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Comparison of PRIMO Monte Carlo code and Eclipse treatment planning system in calculation of dosimetric parameters in brain cancer radiotherapy

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ABSTRACT

Background: It is important to evaluate the dose calculated by treatment planning systems (TPSs) and dose distribution in tumor and organs at risk (OARs). The aim of this study is to compare dose calculated by the PRIMO Monte Carlo code and Eclipse TPS in radiotherapy of brain cancer patients.

Materials and methods: PRIMO simulation code was used to simulate a Varian Clinac 600C linac. The simulations were validated for the linac by comparison of the simulation and measured results. In the case of brain cancer patients, the dosimetric parameters obtained by the PRIMO code were compared with those calculated by Eclipse TPS. Gamma function analysis with 3%, 3 mm criteria was utilized to compare the dose distributions. The evaluations were based on the dosimetric parameters for the planning target volume (PTV) and OAR including D_{min}, $D_{mean,}$ and D_{max}, homogeneity index (HI), and conformity index (CI).

Results: The gamma function analysis showed a 98% agreement between the results obtained by the PRIMO code and measurement for the percent depth dose (PDD) and dose profiles. The corresponding value in comparing the dosimetric parameters from PRIMO code and Eclipse TPS for the brain patients was 94%, on average. The results of the PRIMO simulation were in good agreement with the measured data and Eclipse TPS calculations.

Conclusions: Based on the results of this study, the PRIMO code can be utilized to simulate a medical linac with good accuracy and to evaluate the accuracy of treatment plans for patients with brain cancer.

Key words: radiotherapy; PRIMO code; treatment planning system; Eclipse; brain cancer

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Introduction

Brain cancer, which has doubled in frequency in the past, is accounted as a disease that can be treated with radiotherapy. Brain sensitivity is also prominent in patients with brain cancer, and the average survival does not exceed 12 to 15 months. Various radiotherapy techniques can be used for treatment of brain cancer, including three-dimensional conformal radiation therapy

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(3DCRT) and intensity-modulated radiation therapy (IMRT). In radiotherapy techniques, the radiation dose to the surrounding normal tissues is an important issue in which the normal tissue tolerance dose should not be exceeded. A high dose to the tumor may cause damage to the healthy organs surrounding the tumor, so the doses given to the tumor must be accompanied by the protection of these organs. Advanced radiotherapy technologies were developed as innovations in the era of radiation therapy and have been used to improve the tumor dose coverage as well as for protection of organs at risk (OARs) [1, 2]. These treatment techniques require ensuring the quality and safety of dose delivery and reducing the discrepancies in dose distribution that take place in the treatment planning and dose delivery [3, 4].

PRIMO is a standalone Monte Carlo (MC) code that includes Penetration and Energy Loss of Positrons and Electrons (PENELOPE) as a main code. There is a general-purpose main program for the PENELOPE code which allows simulation of radiation transport in the head of linacs, phantom, and patient body phantom with introducing computerized tomography (CT) images of patients. This code is regarded as a user-friendly solution with the ability of MC simulations of several medical linear accelerators [5, 6]. The DPM for fast MC simulation of coupled electron and photon transport is also incorporated in the PRIMO code [7]. A graphical user interface contains different components in a single user-friendly environment [8].

