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Application of Monte-Carlo Code to dose distribution calculation in a case of lung cancer by the emitted photon beams from Linear Accelerator

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Abstract: The dose distribution calculation is one of the major steps in radiotherapy. In this paper the Monte Carlo code MCNP5 has been applied for simulation 15MV photon beams emitted from linear accelerator in a case of lung cancer of the General Hospital of Kien Giang. The settings for beam directions, field sizes and isocenter position used in MCNP5 must be the same as those in treatment plan at the hospital to ensure the results from MCNP5 are accurate. We also built a program CODIM by using MATLAB® programming software. This program was used to construct patient model from lung CT images obtained from cancer treatment cases at the General Hospital of Kien Giang and then MCNP5 code was used to simulate the delivered dose in the patient. The results from MCNP5 show that there is a difference of 5% in comparison with Prowess Panther program – a semi-empirical simulation program which is being used for treatment planning in the General Hospital of Kien Giang. The success of the work will help the planners to verify the patient dose distribution calculated from the treatment planning program being used at the hospital.

Keywords: *linac, radiotherapy, absorbed dose, lung cancer, MCNP5.*

I. INTRODUCTION

The lung cancer causes the highest death rate among other cancers. It is 13% in all cancer, but cancer death rate is 28% over the world [1]. In Viet Nam, lung cancer rate is about 29.6/100000 for men (the second-most commonly diagnosed cancer after liver cancer for men), lung cancer is also one of the fourth most common cancer with rate of 7.7/100000 for women [2]. The major risk factors for lung cancer are cigarette smoking, ionizing radiation, and virus. Long-term exposure of these factors causes changes in DNA of bronchus (bronchus epithelium). If there are many injured tissues, the lung cancer probability seems increasingly. The detection and treatment for lung cancer is extremely difficult and complicated. One of the most common treatment methods for lung cancer are radiation therapy or chemotherapy. In fact, these methods use the photon beam that is emitted from the linear accelerator to kill the tumor and/or combine with other treatment methods such as operation, chemotherapy. Because of releasing maximum dose at a depth of few centimeters under skin surface and passing through patient body, the photon beam not only delivers kinetic energy at tumor location but also releases kinetic energy at almost regions it irradiates. This factor is the leading cause of distributing high radiation dose

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on normal tissue around tumor. If the energy, field size, lead block shape are incorrectly calculated, the tumor will not receive enough radiation dose and the normal tissue will absorb overdose. As a result, the treatment for patient is not only effective but also causes the unexpected results. Nowadays, the semi-empirical radiation dose calculation programs in hospitals can calculate fast, but it is limited in accuracy [3] and the Monte Carlo method is so-called the gold standard of other methods[4, 5] with very high accuracy. Therefore, in this work, we use the Monte Carlo method in MCNP5 [6] to simulate the electron beam that is emitted from the window of linear accelerator and hits the target to create 15MV photon beam for treatment planning in a lung cancer case at the General Hospital of Kien Giang in other to accurately calculate the radiation dose distribution when the photon beam go into patient body.

II. MATERIAL AND METHOD

In this work, we use Monte Carlo code MCNP5 to simulate the Primus linear accelerator (SIEMENS) in the General Hospital of Kien Giang for dose distribution calculation in patient body that is radiated by its photon beam. The patient model is created by importing CT images of the lung cancer case into the treatment planning system of the General Hospital of Kien Giang. We also use Matlab code (CODIM) [7] for creating input used in MCNP5, processing output, and image viewing.

The Head Configuration of linear accelerator PRIMUS HPD with 15MV photon beam.

The head configuration that is created in MCNP5 is based on receiving necessary parameters such as dimensions and physical properties of important components of the head. After completing importing data, Visual Editor program of MCNP5 will process and export a 2D image of head configuration (see Figure 1). In order to receive high quality electron beam and accurate results, the simulation is executed after the electron beam exits from the window of accelerating system.

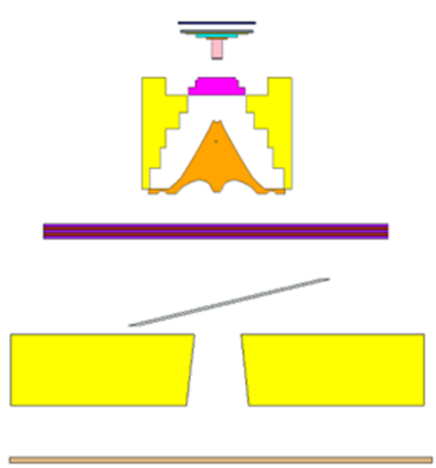

Fig. 1. 2D image of head configuration in linear accelerator is created by Visual Editor in MCNP5 for 15MV photon beam [7].

