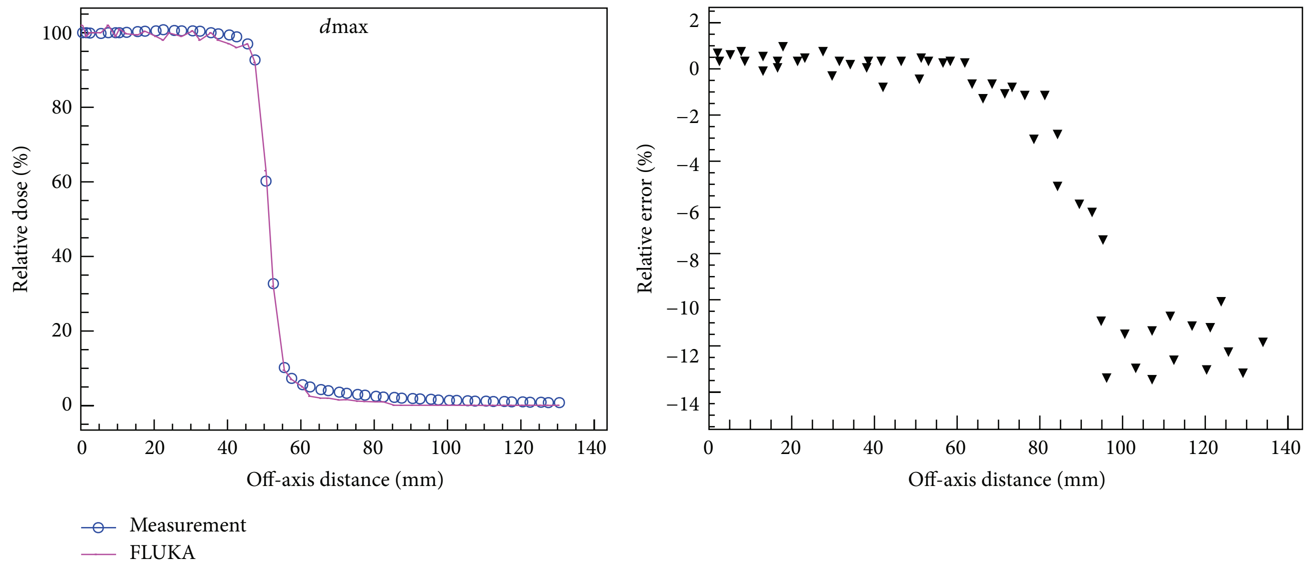
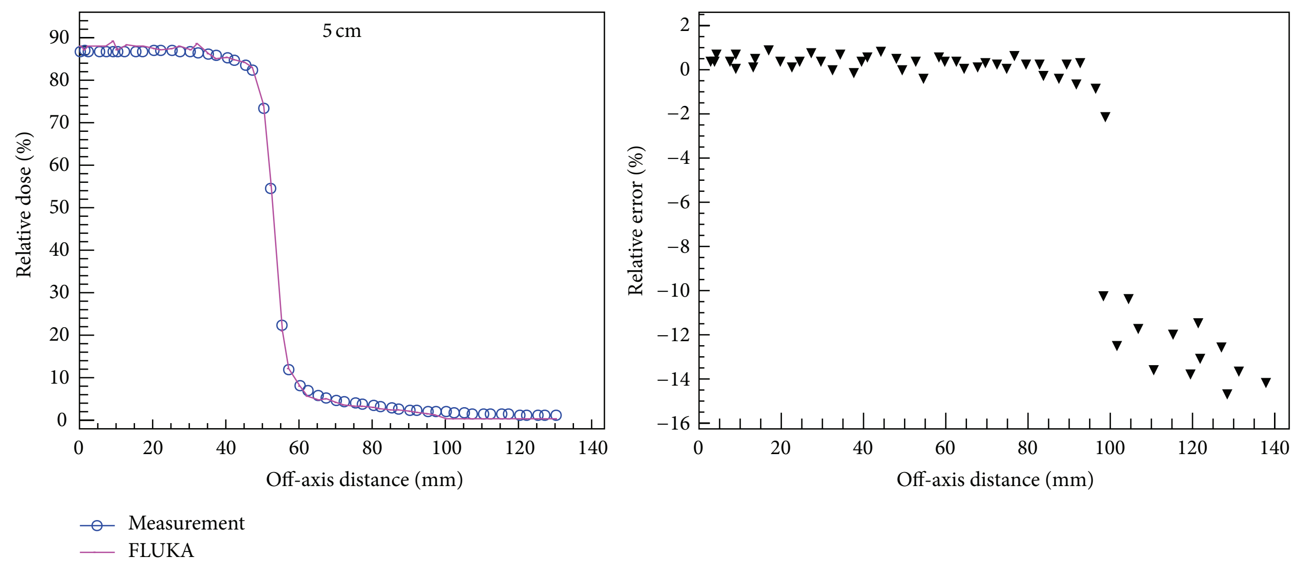