There are various studies [9–12] which have dealt with application of PRIMO code and its accuracy and verification by simulation of different linac models followed by a comparison of dosimetric data obtained by the PRIMO code and in-phantom measurements or TPS calculations. There are also various studies in which other Monte Carlo codes, such as Geant4 Application for Tomographic Emission (GATE) and Monte Carlo N-Particle (MCNP), were used to simulate linear accelerators and the simulated percent depth dose and dose profiles were compared with the measured ones [13–14]. Brucella et al. [9] simulated a Varian Clinic linac (2100 model) by the PRIMO code and performed fine-tuning of the linac beam parameters to produce a good match between the simulated and measured dose profiles. In the simulations, a water phantom was simulated, and the energies were between 6 MV and 10 MV. A set of different spectra for different Varian linacs were calculated using the PENELOPE/PRIMO MC system. The spectra were extracted from phase-space files tallied for 10×10 cm^2 and 15×15 cm^2 field sizes for photon and electron beams [10]. Rodriguez et al. [12] considered volumetric-modulated arc therapy (VMAT) clinical cases of prostate, head, and neck cancer irradiated by Varian's Clinac iX linac, equipped with 120 multileaf collimators (MLCs). The original plans were created with ISOgray TPS, and a set of dynalog files corresponding to one treatment session was chosen arbitrarily for each clinical case. That study aimed to validate the methods incorporated in the PRIMO code to evaluate the deviations introduced in dose distributions due to discrepancies in the positioning of the leaves of the MLCs during patient treatment. To verify the accuracy of the radiotherapy treatment plans from the information recorded in the Varian's dynalog files, they were verified by the PRIMO code. These files include the data about the planned locations of MLCs and the delivered dose in the segments in the radiation field. Acceptance criteria were based on percentage agreement (PA) values and the gamma pass rate (GPR). Esposito et al. [12] utilized PRIMO code for running the intensity-modulated radiation therapy (IMRT) technique for a Varian Trilogy linac with 120 Millennium MLCs and a Varian Novalis linac with 120HD MLCs. An RW3 multi-slab phantom was also irradiated while Gafchromic films were inserted between the slabs. PTW-Verisoft software and gamma function (with 2%, 2 mm criteria) were used to compare the simulated and experimental results. To the best of our knowledge, dosimetric parameters in brain cancer have not been previously simulated by the PRIMO code. This study aims to compare the dose calculation by the PRIMO Monte-Carlo code and Eclipse TPS in radiotherapy of brain cancer patients.

Materials and methods

The recent version of the PRIMO code (Version 0.3.1.1800) was used in this study. A Varian Clinic 600C linac was considered in this code. The study was carried out in two stages: In the first stage, the energy for the simulated model of the Varian Clinic

600C linear accelerator was tuned, and the simulation results of the percentage depth dose (PDD) and beam profiles were compared with the measured data. Then treatment plans of 5 brain cancer patients which were designed by the Eclipse TPS were uploaded in the PRIMO simulation code to simulate the reconstructed plans.

Patients' treatment plan

The radiotherapy treatment data of 5 patients (2 males and 3 females) with an average age of 55 years with brain cancer, who had been treated with IMRT, were provided by Radiotherapy Department of Shohada-e-Tajrish Hospital (Tehran, Iran). IMRT is a technique of cancer treatments which delivers beams with different intensities from a number of different angles. One of the advantages of using IMRT is to decrease delivered dose to normal tissues compared to 3D-conformal radiation therapy. The prescribed dose and number of beams for each patient is presented in Table 1. Each number of beams contains reference beams varying from 1 to 6.

The Digital Imaging and Communications in Medicine (DICOM) files are widely used in radiology and radiotherapy applications. One type of these files is DICOM-RT which is one of the first extensions applied for use in radiotherapy. DICOM-RT files contain seven objects: RT Image, RT Structure Set, RT Plan, RT Dose, RT Beams Treatment Record, RT Brachy Treatment Record, and RT Treatment Summary Record. In the treatment planning stage in this study, radiotherapy structure files which contain information related to regions of interest (ROIs) and patient's anatomy file (RTStruct), radiation dose data file (RTDose) and treatment planning data file (RTPlan) of the patients which were obtained by treatment planning were introduced in the PRIMO code. Different dosimetric parameters, including minimum dose (D_{min}), mean dose (D_{mean}) and maximum dose (D_{max}) for the planning target volume (PTV) and OARs as well as homogeneity index (HI) and conformity index (CI), were calculated. The gamma function analysis was used to compare the dose distribution calculated by PRIMO code and Eclipse TPS.

