Calculation of size specific dose estimates (SSDE) value at cylindrical phantom from CBCT Varian OBI v1.4 X-ray tube EGSnrc Monte Carlo simulation based

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Abstract. The aim of this research was to calculate Size Specific Dose Estimates (SSDE) generated by the varian OBI CBCT v1.4 X-ray tube working at 100 kV using EGSnrc Monte Carlo simulations. The EGSnrc Monte Carlo code used in this simulation was divided into two parts. Phase space file data resulted by the first part simulation became an input to the second part. This research was performed with varying phantom diameters of 5 to 35 cm and varying phantom lengths of 10 to 25 cm. Dose distribution data were used to calculate SSDE values using trapezoidal rule (trapz) function in a Matlab program. SSDE obtained from this calculation was compared to that in AAPM report and experimental data. It was obtained that the normalization of SSDE value for each phantom diameter was between 1.00 and 3.19. The normalization of SSDE value for each phantom length was between 0.96 and 1.07. The statistical error in this simulation was 4.98% for varying phantom diameters and 5.20% for varying phantom lengths. This study demonstrated the accuracy of the Monte Carlo technique in simulating the dose calculation. In the future, the influence of cylindrical phantom material to SSDE would be studied.

1. Introduction

The accuracy in radiotherapy is influenced by many factors, one of which is the technology used. In the case of tumor radiotherapy, tumor deformation (movement) is one factor that must be considered. Cone Beam Computed Tomography (CBCT) can be used as an imaging modality to record a tumor movement. CBCT consists of a tube and a detector mounted on a rotatable tool. CBCT system enables a sequence of 2D radiographic projection images to be acquired from a kV source and flat panel detector imaging system [1]. Used daily, CBCT allows a more precise positioning of the treatment isocenter by shifting images performed before each session on the initial dosimetric imaging [2]. The dosimetry for the CBCT has become more important due to its widespread applications for IGRT and multislice CT scanners. CBCT has some kind of modalities, one of which is Varian On Board Imager (OBI) v1.4 released in 2008.

The radiation dose received by a patient during a scanning process is highly variable and depends on many technical factors. The technical factors that affect the radiation dose generally comprise a function of the X-ray beam quality, geometry, limitation devices, and acquisition imaging dose rate.
settings. The amount of the radiation dose received from the scanning also depends on the phantom geometry, shape, and material [2]. The radiation dose received by the patient will cause changes in his or her biological systems and can increase the risk of cancer in the sensitive organs. Therefore, it is very important to estimate accurately the patient’s allowed dose generated by CBCT. CTDI is a standardized measurement of the radiation dose output from the scanning process. In fact, the dose received by a patient from a scanning process depends on the patient’s characteristics. SSDE is better for estimating the dose given to the patient [3].

Monte Carlo (MC) method is a numerical method for statistical simulation which utilizes sequences of random numbers to model a process of experimentation through a process simulation system. MC simulation has been widely applied in various fields, such as medical physics, particularly radiation dosimetry, and also for analyzing nuclear reactors. In medical physics, this method has been widely used in nuclear medicine detector and dose calculation in radiotherapy. MC is the most accurate method for simulating dose distributions in homogeneous and inhomogeneous tissues when the electron transport effects cannot be accurately calculated by conventional methods [4]. Therefore, the aim of this research was to calculate Size Specific Dose Estimates (SSDE) generated by variant OBI CBCT v1.4 X-ray tube working at 100 kV and using EGSnrc Monte Carlo simulations. Results of this study will provide information about the SSDE generated by the X-ray tube Varian OBI CBCT v.1.4 deposited by the cylindrical phantom.

2. Method

2.1. Set up of X-ray tube and cylindrical phantom
The EGSnrc Monte Carlo code is a well-known code used to simulate the biography of photon and electron through a medium [5]. The particles simulated have the energy range from a few keV up to hundreds of GeV. EGSnrc has enormous flexibility allowing the user to run the simulation even with only little understanding about the program. In EGSnrc, transports of photons and electrons were simulated in multiple steps where each step has a random length [4]. To get the final result of the simulation, a lot of history is recommended to be simulated.

MC simulation for determining dose distribution in the cylindrical phantom generated by Varian OBI CBCT v1.4 X-ray tube performed using the EGSnrc program package consists of BEAMnrc and DOSRZnrc. BEAMnrc was used to design and simulate X-ray tube; DOSRZnrc was used to design and perform simulations in the cylindrical phantom. The dose distribution obtained from the simulation was used to calculate SSDE using Matlab. The schema of this research is presented in figure 1.