The source of 15MV photon beam:

The simulated source in MCNP5 that creates the 15MV photon beam is the electron source in disk shape with a radius of 1.5mm and within the energy spectrum from 0.7MeV to 15.5MeV with emitting probability given in the Table I.

Table I. Energy bands and emitting probability of the electron beam to create 15MV photon beam [7].

Energy band(MeV)	Probability
0.7 – 9.0	7.60×10^{-24}
9.0 – 10.0	1.38×10^{-11}
10.0 – 11.0	4.29×10^{-4}
11.0 – 11.5	7.36×10^{-3}
11.5 – 12.0	4.52×10^{-1}
12.0 – 12.5	4.52×10^{-1}
12.5 – 13.0	4.74×10^{-2}
13.0 – 13.5	4.29×10^{-4}
13.5 – 14.0	2.87×10^{-7}
14.0 – 14.5	1.31×10^{-11}
14.5 – 15.0	3.93×10^{-17}
15.0 – 15.5	7.62×10^{-24}

CT images

The CT images for simulation are obtained from a lung cancer case at the General Hospital of Kien Giang that are captured by the CT simulator (SIEMENS). The image has 512x512 pixel resolution. The size of a pixel is about 0.8945x0.8945 mm^2 and slice thickness is 6mm (Figure 2). These parameters are received from CT image header information.

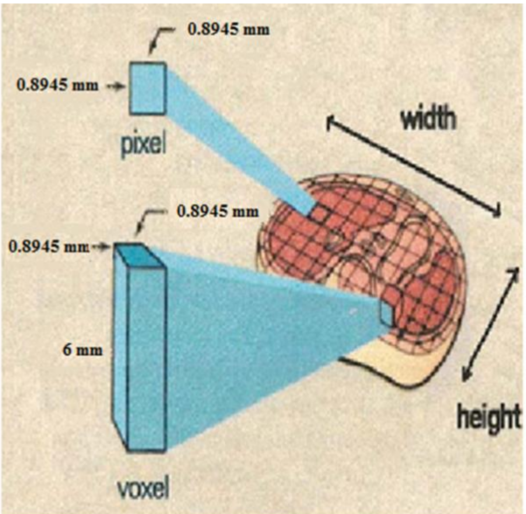

Fig. 2. The voxel size of CT image [7].

Patient Model

The patient model is designed for MCNP5 input data by using CODIM program (see Figure 3). Each CT number on the CT image is converted into a density and a corresponding material element in the patient model. Each voxel size in patient model equals each voxel size of each CT slice (these parameters are received from CT image header information).

Setting photon beams for simulation of CT images

Simulation is carried out with three 15MV photon beams. Isocenter position: X =0.8cm, Y =2.5cm, and Z =-90.3cm as following:

- The first beam: at 60° from the vertical line with superior-inferior direction, field size is 1.3cm x 10.8cm (the dimension on x and y axis, respectively), selected beam quality is 100%.

- The second beam: at 154° from the vertical line with inferior-superior direction, field size is 10.3cm x 10.8cm (the dimension on x and y axis, respectively), selected beam quality is 100%

- The third beam: at 330° from the vertical line with inferior-superior direction, field size is 10.4cm x 10.6cm (the dimension on x and y axis, respectively), selected beam quality is 100%.

