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MODELING OF PHOTON AND ELECTRON BEAMS FOR MONTE CARLO SIMULATION BASED ON TREATMENT PLANNING SYSTEMS

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Abstract

Monte Carlo simulation (MC simulation) is considered the golden standard for radiation transport. In order to calculate the dose by Monte Carlo simulation based on treatment planning systems (TPSs), the detailed geometry of the medical linear accelerator (linac) treatment head components must be accurately modeled. Thus in the present work, photon and electron beams from Varian trilogy machine were simulated using Monte Carlo method. Simulated Percentage depth doses (PDDs) and profiles were compared to measurement for both photon and electron beams. We have presented simulated PDDs and profiles for 6 MV photon beams with 4 x 4 cm^2, 6 x 6 cm^2, 10 x 10 cm^2, and 20 x 20 cm^2 field areas, we also presented simulated and measured 6 MeV electron beams for 6 x 6 cm^2, and 10 x 10 cm^2 field areas. Analysis showed good matching between the simulation and measurement. It can be concluded that Monte Carlo code was capable of modeling both photon and electron beams. It was shown that Monte Carlo simulation is a powerful tool in radiotherapy (RT) research.

Key words: Radiotherapy (RT), Monte Carlo simulation code (MC simulation code), the Percentage Depth Dose (PDDs), Treatment Planning Systems (TPSs).

Introduction:

Radiotherapy is playing a great and an important role in the treatment of cancer (1,2,3). Radiotherapy aims to deliver a radiation dose to the tumor which is high enough to kill all tumor cells (4,5). This can be a difficult task from the physical and the technical point of view, because malignant tumors often are located close to radiosensitive organs, these so-called organs at risk must not be damaged during radiotherapy. For this difficult task, new technologies in radiation oncology as 3D conformal radiotherapy (3D CRT) (6), Intensity-modulated radiation therapy (IMRT) (7), and Modulated electron therapy (MET) (8,9,10) was developed in order to, enhance local tumor control (11). In addition many in-house and commercial Treatment Planning Systems (TPSs)(12,13,14) were developed for accurate generation of treatment plans. In recent years, the sophistication and complexity of the clinical treatment planning and treatment planning systems has increased significantly. A major advance in dose calculation methods occurred when radiation was decomposed into its primary and scatter components. In fact, the evolution of algorithms has been marked by a steady progressive decomposition of the dose components. The advantage is that each component can be adjusted independently for beam shape, beam intensity, surface topology of the patient, and internal tissue densities. Scatter contributions from various subvolumes of different shape can, however, be isolated if data are available for a variety of depths and field areas [15]. The Algorithms for Dose Calculation have been taken two approaches [16,17], one is correction based methods and the second is Model based methods. In correction-based methods, the starting point is always the dose distribution for an all-water absorber, with secondary corrections introduced to account for tissue density. In the model-based methods, there is much greater reliance on the fundamental physics of scattering and the dose distribution in water is no longer a prerequisite. Monte Carlo simulation is considered a model based method. Monte Carlo method has been shown in literature to be the most precise algorithm to be used in the treatment planning process. Thus the aim of this work is to model photon and electron beams from medical linear accelerators and evaluate the Monte Carlo simulation code as a research tool in radiotherapy.

Material and Methods:

In this study we have used the Linear accelerator-Varian model which is dual high energy machine capable of delivering 6 and 10 MV photon beams and electrons of energies 6,9,12, and 15 MeV. Farmer ionization chamber has been used for dosimetric measurement in water for both photon and electron beams. The waterproof Semiflex chamber (0.125 cm^3) has been used with dose scanning system for acquiring the percentage depth doses and profiles in a big water phantom.

Monte Carlo simulation was performed utilizing MCBEAM and MCSIM codes for linear accelerator machine simulation and water phantom simulation, respectively. This work was performed essentially in three steps: (i) Radiation dose distribution measurements in water phantom with certain field areas for photon (6MV) and electron (6MeV) beams. (ii) Calculation of the Radiation dose distributions with the same physical parameters by using the MC code. (iii) Comparison of the measured PDDs and profiles to that calculated by MC simulation.

