Simulation of VMAT (Volumetric Modulated Arc Therapy) Delivery techniques on Cylinder Phantom Based on DICOM Data using Monte Carlo Method - EGSnrc

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Abstract.
This research aims to study one of the radiotherapy techniques of VMAT and calculate the dose distribution on phantom cylinders using the Monte Carlo EGSnrc method. VMAT is one of radiotherapy technique where is all the fractions of the dose are given continuously when the gantry rotates around the patient with manages gantry rotation speed, MLC leaf position and the dose fraction is given. The simulation process begins with head linac modeling using BEAMnrc, and using the Monte Carlo VMAT simulation uses DOSXYZnrc software. The parameters for the BEAMnrc and DOSXYZnrc simulations using information from DICOM data set rtpPlan AAA are read using the pycom code. The results of this study provide information about the characteristics of 6 MV photon files such as fluence, fluence energy, spectral distribution, and fluence energy distribution, and dose distribution in phantom cylinders. The VMAT Monte Carlo simulation was carried out using 300 million particles which resulted in a VMAT dose distribution in the form of a dose profile curve and an isodose curve, the result shows that the curve of VMAT simulation using phantom cylinders produced the maximum dose distribution in the isocenter.

Keyword: VMAT, Monte Carlo, EGSnrc, DICOM, AAA

1. Introduction
Radiotherapy is one of the treatments of cancer by giving the maximum possible dose of cancer tissue and the minimum dose possible for healthy tissue. Linear Accelerator (Linac) is one of tools or machine which functions to accelerate charged particles such as electrons for treatment and is able to produce high-quality X-ray beam which is then used for cancer tissue radiation therapy [1]. Nowadays there are many therapy techniques that have been developed including Intensity Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT). The IMRT technique has the ability to give maximum doses to the
target and provide minimal doses to healthy tissue by regulating the movement of the Multileaf Collimator (MLC)[2].

IMRT technique has developed and has many types including IMRT step and shoot also IMRT sliding window [1]. Step and Shoot IMRT, MLC is set to static and it is carried out at certain gantry positions and angles. While the IMRT sliding Window, MLC is set to be dynamic but the position and angle of the gantry remain static. The development of the IMRT technique is VMAT which was first introduced by Otto in 2008, this technique is different from IMRT because the radiation is given simultaneously when the gantry rotates around the patient [3]. Parameters that move dynamically during the treatment process are gantry rotation, MLC and dose rate [4]. VMAT can improve the efficiency of the monitor unit (MU) given to patients, which means that the MU given during treatment is lower. One example is in the case of the prostate plan, where VMAT is able to reduce the number of monitor units (MU) given to patients by up to 4 % lower [5].

One important part of the radiotherapy process is the accuracy of the calculation of the dose distribution or Treatment Planning. Calculation of dose distribution can be obtained using a program or algorithm. Monte Carlo method use principle of random number a probabilistic, this method is to analyze particle interaction simulation accurately in calculating the dose distribution [6]. Software that utilizes the Monte Carlo method in the process of dose distribution is the EGSnrc software, which is a software used to simulate electron and photon transport based on physical interactions that occur randomly. This EGSnrc software has several user codes, namely BEAMnrc which is used for simulation of particle transport in the linac head and DOSXYZnrc which is used for modeling particle transport in voxels inside phantom [7].

The parameters used in the Monte Carlo - VMAT simulation are derived from implant data for thorax cancer cases, the simulation process has also been carried out using the Analytical Anisotropic Algorithm (AAA) algorithm at Tan Tock Seng Hospital, Singapore. The implant data is made in a format of Digital Imaging and Communication in Medicine (DICOM) which is used to print, store and send information in medical imaging. RTT data is reading using PYCOM programming code (PYTHON DICOM). The programming is pycom.py which functions to convert TPS data into input files for BEAMnrc and DOSXYZnrc. The renewal or excellence of this research is trying to do the reading of VMAT parameters in rtplan.dcm using python programming, because the process of reading manually is difficult, the data is very large and must be rearranged (if using MATLAB). The first step is reading all data and to get information about the size of JAWs, MLC leaf position, isocenter coordinates, gantry rotation and dose fraction, and then simulates the distribution of VMAT doses on a cylindrical phantom with acrylic or PMMA material and with photon 6 MV. The results of this study will provide a dose distribution for phantom and only a few slices are displayed.

2. Methods
2.1. Reading DICOM data, Head Linac Design and simulation
The DICOM data used are radiotherapy planning AAA (rtplan.dcm) data which is read using pycom.py python code software from Zhan L [8] which has been modified by the author so that it can read and convert rtplan.dcm data properly. The results are input parameters for BEAMnrc, namely the size of JAWs and MLC Leaf Position, isocenter coordinates, gantry rotation and dose fraction, and then simulates the distribution.

Linac head design using BEAMnrc it shows figure 1. the design is a Linac Variant with a photon energy of 6 MV, ECUT 0.512 MeV and PCUT 0.01 MeV. Verification of the Linac model made by IGE was conducted [10].

