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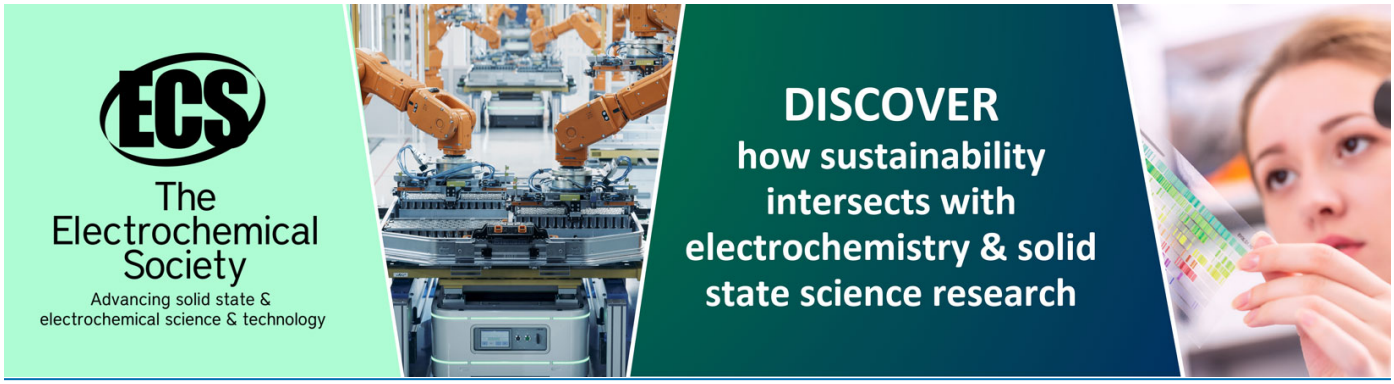

Dose-volume Histograms Comparison From Two Different Beam Configurations In The Monte Carlo Simulation of 6MV Clinac2100 Using PRIMO Program

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Abstract. The Monte Carlo (MC) method is widely considered to provide the most accurate dose distribution in external beam radiotherapy. A self-contained, full MC linac simulator and dose calculator, PRIMO is a windows-based, freely-distributed software which allows the importation of external compliant phase-space files among its many capabilities. Using PRIMO, a Varian Clinac2100 is simulated at 6 MV nominal energy for 10^8 number of histories. The dose calculations are compared using two different initial electron beam configurations. The tuned-beam profile has initial electron beam energy of 6.26 MeV, 0.150 MeV full-width-half-maximum (FWHM), 0.150 cm focal spot FWHM and 2 degrees beam divergence. The default configuration given in PRIMO has 5.40 MeV as initial electron beam energy and zero values for all the other beam parameters. A brain computerized tomography (CT) volume is imported into PRIMO and using its contouring tools, these structures are delineated: a hypothetical gross-tumor volume (GTV), the brain, the left and right eye lens. The CT volume is irradiated with two parallel-opposed fields of size 10 cm by 10 cm with the brain conformed using the 52-leaf MLC. The dose-volume histogram (DVH) of the GTV and the brain for the tuned-beam profile has a larger extent into the high dose region compared to the DVHs of the default beam configuration. The dose given to 95% of the volume (D_{95}) and the percentage of the volume receiving a dose equal to 95% (V_{95}) are also compared. The GTV for the default beam profile has D_{95} = 86.31% with V_{95} = 0.44%, while for the tuned-beam profile, D_{95} = 88.30% with V_{95} = 0.95%. For the brain, D_{95} = 2.55% with V_{95} = 1.13% for the default profile while the tuned beam profile gives D_{95} = 2.43% with V_{95} = 2.33%. For the left [right] lens, D_{95} = 0.15% [D_{95} = 0.11%] for the default profile and D_{95} = 0.16% [D_{95} = 0.081%] for the tuned-beam profile. Both beam profiles give V_{95} = 0% for the left- and right- eye lens.

1. Introduction

One of the leading cause of death is cancer. Over 18.1 million new cases of cancer worldwide have been reported by the International Agency for Research on Center (IARC) resulting from 9.6 million deaths in the year 2018. And the number of cancer cases are expected to increase to over 24 million new cases per year in the year 2030 [1]. This is due to several factors that include population growth, aging, social and economic development. Thus, availability of the treatment for the increasing number of cancer cases is one of the major concerns.