Results and Discussion:

The Monte Carlo simulation was performed in two sequential steps for each beam. In the first stage the machine treatment head was simulated and a phase space file was scored just after the jaws for case of photon beams and before the last scraper of the applicator for case of electron beams. Phase-space files were used as the source input file for the dose calculations in water phantoms using the Monte Carlo code MCSIM. The dimensions of the dose computation grid were chosen to closely simulate the dimensions of the detectors used in the measurements. In order to ensure accurate phase-space representation of clinical photon and electron beams, the Monte Carlo dose calculations were benchmarked using open 10 x 10 cm^2 field area and an SSD of 100 cm. The parameter that was iteratively modified in the calculations was the electron energy assuming all the other components were simulated in a manner that accurately reflected the accelerator geometry. It should be mentioned that for electron beams the incident beam was assumed to be mono-energetic, an initial estimate of the energy was formed using the measured value of R_{50} (the depth of the 50% dose value on central-axis) and knowledge of the average energy loss of the through the linac components that intersected the beam. The incident electron beam energy was adjusted iteratively until the central-axis calculated values of relative dose agreed with the measurements to within 2% of Dmax. For 6MeV an energy spectrum was needed to match the measured percent depth doses (PDDs).

I-Photon beams: Good agreement was achieved between measured PDDs and profiles with that calculated by Monte Carlo simulation. This was verified for PDDs and profiles taken at different field areas and with profiles taken at different depths. Figure 1 shows the measured PDDs for a 6 MV photon beam with 4 x 4 cm^2 , 6 x 6 cm^2, 10 x 10 cm^2, and 20 x 20 cm^2 field areas compared to that simulated with Monte Carlo code. A good match is clear between all measured and simulated PDD curves. In figure 2 Profiles were taken at four different depths for a 6 MV photon beam of 10 x 10 cm^2 field area. Measurement was compared with simulation and the resulting agreement between them was greatly obvious. The Monte Carlo dose distributions resulting from the 10 x 10 cm^2 photon field area agreed to 3%, or 2mm with ion chamber and film measurements. In order to further confirm the accuracy of our simulation of the machine treatment head and verify our modeling of the photon beams, profiles at different depths and different field areas were also explored.