From table 1 shows that the gantry is set for two rounds and the number of control points used is 228 segments which are an optimization point in administering doses to patients by regulating each MLC change and giving MU (monitor unit) as long as the gantry rotates. In
addition, table 2 shows the parameters of MLC position changes for bank A and bank B. MLC position data is created in the sequences which are then carried out by BEAM shared library to synchronize BEAMnrc and DOSXYZnrc.

| Parameter JAWs                             |  |
|-------------------------------------------|--|
| Parameter Beam Position                   |  |
| Total Arc                                 | 2 |
| The angle of Gantry Arc 1: 180 - 89        |  |
| Arc 2: 89 - 180                           |  |
| JAWX1 5.505 cm                            |  |
| JAWX2 6.675 cm                            |  |
| JAWY1 2.03 cm                             |  |
| JAWY2 2.599 cm                            |  |

| Table 2. Parameter MLC Leaf Position       |  |
|-------------------------------------------|--|
| Bank A Bank B                              |  |
| 0.000 0.000                               |  |
| 0.000 0.000                               |  |
| 0.000 0.052                               |  |
| 0.000 0.026                               |  |
| -0.367 0.462                              |  |
| -0.622 0.845                              |  |
| -0.877 1.100                              |  |
| -1.004 1.227                              |  |
| -0.877 1.163                              |  |
| -1.004 0.972                              |  |

Linac head simulation is divided into two, namely linac head part 1 using ISOURCE-19 (an elliptical beam) to produce phsp head file and linac head part 2 using ISOURCE-21 (phsp beam data file) generate phsp under JAWs, because in this study the MLC component moves dynamically when the gantry rotates, then phsp under JAWs is used for VMAT simulation on DOSXYZnrc.

2.2. Cylindrical phantom design and VMAT simulation
The Phantom cylinder design code in python language made by Kyohei Fukata in 2017 [9], the program can produce files in the .egsphant format and can be a phantom input on DOSXYZnrc. The Phantom cylinders used are made from PMMA with a diameter of 27.4 cm and a length of 51.2 cm, with a voxel of 0.4 cm, as for the number of X-axis voxels, Y-axis 128, and Z-axis 68.

During the Monte Carlo VMAT simulation, information on MLC leaf position data, shared library BEAM process, phase space file under jaws, a phantom with extension .egsphant and
control point settings in DOSXYZnrc. Control point settings at ISOURCE-20 to adjust isocenter coordinates it shows Table 4, dose fraction and gantry angle. The output of this simulation is the form of dose distribution with extension .3ddose and analyzed by stat dose and dosexyz to see the distribution of doses of 1D and 2D respectively.

### Table 3. Setting Control Point

| Control Point | xiso(cm) | yiso(cm) | ziso(cm) | theta(°) | phicol (°) | d(cm) | MU Index |
|---------------|---------|---------|---------|----------|-----------|-------|---------|
| 1             | 0.4     | 0.12    | -13     | 90       | 180       | 45    | 0.000000 |
| 2             | 0.4     | 0.12    | -13     | 90       | 181       | 45    | 0.002295 |
| 3             | 0.4     | 0.12    | -13     | 90       | 184       | 45    | 0.006884 |

3. Result

Linac head simulation with 1 billion particles requires 19 hours of simulation time, this simulation uses computer cluster facilities of the Indonesian Institute of Sciences (LIPI) and for VMAT dose distribution simulations, simulating 300 million particles takes 19.46 hours with the specification of core3 computers in the Lab. Physics Modeling of UIN SGD Bandung. The distribution of doses produced is as follows. Figure 3 the graph is a 1D dose distribution along the X-axis indicating that the maximum dose distribution is in the middle of the 3 cm depth and then the dose distribution decreases to both sides of the X-axis. Based on two-dimensional (2D) data, figure 4 shows that the maximum dose distribution is marked in red in the middle on the surface of the phantom, while the minimum dose is on the side marked in yellow and blue. This can explain the part of the isocenter area for the X-axis direction.

Based on Figure 5, it illustrates the dose profile curve (1D) for the Y-axis, indicating that the maximum dose distribution is in the middle at a depth of 2 cm, then the dose distribution decreases to both sides of the Y-axis. When viewed based on two-dimensional (2D) data, namely the isodose curve in Figure 6, it shows that the maximum dose distribution is marked in red in the middle part of the phantom, while the minimum dose is on the side marked yellow and blue. This can explain the part of the isocenter area for the Y-axis direction.

Based on Figure 7, the dose profile curve (1D) for the Z-axis shows that the maximum dose distribution is at the left at a depth of -10.3 cm, then the dose distribution decreases to the right side of the Z-axis. Based on two-dimensional (2D) data, the isodose curve in Figure 8 shows that the maximum dose distribution is marked in red in the middle of the phantom surface.
while the minimum dose is on the side which is marked in yellow and blue. This can explain the part of the isocenter area for the Z-axis direction.

4. Discussion
Based on the graphs that have been obtained, it can be analyzed that the 1D dose distribution graph for each coordinate axis has a different graph pattern, the result in changes in MLC position during the simulation process and can also indicate that MLC has changed position or movement, indicator of movement. This MLC is important because it is to prove and know about the design of the MLC. The 2D dose distribution can be analyzed by looking at the maximum dose section, it can be seen that for each coordinate axis the maximum dose is at isocenter -5 cm to 5 cm according to the design of the JAWs X opening in figure 1.

5. Conclusion
Based on the results obtained, it can be concluded that the process of reading VMAT parameter input data from the rtplan.dcm using python code has been successful and can be used as a Monte Carlo simulation input - EGSnrc and the simulation run well. However, to verify whether the python code used can produce an accurate or experimental dose distribution, then the dose
distribution data from this study will then try to compare it with experimental data or other verification data.

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