Table 1. Prescribed dose of patients with brain cancer treated with intensity-modulated radiation therapy (IMRT)

Patient number	Total dose [Gy]	Fractions	Number of beams
Patient 1	59.4	33	4
Patient 2	60	30	4
Patient 3	59.4	33	3
Patient 4	60	30	3
Patient 5	59.4	33	4

Validation of linac simulations

It is possible to use the PRIMO code to simulate linac's head and to score particles in the form of phase space file (PSFs). The PSFs can be used to score different dosimetric parameters in water or patient-based phantom [15]. The purpose of using this code is to ensure treatment quality in advanced radiotherapy and verify dose distribution in the body of cancer patients. Final discrepancies between the planned and calculated doses, can be evaluated and this allows to determine if there is any inaccuracy in the calculation by TPS [16].

As the first step, Varian Clinac 600C linac was simulated by the PRIMO code. The phantom dimensions were defined as follows: $50 \times 50 \times 30$ cm^3, and then the dose distribution was scored in the phantom. The simulation was started with default values presented by the PRIMO code for the 6 MV photon beam. The primary electrons hitting the target were defined with a Gaussian distribution. The default values which are contained in the PRIMO code for Varian Clinac 600C linac were used as follows: nominal energy = 6 MV, initial energy = 5.7 MeV, full-width at half maximum (FWHM) of 0.187 MeV, focal spot size of 0.140 mm, and beam divergence of 0.2°. The source to surface distance (SSD) was fixed at 100 cm and field size was defined as 10×10 cm^2. Starting with the default values and slightly modifying the values, the simulation was repeated several times to find the optimum energy. The energy with the best agreement between the simulated and measured percent depth dose (PDD) was considered as the optimum energy. After optimizing the initial energy, the focal spot size, FWHM of energy, and beam divergence values were adjusted to achieve the closest matching to the measured profiles. Then the measured PDDs for 20×20 cm^2, and 30×30 cm^2 field sizes and beam dose profiles for 10×10 cm^2, 20×20 cm^2, and 30×30 cm^2 fields at d_{max}, 5 cm, and 10 cm depths were used for validation of the simulations. To run the simulations,

the number of 3×10^7 histories was set based on a previous study [15]. The related uncertainty was 1.6 % on average, which is relatively low. The simulations were performed in the PRIMO code to obtain dose distribution within the phantom in three stages. In the first stage (S1), simulations were performed for the upper part of the linac. The second stage (S2) was for the multi-leaf collimators (MLCs) and jaws before the beam entering the phantom, while both the S1 and S2 steps provided PSFs as output. The last stage (S3) in the simulation was to calculate the dose distribution within the phantom, using the PSFs created in the S2 step for simulation of three-dimensional (3D) dose distribution. In the S3 step, a homogeneous water phantom with dimensions of $50 \times 50 \times 30$ cm^3 with voxel sizes of $0.2 \times 0.2 \times 0.2$ mm^3 was defined to calculate the dose. Different steps (S1, S2 and S3) of the linac simulation in the PRIMO environment are illustrated in Figure 1. The components of the Varian Clinac 600C linac include: a tungsten target, primary collimator, flattening filter, ionization chamber, mirror, secondary collimators and MLCs.

The simulations were run using a system with 8-core central processing unit (CPU) and 8 GB of random-access memory (RAM). For analyzing the PDD curve, to obtain high spatial resolution in the dose build-up region, a bin size of 2 mm was chosen along the central axis of the beam. In the lateral direction, a bin size of 2 mm × 2 mm × 2 mm was found to be adequate for evaluation of the dose profiles in the penumbra region. This bin size is routine in calculations in radiotherapy applications and setting a smaller bin size will significantly increase the time of simulation. The nominal sensitive volume of the used Farmer ionizing chamber was 0.6 cm^3 which relatively corresponds to the voxel size which was used in the simulations. PRIMO code requires defining a set of simulation parameters called transport parameters [23]. To reduce the variance in the calculations by the PRIMO code, in the simulation process in the S1 and S2 steps, splitting roulette and rotational splitting variance reduction techniques were used [18]. Manufacturers recommended splitting roulette for energies which are less than 15 MV and rotational splitting for those higher than this level [19, 20]. To apply simple splitting in the water phantom, the values of the splitting factors used to obtain the low uncertainty were between 100 and 300.