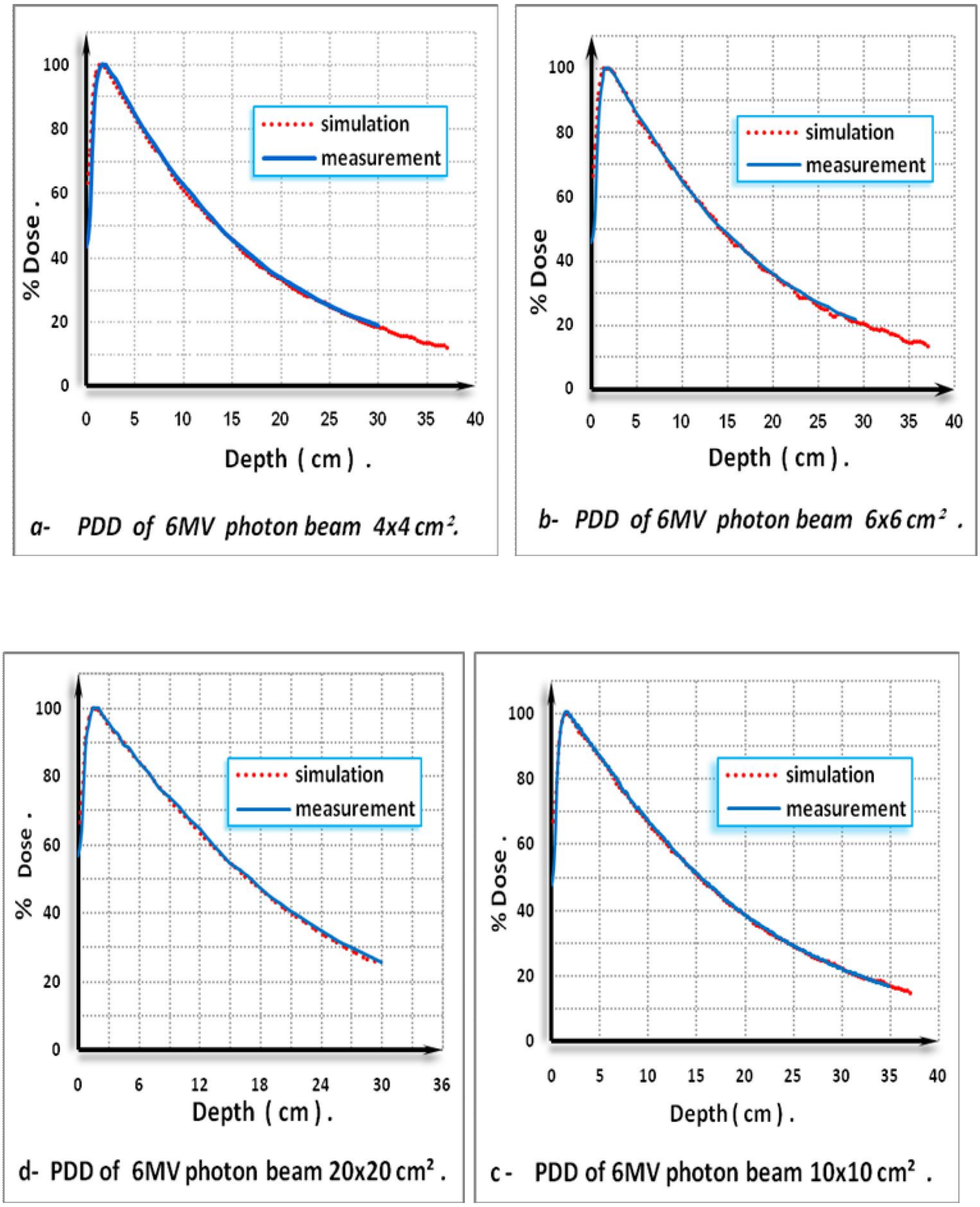

Fig. 1. PDD curves Simulation and measurement for 6 MV photon beam for four different field areas (doted lines are the measurement and the straight lines are the measurement), (a) PDD for 4 x 4 cm^2 field area, (b) PDD for 6 x 6 cm^2 field area, (c) PDD for 10 x 10 cm^2 field area, and (d) PDD for 20 x 20 cm^2 field area.