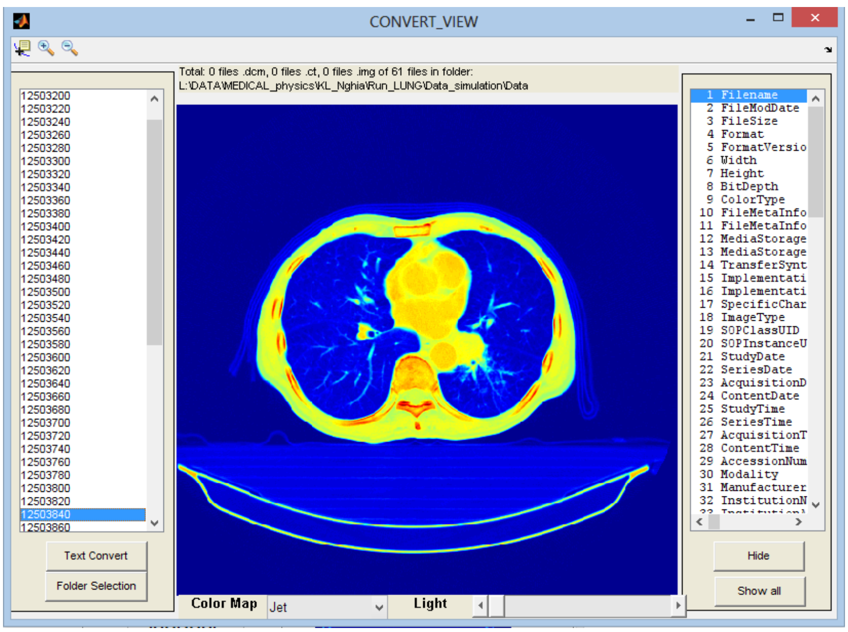

Fig.3. Convert view of CODIM program (Convert_View).

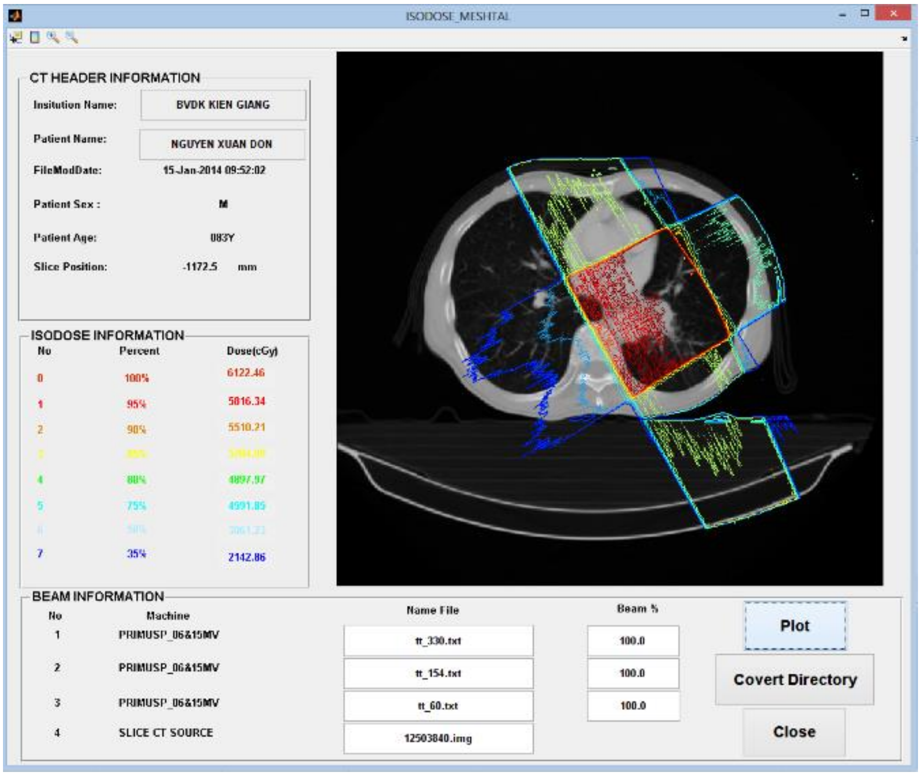

Fig.4. The CODIM program (Isodose_Meshtal) shows patient dose distribution with three photon beams on the center CT image in MCNP5.

III. RESULTS AND DISCUSSION

Calculating patient dose distribution in MCNP5 program and comparing with the Prowess Panther program.

After completing the calculation in MCNP5, CODIM program analyzes output data and displays patient dose distribution on each CT image. The achieved images of the distribution of different relative dose values are displayed in Figure 4.

Figure 5 shows patient dose distribution in MCNP5 and Prowess Panther program. The high dose region of the tumor and the low dose regions that are far from the tumor are represented in different colors. In Figure 5A, in order to distinguish the radiation dose regions easily, it has named as the following: dark red, bright red, red, and orange. In the dark red region, the highest patient dose distribution on tumor corresponds to the 100% isodose line and marked with point O, the bright red region is marked with point A corresponding to the 95% isodose line, the red region is marked with point B corresponding to the 90% isodose line, and the orange region is marked with point C corresponding to the 85% isodose line. Figure 5 also shows that the isodose distribution that are calculated by MCNP5 and Prowess Panther program has a fairly good matching. The good matching is at the high dose regions. It is possible to discriminate different dose regions by the difference in the colors. Max isodose in MCNP5 is at the center of the tumor and the same as Prowess Panther program.