The measurements were carried out for PDDs and dose profiles using PTW phantom (MP3RW3 model, Germany) at 100 cm SSD for field sizes of 10×10 cm^2, 20×20 cm^2, and 30×30 cm^2. The dose profiles were also mea-

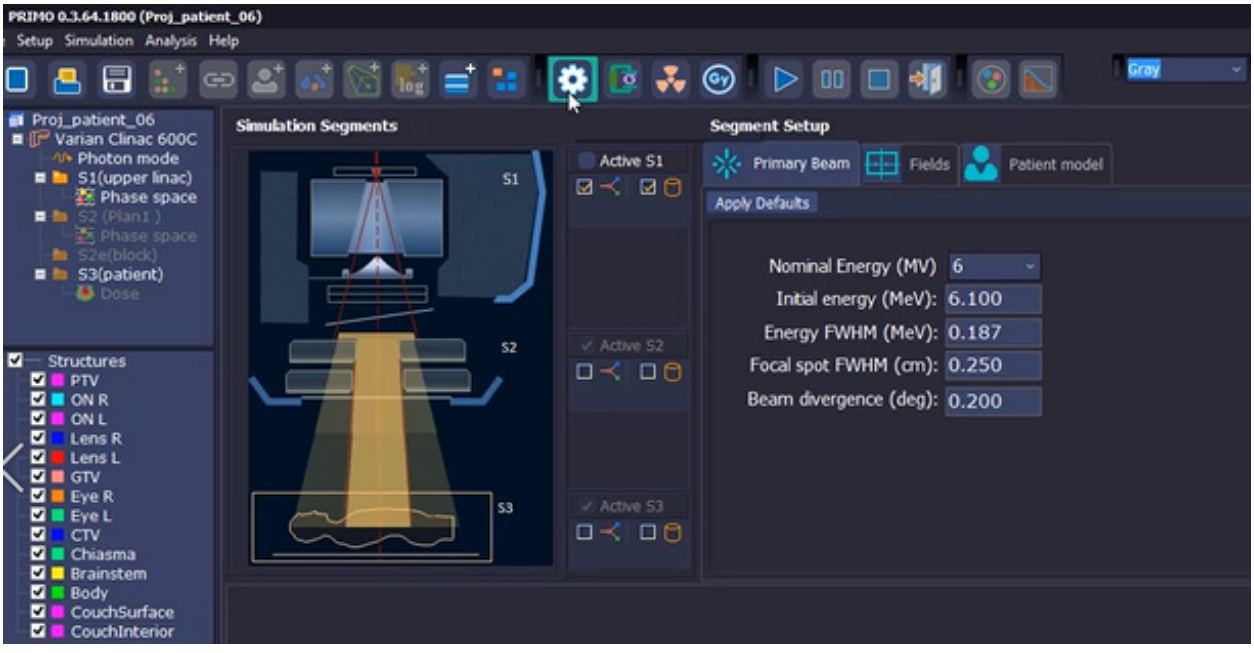

Figure 1. The PRIMO environment with the optimum values illustrating the three stages (S1, S2, and S3) of the simulation in the PRIMO code

sured at different depths (d_{max}, 5.0 cm, and 10.0 cm) for 10 × 10 cm^2, 20 × 20 cm^2, and 30 × 30 cm^2 field sizes. A Farmer ionization chamber (016 cc, Germany) and a PTW electrometer (Unidos E, Germany) were used for measurement of dose profiles. The measured PDD and dose profiles in the ".dat" format were then imported into the PRIMO code for numerical gamma analysis. To quantify the level of agreement/disagreement between the simulated and measured curves, the gamma analysis method was chosen [23] with criteria of 3 %/3 mm for DD and DTA, respectively.