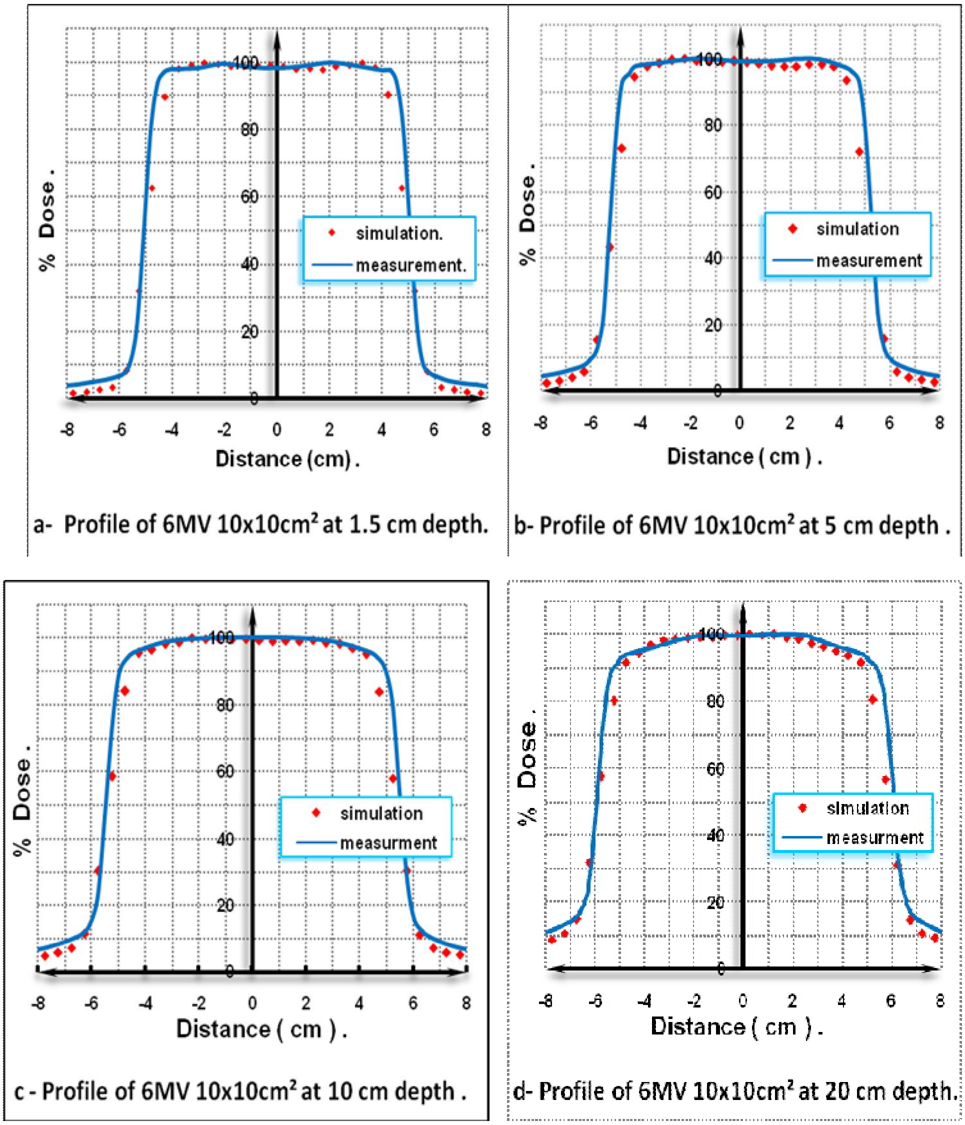

Fig. 2. Simulation and measurement profiles of 6 MV beam at different depths for 10 x 10 cm^2 field area, (a) Profile at 1.5 cm depth, (b) Profile at 5 cm depth, (c) Profile at 10 cm depth, and (d) Profile at 20 cm depth.

It is well known that the 10 x 10 cm^2 is the reference and standard field area for the machine calibration and we have already demonstrated a nice match obtained between simulation and measurement for this field area. We have selected three other field areas such that, two are smaller and one are larger than our reference 10 x 10 cm^2 field area.

Figures 3, and 4 shows the profiles at different depths 1.5, 5, 10, and 20 cm of the two smaller field areas; 4 x 4 cm^2, and 6 x 6 cm^2; respectively.

Also in these field areas states the clear fitting is presented, which concluded that MC code can simulates the field areas smaller than the reference 10 x 10 cm^2 field area.