FIGURE 3: Comparison of calculated and measured percentage depth dose for 15 MV photon beam for field sizes $5 \times 5\,cm^2$ (a), $10 \times 10\,cm^2$ (b), $15 \times 15\,cm^2$ (c), and $20 \times 20\,cm^2$ (d). Relative error is shown on right side.



(a)



(b)

FIGURE 4: Comparison of calculated and measured depth dose profile and relative error (right side) for 6 MV photon beam for depth of maximum dose (a) and 5 cm depths (b).

between simulation and measurement results were calculated for accurate comparison between results.

2.4. PDD and Beam Profile Comparison. Using the modeled dual energy linac, percentage depth dose and beam profiles were generated. PDD of both energies for $5 \times 5\,cm^2$, $10 \times 10\,cm^2$, $15 \times 15\,cm^2$, and $20 \times 20\,cm^2$ were generated using FLAIR of FLUKA Monte Carlo. This study estimates the accuracy and adequacy of our simplified model. The beam profiles of 6 and 15 MV photon, including sharp dose fall off penumbra region (dose region between 80% and 20%) for $10 \times 10\,cm^2$ at depth of maximum dose and at 5 cm depth is compared in this study.

3. Results and Discussion

The Monte Carlo simulated percent depth dose curves and profiles across the central axis for flattened beams at different depths were compared against the measured data to verify the goodness of the MC model. The PDD curves are only sensitive to the mean energy of the incident electron, but dose profile curves are both dependent on the mean energy. Therefore, logically, one can use PDD to find the optimal energy. In our study $10 \times 10\,cm^2$ field size is used to optimize the beam energy. The optimum beam energy for 6 MV and 15 MV clinical photon is found as 6.2 MeV and 15.3 MeV. These values are largely dependent on the Monte Carlo models where linac head components are simulated.