Comparison of dosimetric parameters for brain cancer patients from PRIMO code and Eclipse TPS

After completing the validation of the linac and finding the optimum energy, the step of implementing treatment plans for brain cancer patients was performed. For this purpose, treatment plans which were designed using the Eclipse TPS in the Radiotherapy Department of Shohda-e-Tajrish Hospital (Tehran, Iran) were uploaded in the PRIMO code by introducing CT scans and TPS data including RTStruct, RTDose and RTPlan files of patients. Dose distributions in the patients' phantoms were recalculated considering the TPS calculated monitor units (MUs). The simulated lateral dose profiles, in the isocenter planes in the axial and sagittal views were also compared against Eclipse TPS data. The dose parameters which were calculated for five patients with brain cancer included: D_{min}, D_{mean}, $D_{max,}$ homogeneity index (HI), and conformity index (CI). Additionally, the dose parameters (D_{min}, D_{mean}, and D_{max}) were calculated for OARs (chiasm, right optic nerve, left optic nerve, right eye, and left eye).

HI in PTV is defined by the Equation (1):

$$HI\ (\%) = \left(\frac{D_{2\,\%} - D_{98\,\%}}{D_{\text{Prescribed}}}\right) \times 100 \quad (1)$$

where $D_{2\%}$ and $D_{98\%}$ are the minimum and maximum doses delivered to 2% and 98% of the PTV. A small HI value indicates high homogeneity [21, 22].

The CI is defined as follows:

$$CI = \left(\frac{V95\,\%}{Volume\ of\ PTV}\right) \quad (2)$$

$V_{95\,\%}$ is the volume of PTV covered by at least 95% of the prescribed dose.

Results

Validation of linac modeling

While the nominal energy was 6 MV to obtain the optimum energy, different photon energies including 5.7, 5.8, 5.9, 6.0, 6.1, 6.2, 6.3, and 6.4 MeV, were examined. The optimum energy with the best agreement was 6.1 MeV, based on comparison of the PDD for the 10 × 10 cm^2 field size from the simulations and measurements (Tab. 2).

Table 3 shows gamma passing rates for PDDs with the initial photon beam energy of 6.1 MeV for 10 × 10 cm^2, 20 × 20 cm^2 and 30 × 30 cm^2 fields. The best agreement between the simulated and measured PDD curves, which was obtained for the 10 × 10 cm^2 field, for initial electron energy value of 6.1 MeV is illustrated in Figure 2.

The FWHM values of energy and beam divergence value were adjusted iteratively to obtain the closest match for the simulated dose profiles for the 10 × 10 cm^2, 20 × 20 cm^2 and 30 × 30 cm^2 field sizes at 5 cm, 10 cm and d_{max} depths with the 3 %/3 mm criteria for calculation of gamma function. For this purpose, the FWHM of energy values ranging between 0.140 to 0.187 MeV were examined. The beam divergence was also adjusted from 0.2° to 2°. The average statistical uncertainty reported by PRIMO was approximately 3.68 % for the field of

Table 2. Validated optimum simulation parameters for 6 MV photon beam of Varian Clinac 600 Clinac obtained by the PRIMO code

Optimum energy (MeV)	FWHM of energy (MeV)	Focal spot size [cm]	Beam divergence [degree]
6.1	0.187	0.250	0.200

Table 3. Gamma pass rate (%) with 3 %/ 3 mm criteria for percent depth dose (PDDs) with the initial photon beam energy of 6.1 MeV for 10 × 10 cm^2, 20 × 20 cm^2 and 30 × 30 cm^2 fields

Field size	Gamma pass rate (%)
10 × 10 cm^2	100.0
20 × 20 cm^2	99.7
30 × 30 cm^2	99.8