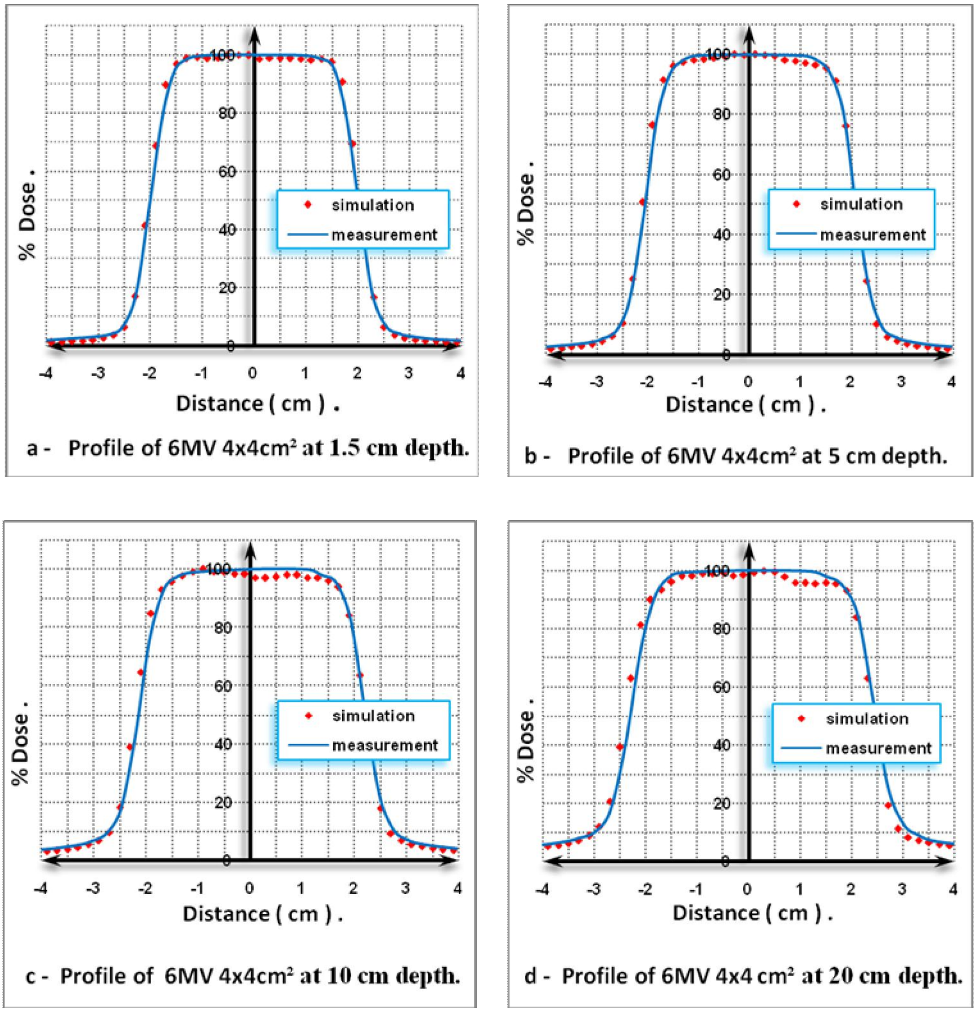

Fig.3. Simulation and measurement profiles of 6 MV photon beam at four different depths for 4 x 4 cm^2 field area, (a) Profile at 1.5 cm depth, (b) Profile at 5 cm depth, (c) Profile at 10 cm depth, (d) Profile at 20 cm depth.