Additionally, Figure 5A shows that MCNP5 calculates the patient dose distribution when the photon beams go through the fixed mask used in beam directions 60º and 330º and the treatment couch in beam direction 154º. Meanwhile, in Prowess Panther planners had rejected above factors in the calculating patient dose distribution (see Figure 5B).

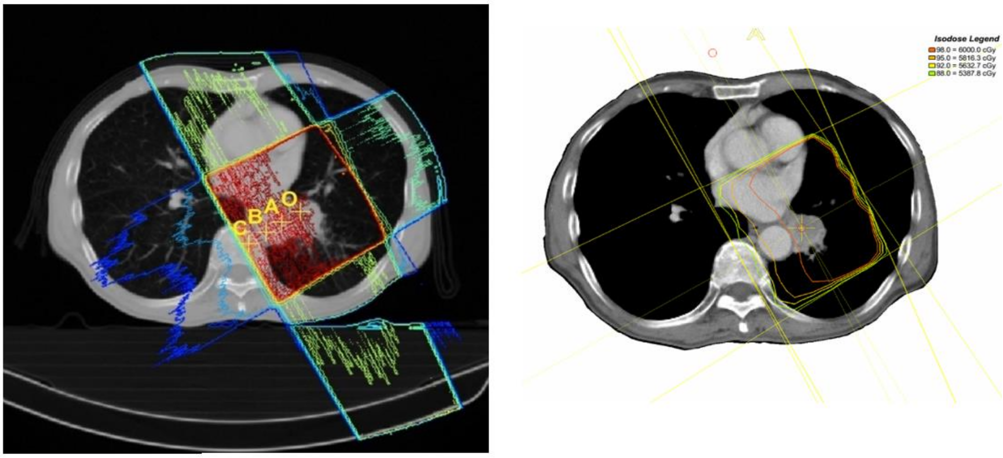
(A) (B)

Fig.5. (A) Isodose distribution in MCNP5 and Prowess Panther (**B**).

Table II. Coordinate and relative dose calculated by MCNP5.

Position	Pixel coordinates	Relative dose in MCNP5 (%)	Relative dose in Prowess Panther (%)
O	(297;251)	100	100
A	(275;261)	93.6	95.0
B	(264;269)	92.5	92.0
C	(251;278)	90.1	88.0

Table II shows calculated relative doses in MCNP5 and Prowess Panther program at four points that are marked in Figure 5A. In this table, the relative dose ratios in MCNP5 and Prowess Panther program are the same at different dose regions. When using relative doses, the MCNP5 also clearly distinguish the different relative dose regions 98%, 95%, 92%, and 88% and the same as the Prowess Panther program. The difference between the reference points is lower 5%. It is enough small to accept the agreement of the results between MCNP5 and Prowess Panther. This difference between two programs can be explained as following. The quite high fluctuation of results in MCNP5 program are caused by the not enough long calculating time [8]. As a result, radiation dose region separation is not clear. The radiation dose regions have still many overlapping points, which causing the interference in dose. Meanwhile, the Prowess Panther program used semi-empirical data and deterministic algorithm, so relative dose calculating based on fixing experimental data and approximation methods leads errors. In addition, in the calculation process, the planners automatically removes some objects on the CT images such as fixed masks, lead markers, and treatment couch, which causes errors. Another reason that also be mentioned here is the limitation of CODIM program in using the kerma data set converted into the absorbed dose data set of tissues, while the converted factor used in the Prowess Panther program has the different value. On the other hand, parameters such as intensity, radiation time, field sizes, and exact composition of the components of the linear accelerator head can also cause the difference between two programs.

IV. CONCLUSION

Through studying the head configuration of PRIMUS linear accelerator used in radiation therapy and based on the data set of the lung cancer case at the General Hospital of Kien Giang, we have applied the MCNP5 program to simulate the patient dose distribution. The error of achieved results is lower 5% when comparing with the commercial Prowess Panther program being used at the hospital. The more accurate radiation dose calculation by Monte Carlo code will help the medical physicists to verify the patient dose distribution calculated from the treatment planning program being used at the hospital.

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