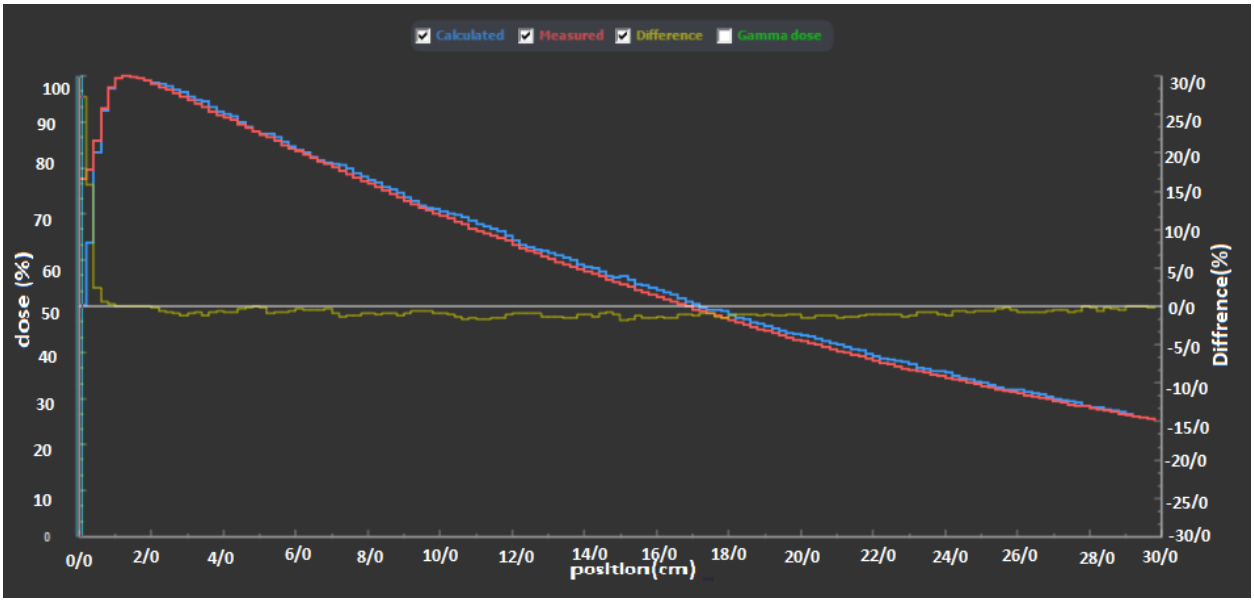

Figure 2. Comparison of percent depth dose (PDD) curves obtained by simulations with the PRIMO code at 6.1 MeV and measurements for the 10 × 10 cm^2 field size. The results of the percentage differences are also shown in this figure

Table 4. Gamma pass rate (%) with 3 %/ 3 mm criteria with the initial photon beam energy of 6.1 MeV and the energy full-width at half maximum (FWHM) of 0.187 MeV and FWHM for focal spot of 0.140 cm for depth of d_{max}, 5 cm and 10 cm depths for the 10 × 10 cm^2, 20 × 20 cm^2 and 30 × 30 cm^2 field sizes in a water phantom

Field size	Uncertainty (%)	Gamma pass rate (3 % / 3 mm)	Depth
10 × 10 cm^2	3.68	86.7	d_{max}
20 × 20 cm^2	3.58	97.69	d_{max}
30 × 30 cm^2	8.68	96.11	d_{max}
10 × 10 cm^2	3.68	93.67	5
20 × 20 cm^2	3.58	97.62	5
30 × 30 cm^2	8.68	100.00	5
10 × 10 cm^2	3.68	88.61	10
20 × 20 cm^2	3.58	90.14	10
30 × 30 cm^2	8.68	96.11	10

10 × 10 cm^2 running for 3 × 10^7 particles with the application of the Splitting Roulette technique. The results are tabulated in Table 4.The best agreement between the simulated and measured dose profiles, which was obtained for the 30 × 30 cm^2 field for 6.1 MeV at 5 cm depth, is illustrated in Figure 3.

Dose profiles from simulation by the PRIMO code and measurements for three fields of 10 × 10 cm^2, 20 × 20 cm^2, and 30 × 30 cm^2 at 10 cm depths are illustrated in Figure 4.