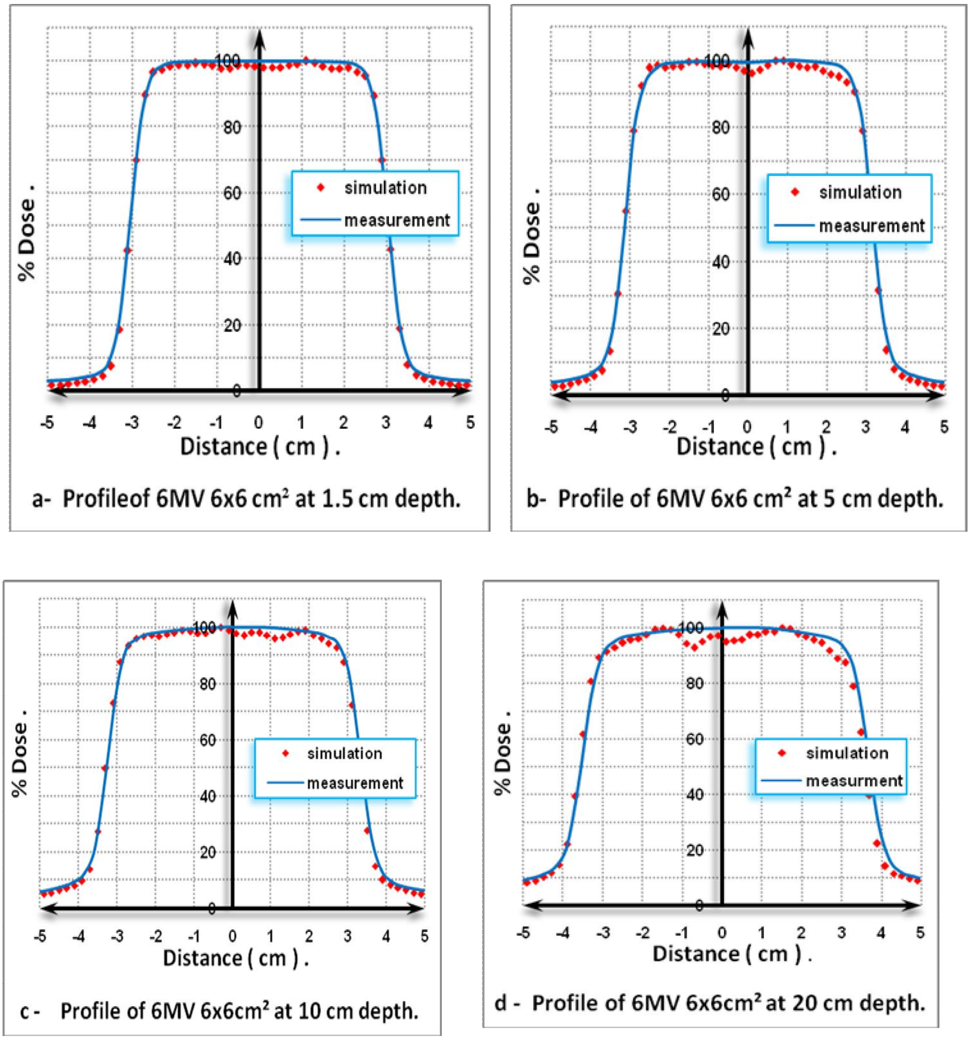

Fig.4. Simulation and measurement profiles of 6 MV photon beam at four different depths for 6 x 6 cm field area, (a) Profile at 1.5 cm depth, (b) Profile at 5 cm depth, (c) Profile at 10 cm depth, (d) Profile at 20 cm depth.

Figure 5 shows the profiles at the same depths but of one larger field area of 6 MV photon beam, 20 x 20 cm^2. Again in this field area, matching state is clear, which concluded that MC code also can simulate the field areas larger than the reference 10 x 10 cm^2 field area.

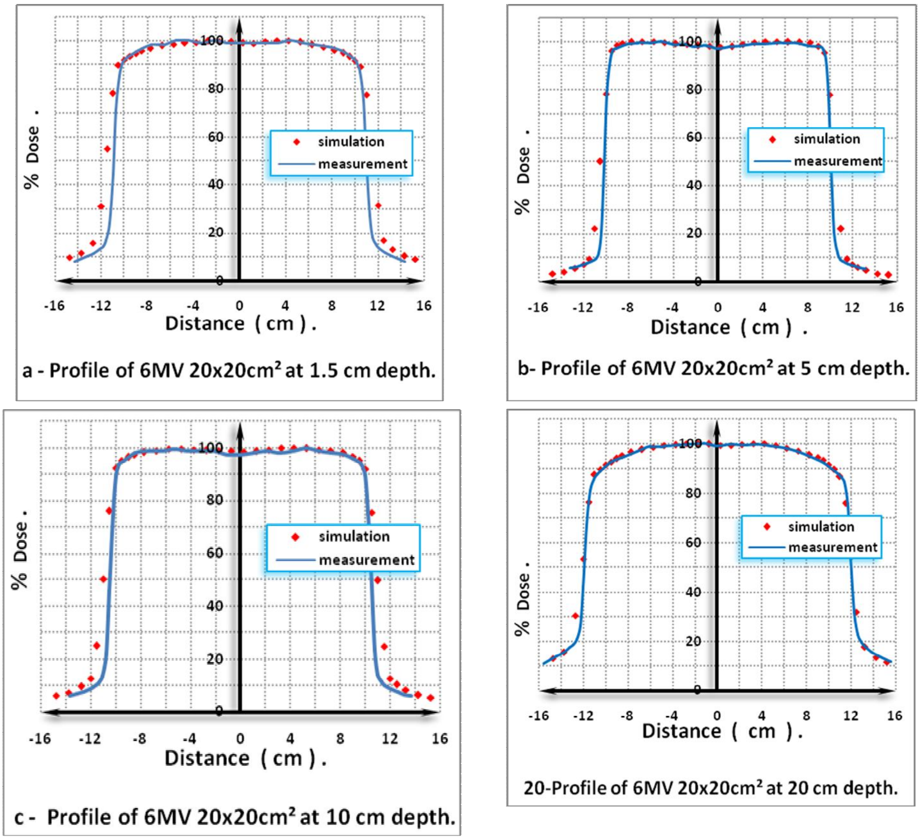

Fig.5. Simulation and measurement profiles of 6 MV beam at different depths (1.5 cm, 5 cm, 10 cm, and 20 cm, respectively) for 20 x 20 cm^2 field area, (a) Profile at 1.5 cm depth, (b) Profile at 5 cm depth, (c) Profile at 10 cm depth, (d) Profile at 20 cm depth.

Figures 1, 2, 3, 4, and 5 and shows PDDs curves and profiles curves for 6 MV photon beams with 4 x 4 cm^2, 6 x 6 cm^2, 10 x 10 cm^2, and 20 x 20 cm^2 field areas respectively. The agreement between simulation and measurement is still within 3%, or 2mm. This good matching state in the comparison between the measured and the simulated profiles verified that the Monte Carlo code is a good simulation tool for photon beams.