The treatment modality for cancer can be surgery, chemotherapy, radiation therapy or a combination by either of these modalities. More than 50% of cancer patients undergo radiation therapy as one of their treatment modality and 40% are being cured [2]. Correct radiation treatment planning and accurate dose distribution calculation have are of major significance in the success of the treatment.

Radiation therapy uses ionizing radiation of either photon or electron beams to destroy cancer cells. Radiation treatment planning is done to generate the proper dose distributions to the target area. The dose distributions are produced using complex algorithms. The most commonly used algorithm in radiotherapy treatment planning system produce treatment plans within a short period of time with reasonable accuracy. However, there are more accurate algorithms that can be produced by using the full Monte Carlo (MC) system. It is based on the various physical interactions of individual photons or electrons per cross-sectional area but it requires exceedingly long simulation times in addition to the mastery of these technique to generate dose distribution.

Recently, a new Monte Carlo based algorithm, PRIMO [3-7], which is a window-based, freely distributed software that contains a full MC linac simulator and dose distribution calculator was introduced. A graphical user interface is present in this feature that makes it easy for the user to configure and execute the simulation. Other features include a variance reduction technique in order to lessen the amount of time required for the simulation. With these amazing features, PRIMO addresses the two main negative issues of the MC technique earlier mentioned, at the same time producing a more accurate dose distribution.

2. Research Methodology

2.1 PRIMO

PRIMO is one of the Monte Carlo simulation systems that can generate accurate dose distributions. It simulates individual particles starting from the linac going into the water phantom or patient. Its practical use is for dose verification which could be applied in quality assurance for daily clinical practice.

2.2 Simulation Set-up

The simulation is divided into three segments: S1 (fixed upper components of the linac), S2 (movable components of the linac) and S3 (dose tallying in a phantom/patient). A Varian CLinac 2100 linac model having a photon operation mode is created as shown in Figure 1. In this study, S1 is first simulated with 10^8 total number of histories and then the phase-space files are imported for the subsequent simulations of S2 and S3.

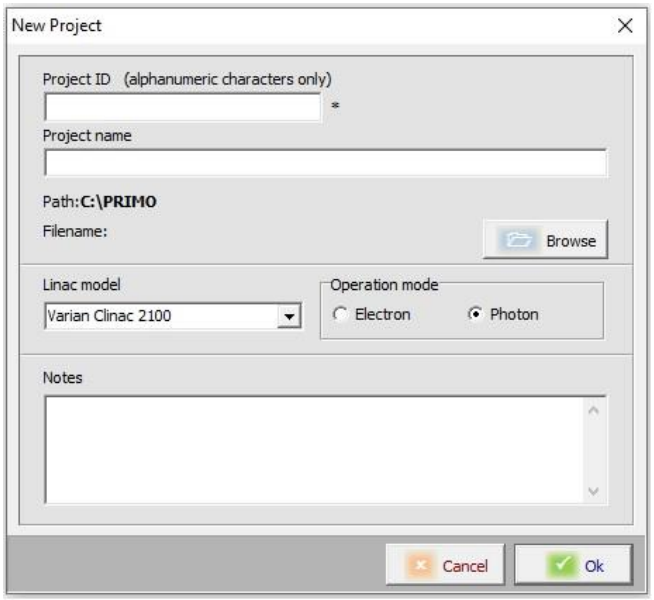


Figure 1. PRIMO windows for creating new project.

2.2.1 Simulation in S1

Simulation for S1 corresponds to the interaction of the particles starting from its generation for specific energy going into the target (flattening filter), primary and secondary collimators, and ionization chamber. Thus, the parameters that are considered are the nominal energy, initial energy, energy full-width-half-maximum (FWHM), focal spot FWHM and beam divergence. Once the simulation is completed, a phase-space file is generated that contains all of the information of the particle is recorded.

The default beam configuration given in PRIMO has 5.40 MeV as initial electron beam energy and zero values for all the other beam parameters shown in Figure 2.