![Figure 1. Schema of research methodology.](image)

Monte Carlo code used in this simulation was divided into two parts. The first part was simulation of varian OBI CBCT v1.4 X-ray tube using BEAMnrc. The tube consists of several components namely target, exit windows, pre-filter, pre collimator, upper blades, glass, bowtie filter and collimator.
Figure 2 shows the setup of the simulated geometry for the Varian OBI CBCT v1.4 X-ray tube used in this simulation. The particles that have been transported in the X-ray tube will be scored on the scoring plane named phase space (phsp) file. Beam parameters for the CBCT X-ray tube simulation were as follows: ISOURC = 10 (parallel circular beam incident from side) and slice thickness = 1 cm. The number of histories was set to 250 million. Simulation process was run on Linux Ubuntu with the CPU specifications of Intel core i5 3.4 GHz processor and 2 GB RAM. Simulations were performed using a 100 kV voltage.

The second part was the simulation in the cylindrical water phantom using DOSRZnrc. After the BEAMnrc simulation was finished, the phase space file obtained was used as an input source in DOSRZnrc simulations to determine the dose distribution in the cylindrical phantom. This research was performed with varying phantom diameters of 5, 10, 15, 20, 25, 30 and 35 cm. This research was also performed with varying phantom lengths of 10, 15, 20 and 25 cm. The number of histories was set to 500 million. The design of the cylindrical phantom used in this simulation is presented in figure 3.

Dose calculations were performed on two areas, namely the edge phantom (peripheral) region and the middle of the phantom (center) region. Dose distribution data obtained were used to calculate SSDE using Matlab.

2.2. CTDI and SSDE

The computed tomography dose index (CTDI) is a standardized measure of radiation dose output of a CT scanner. The CTDI can be used in conjunction with the patient size to estimate the absorbed dose [3]. The equation of CTDI is
\[
CTDI = \frac{1}{T} \int D(z)dz
\]  

(1)

where \( T \) is the slice thickness and \( D(z) \) is the radiation dose measured at position \( z \) along the scanner's main axis. The dose distribution imparted by a CT scan is still somewhat larger near the skin than in the center of the body [3]. The weighted CTDI was introduced to account for this:

\[
CTDI_w = \frac{1}{3} CTDI_{center} + \frac{2}{3} CTDI_{peripheral}
\]  

(2)

In this case, \( CTDI_w \) is equal to SSDE

\[
SSDE = CTDI_w
\]  

(3)

3. Results

SSDE values obtained were compared with the AAPM 2011 data and the results of the experiment contained in figure 4.

![Figure 4. SSDE curve comparison with varying phantom diameter.](image)

As can be seen in figure 4 that the SSDE value decreases with increasing diameter of the cylindrical phantom. Furthermore, SSDE value were calculated for simulation with varying phantom length as shown in figure 5 below.

![Figure 5. SSDE curve with varying phantom length.](image)

As can be seen in figure 5 that the length of cylindrical phantom affected the dose deposited by phantom. SSDE for varying phantom length increased with phantom length.

4. Discussion
The radiation dose deposited by a phantom during a scanning process depends on some factors. It can be affected by the phantom geometry, size, shape, and material [2]. Phantom diameter has a significant effect on the dose received by the phantom. This is because the dose deposited by a radiation beam into water phantom decreases with phantom depth [6]. The deeper radiation beam entering phantom, the lower dose deposited by phantom. By using a cylindrical phantom with a larger size, the radiation beam will travel a farther distance when entering the phantom and thus the dose will be lower [7]. It was also obtained that the dose at the peripheral region was higher than that at the center region.

It can be seen in figure 4 that the good agreement between the simulated and experimental data was obtained. The SSDE values obtained through the simulation are hardly very different from the SSDE values of AAPM 2011 data and the experimental results. This is indicated by the values of a relatively small deviation error; the average deviation is 2.18%.

As can be seen in Fig. 5, the varying phantom lengths of SSDE for shorter phantoms were much greater than those for longer sizes. The area of the penumbra region has an essential effect in this phenomenon. When using a cylindrical phantom with a longer size, the penumbra region would increase in such a way that the contribution to the total dose calculation due to the dose in the penumbra region also increased [6].

5. Conclusions

SSDE values decreased with the increasing diameter of cylindrical phantom, but contrastively increased with rose of phantom length. Monte Carlo simulation is good enough to use in performing the calculation of the dose at the cylindrical phantom. For the future work, it is suggested to develop this research using heterogeneous phantom.

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