II-Electron beams:

Good agreement was achieved between measured PDDs and profiles with that calculated by Monte Carlo simulation. This was proven with PDDs of different field areas (6 x 6 cm^2, and 10 x 10cm^2) and with profiles taken at different depths (1, 2, and 3cm) with these field areas. Figure 6 showed the agreement between simulated and measured PDDs for 6 MeV beams of two different electron field areas. Figures 7 illustrates the comparison between the measured and the simulated profiles taken at different depths; 1, 2, and 3cm, respectively; for the electron beam with 6 x 6 cm^2 field area.

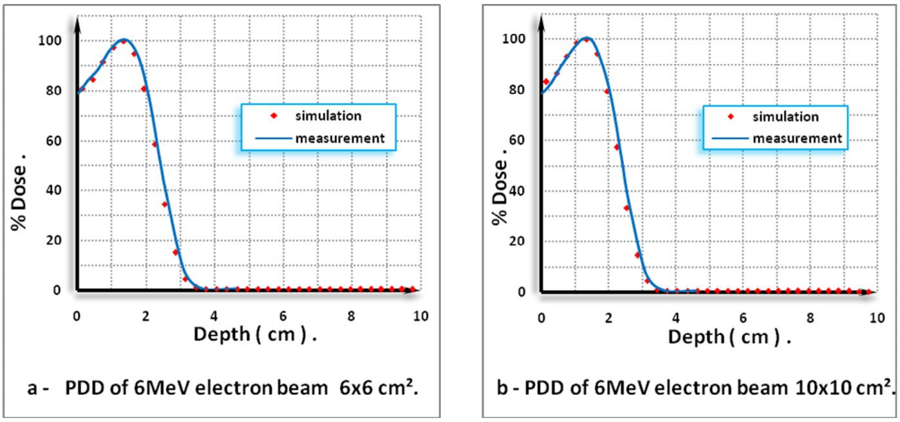

Fig.6. PDD curves Simulation and measurement for 6 MeV photon beam for two different field areas (doted lines are the measurement and the straight lines are the measurement), (a) PDD for 6 x 6 cm^2 field area, (b) PDD for 10 x 10 cm^2 field area.

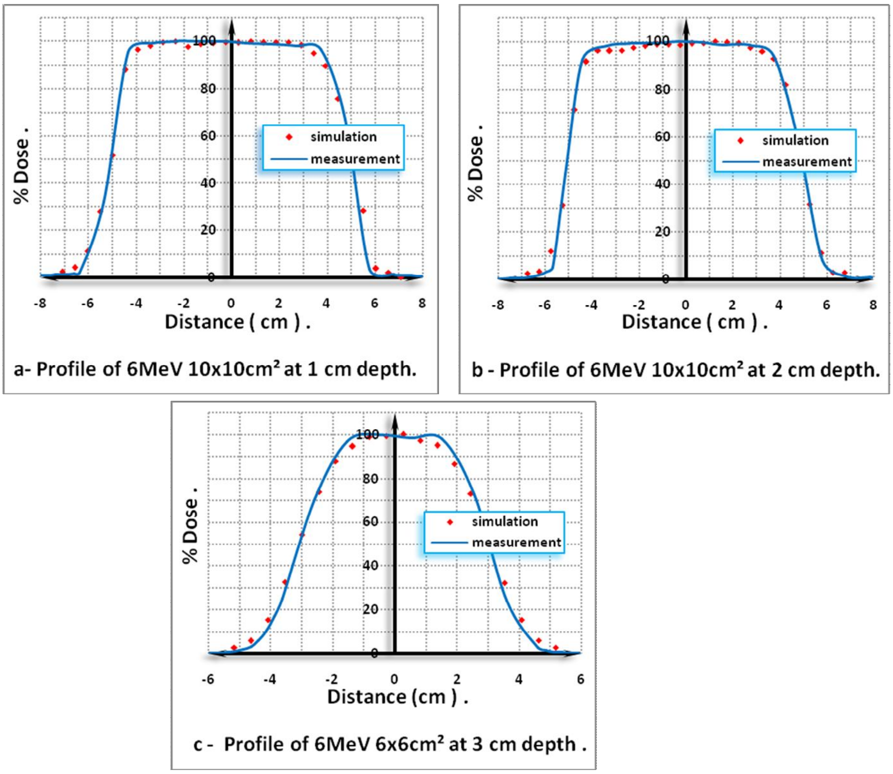

Fig.7. Simulation and measurement profiles of 6 MeV beam at different depths for 6 x 6 cm^2 field area, (a) Profile at 1cm depth, (b) Profile at 2 cm depth, (c) profile at 3 cm depth.