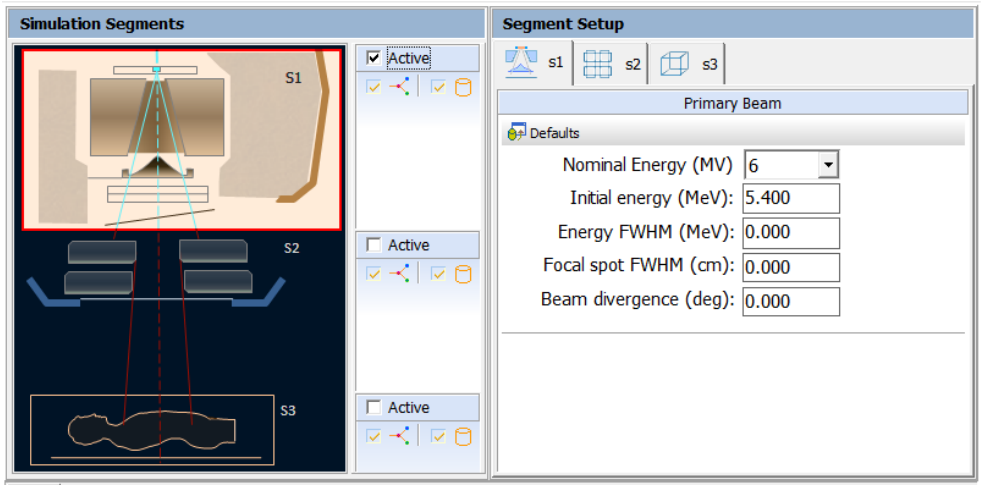


Figure 2. Default beam configuration parameter for S1

The tuned-beam configuration is configured with an initial electron beam energy of 6.26 MeV, 0.150 MeV energy FWHM, 0.150 cm focal spot FWHM and 2° beam divergence as shown in figure 3.

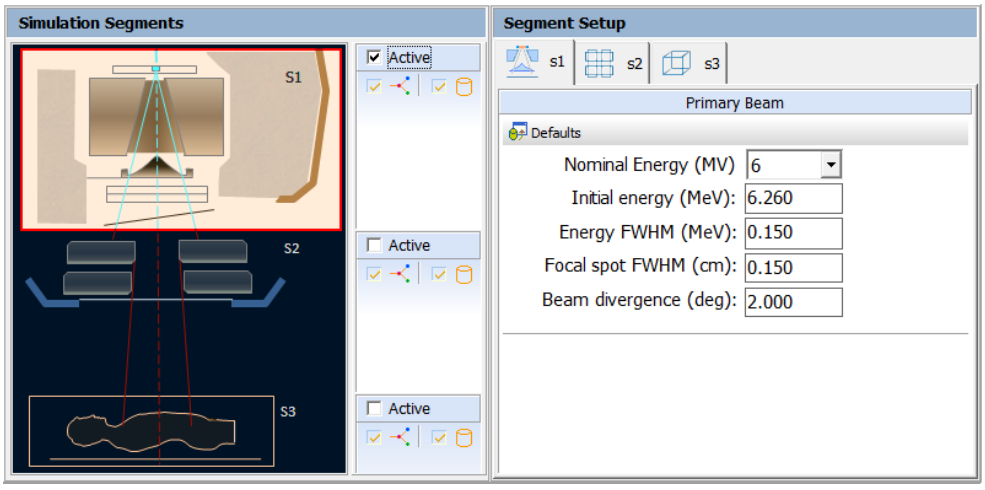


Figure 3. Tune beam configuration parameter for S1

2.2.2 Simulation in S2

Segment S2 corresponds to the simulation of the interaction of the particles generated from S1 going to lower linac that consists of jaws and multileaf collimator (MLC). This segment allows one to configure the field size, gantry and collimator angles, and the isocenter position of the beam. Thus, S2 creates the beam profile for each beam configuration before it goes to the patient or phantom.

In this study, two beams is created each having a field size of 10 x 10 cm^2. Gantry angles are set at 90° and 270° respectively. MLC-52 in PRIMO is chosen as a collimator which limits the field size to the structure of the brain. Irradiation of the beam is isocenter to the gross tumor volume (GTV) shown in figure 4.