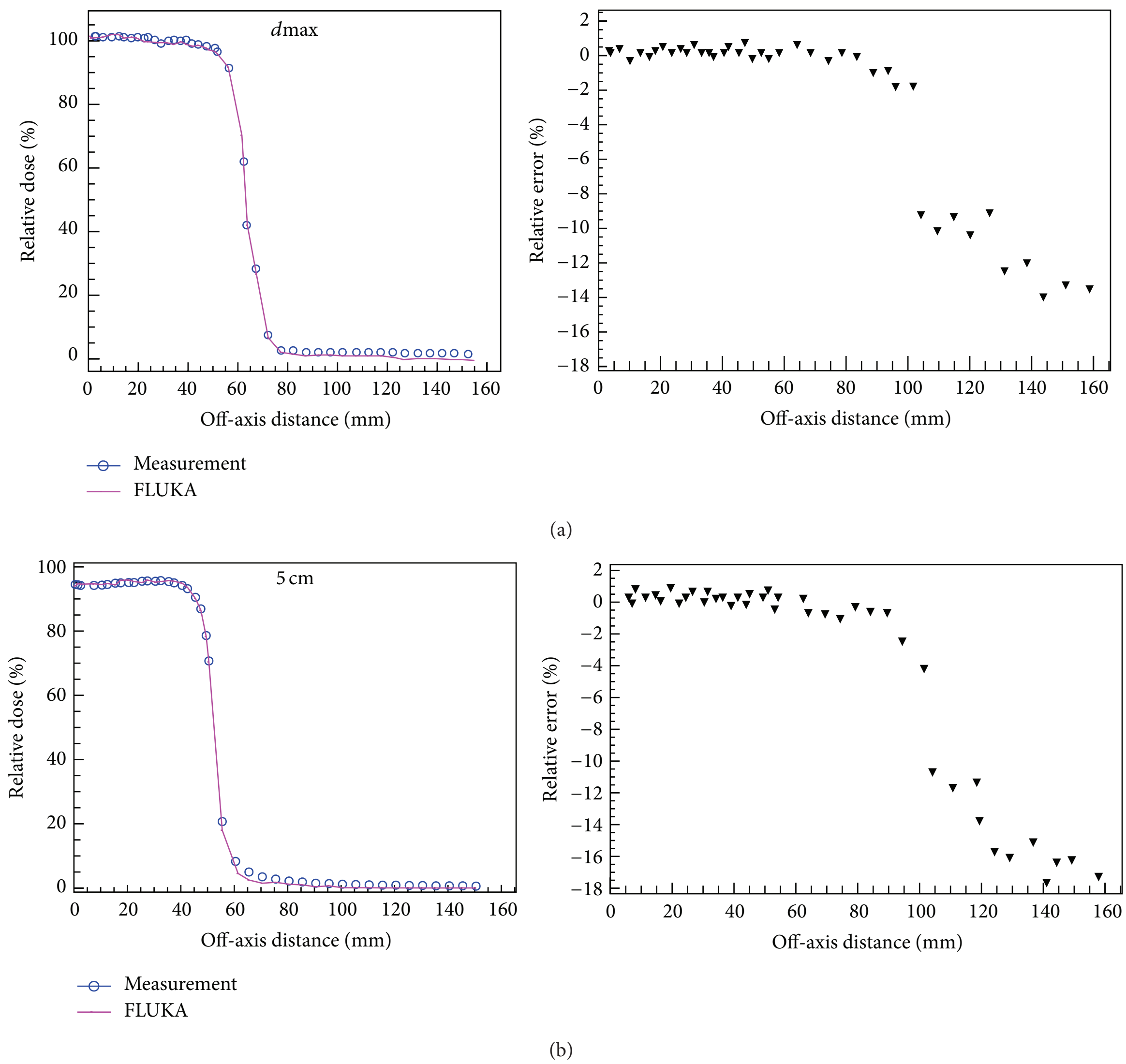


Figure 5: Comparison of calculated and measured depth dose profile and relative error (right side) for 15 MV photon beam for depth of maximum dose (a) and 5 cm depths (b).

3.1. Depth Dose Curves Comparison. A comparison for the depth dose curves is shown in Figures 2 and 3. It can be concluded from the above figures that the Monte Carlo model for 6 and 15 MV photon beam accurately matches the measured data, while central axis depth dose curves for the 6 and 15 MV flattened beams for $5 \times 5\,\text{cm}^2$, $10 \times 10\,\text{cm}^2$, $15 \times 15\,\text{cm}^2$, and $20 \times 20\,\text{cm}^2$ show good agreement between measurement and simulation. Relative errors ((calculated − measured)/calculated) over the depth are plotted separately in the previously mentioned figures. This small variation may be due to the changes in the geometry, especially in the truncated shape of flattening filter. Larger field sizes are not considered in this work due the limited use of such fields in our routine clinical practice.

3.2. Beam Profile Comparison. A cross-plane dose profiles comparison is shown in Figure 4 for 6 MV and Figure 5 for 15 MV photon beam. It is found that the Monte Carlo model has good agreement with the measured data from the previously mentioned figures. The flat region (within the field definition) is 2-3%. The difference in the penumbra is about 10%. The dose profile have a difference of 10–15% between data and simulation with in the field and high energy photon beam have a difference of 12%–18% in out-of-field (low dose) region. In the outside beam edge, our results were in agreement with previous studies [15, 16] where Monte Carlo predicts 20%–30% lower dose than the measurements.

4. Conclusion

This simplified FLUKA Monte Carlo model (avoiding the multileaf collimator) of Varian Clinac iX linac, based on the manufacturer's information, gives good agreement in percentage depth dose curves and beam profile plots. Monte Carlo model with retracted multileaf collimator shows perfect agreement for basic physical properties in standard field sizes. Although percentage depth dose values in the build-up region show more dependence on the field size (Figures 2 and 3), we commissioned calculation results for percentage depth dose curves and beam profiles (Figure 4) for different field sizes using recommended criteria for photon beam models. Measurements and simulation agrees better (<2%) in the flat regions of beam profiles, while the out-of-field regions have a discrepancy of 10%–15%.

Conflict of Interests

The authors declare no conflict of interests.

Acknowledgments

The authors sincerely acknowledge the assistance provided by Professor Roberto Cirio (INFN and University of Torino, Italy). The authors are grateful to Dr. Vincenzo Moncao (INFN and University of Torino, Italy) for his periodic suggestions and fruitful discussion.

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