Figures 8 illustrates the comparison between the measured and the simulated profiles at different depths; 1, 2, and 3cm, respectively; for the electron beam with 10 x 10 cm^2 field area. These good matching states in the comparison between the measured and the simulated PDDs and profiles verified that the MC code is also a good simulation tool for electron beams.

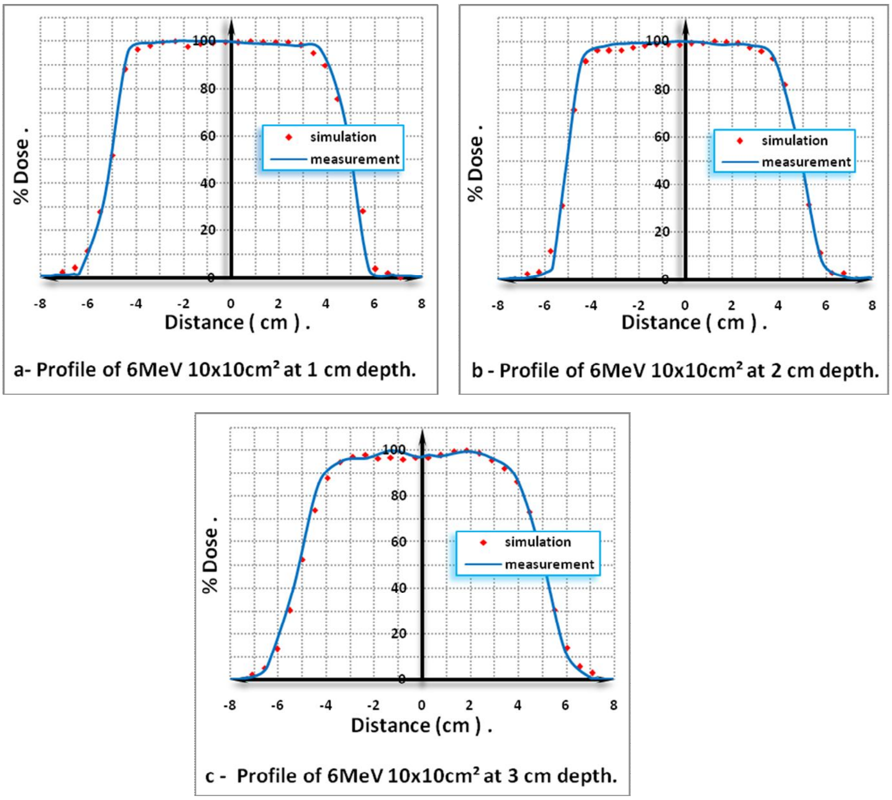

Fig.8. Simulation and measurement profiles of 6 MeV beam at different depths for 10 x 10 cm^2 field area, (a) Profile at 1 cm depth, (b) Profile at 2 cm depth, (c) Profile at 3 cm depth.

Conclusion:

From the previous results, it was shown that the radiation dose distribution calculations based on the Monte Carlo simulation of photon and electron beams were in a very good agreement with measurements in water phantom. Through extensive verification it's clear that Monte Carlo code with the source represented by phase space files was capable of accurately modeling both photon and electron beams. Monte Carlo simulation is an excellent tool that can be used in radiotherapy research, especially the investigations of new techniques which would be very useful in the development of new modalities in radiotherapy. It should be mentioned that even the small discrepancy that was shown in some of the simulated and measured points could be solved in the MC code by increasing the accuracy via introducing larger numbers of histories (number of simulated or used particles to produce the radiation beam) which will be consuming larger time to complete the calculations. Finally; MC code can be considered as a golden tool to simulate the photon and electron beams, and it can be very useful if it is applied with a wide range in radiotherapy research.

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