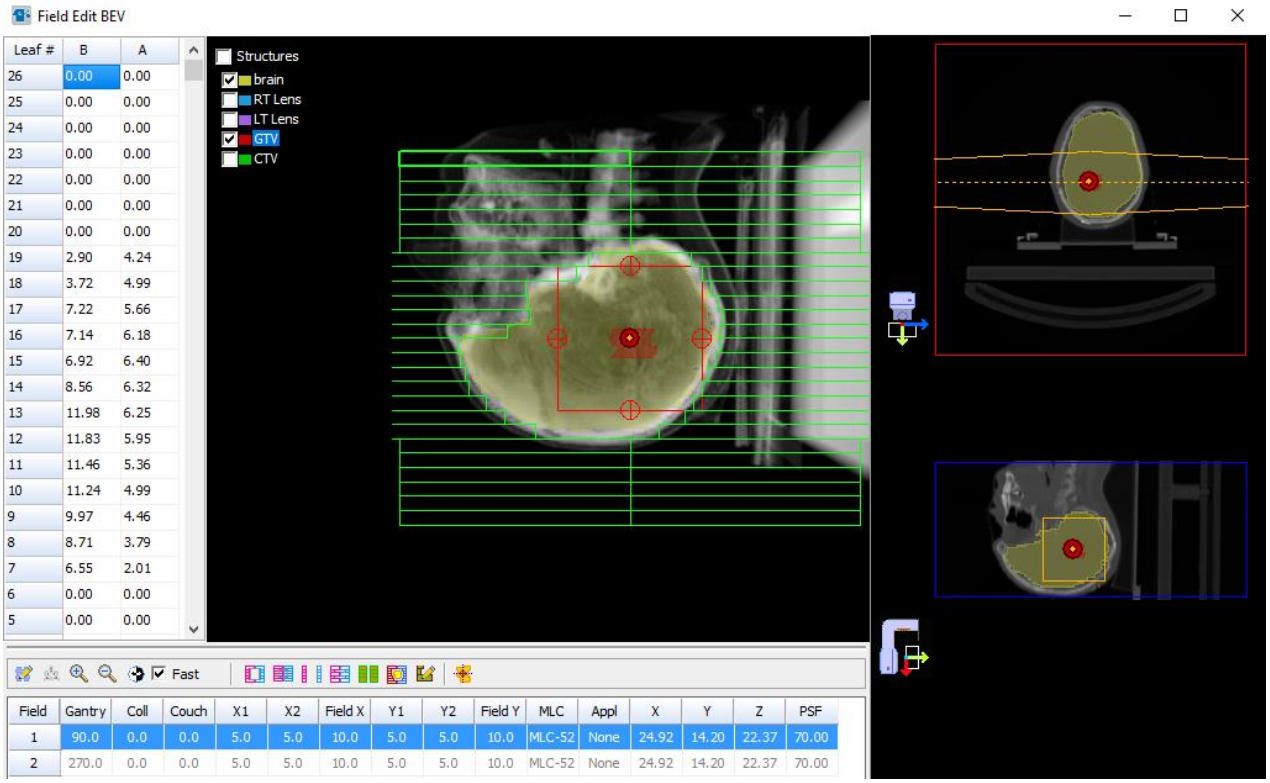


Figure 4. Beam Field Edit

2.2.3 Simulation in S3

Segment S3 tallies the dose estimation from the generated beam profile in S2. CT volume images of the brain are imported into PRIMO and converted into a voxelized geometry which consist of a set of material and mass density value pairs simulating a real time image. Materials that are taken into consideration are air, adipose tissue, soft tissue, and compact bone.

In this study, GTV, the brain, left and right eye lens are delineated for the dose estimation profile by each beam configuration. Splitting-roulette technique is chosen for variance reduction with a splitting factor of 20 that is fitted to the field size currently use in S2.

2.3 Computational Tools

A PRIMO version 0.1.5.1307 is installed in a windows 10 operating system computer laptop having 4 Pentium type processors with a speed of 1.19 GHz for the simulation is used.

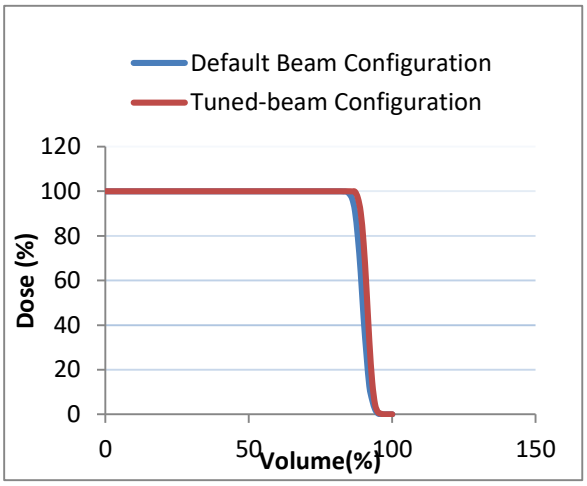
2.4 Data Analysis

The dose-volume histogram for the delineated structure by each beam configuration is compared. The dose estimation results is also presented as 3D dose distributions that is superimposed on the computerized tomography volume.

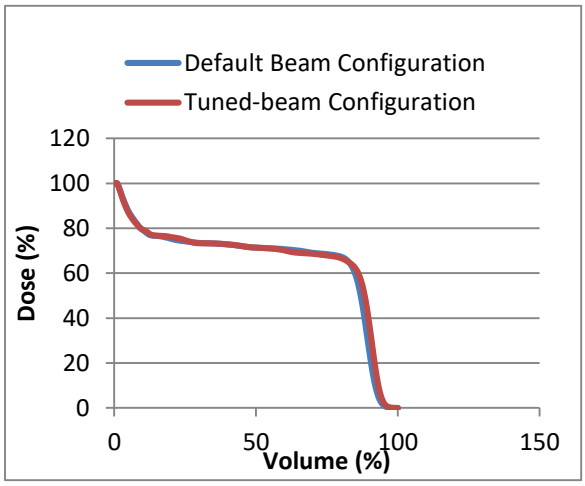
3. Results and Discussions

Delineated Structures	Default Beam Configuration		Tuned-Beam Configuration	
	D_{95}	V_{95}	D_{95}	V_{95}
GTV	86.31%	0.44%	88.30%	0.95%
Brain	2.55%	1.13%	2.43%	2.33%
Left lens	0.15%	0%	0.16%	0%
Right lens	0.11%	0%	0.081%	0%

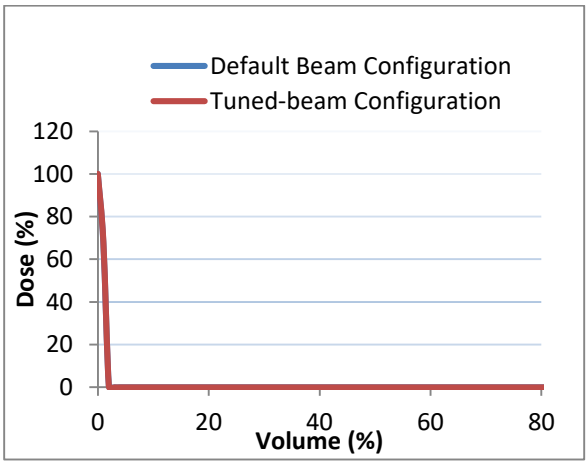
Table 1. The dose given to 95% of the volume (D_{95}) and the percentage of the volume receiving a dose equal to 95% (V_{95}) by the different delineated structure in comparison between the default beam configuration and tuned-beam configuration.



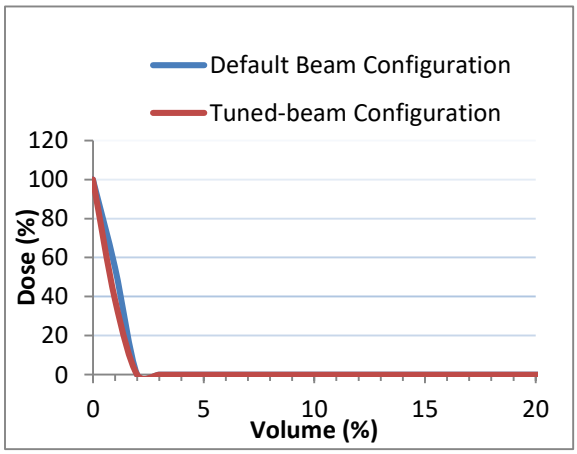
(a) GTV



(b) Brain



(c) Left lens



(d) Right lens

Figure 5. Comparison of the dose-volume histogram between default beam configuration and tuned-beam configuration of the (a) gross tumor volume (GTV), (b) brain, (c) left lens, and (d) right lens.

4. Summary and Conclusions

Increase in the initial electron beam energy lead also to the increase in the dose showing higher dose-volume histogram in the tuned-beam configuration compare to the default beam configuration. In this study it can be shown that PRIMO program can be used for dose verification processes.

5. References

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