Comparison of dosimetric parameters for brain cancer patients from PRIMO code and Eclipse TPS

A sample for the simulated and Eclipse TPS calculated lateral dose profiles in the isocenter plane in the axial view is shown in Figure 5. The simulated dose distribution in the axial, sagittal, and coronal views in the isocenter plane for a sample brain patient is shown in Figure 6. The simulated dose-volume histograms (DVHs) for PTV, and OARs obtained by the PRIMO code and Eclipse TPS for a sample brain cancer patient is shown in Figure 7.

The calculated values of D_{min}, D_{mean}, and D_{max}. HI and CI for the PTV and D_{min}, D_{mean}, and D_{max} for the optic nerve, brain stem, chiasm, right eye and left eye are listed in Table 5. There is a good agreement between the simulated values by PRIMO code and Eclipse TPS for the calculated dosimetric parameters. The best agreement between the simulated values and calculated Eclipse TPS parameters for PTV was seen for the CI index with 0.02 % difference. The best agreement between the values for OARs was seen for the chiasm. The difference is equal to 0.01 % for D_{mean}. The analysis was performed for both the PTV and OARs, separately. The average passing rates were 98.8% for the PTV and 98.7% for the OARs with 3%, 3 mm acceptance criteria.

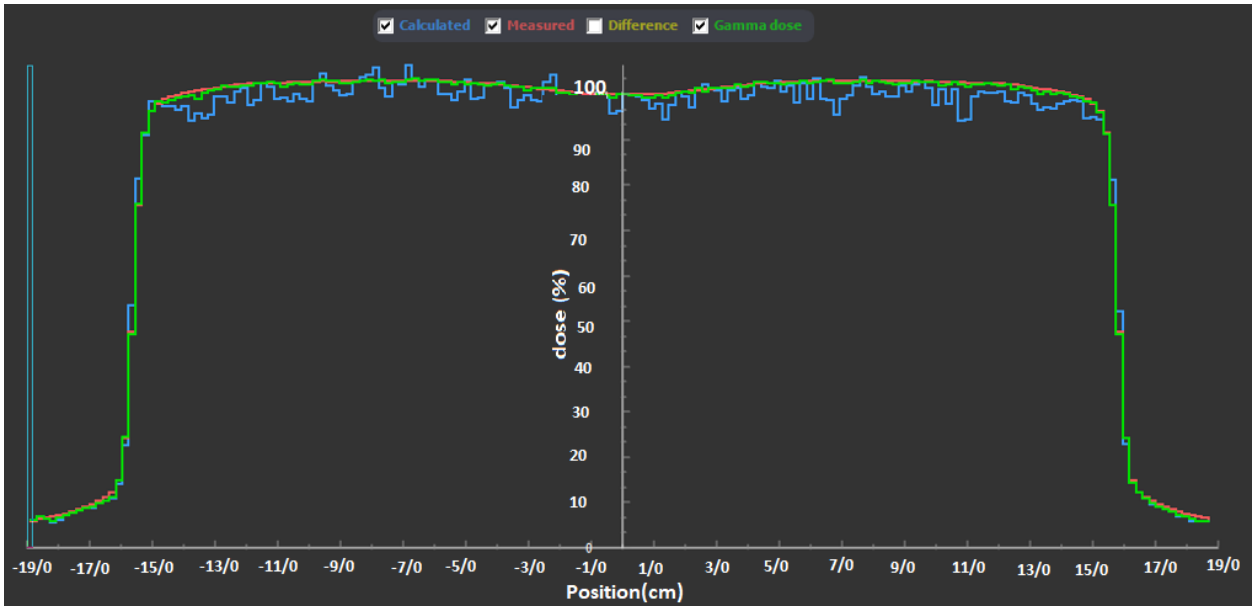

Figure 3. Comparison of dose profiles obtained by simulations by the PRIMO code and measurements at 6.1 MeV for the 30 × 30 cm^2 field size at 5 cm depth

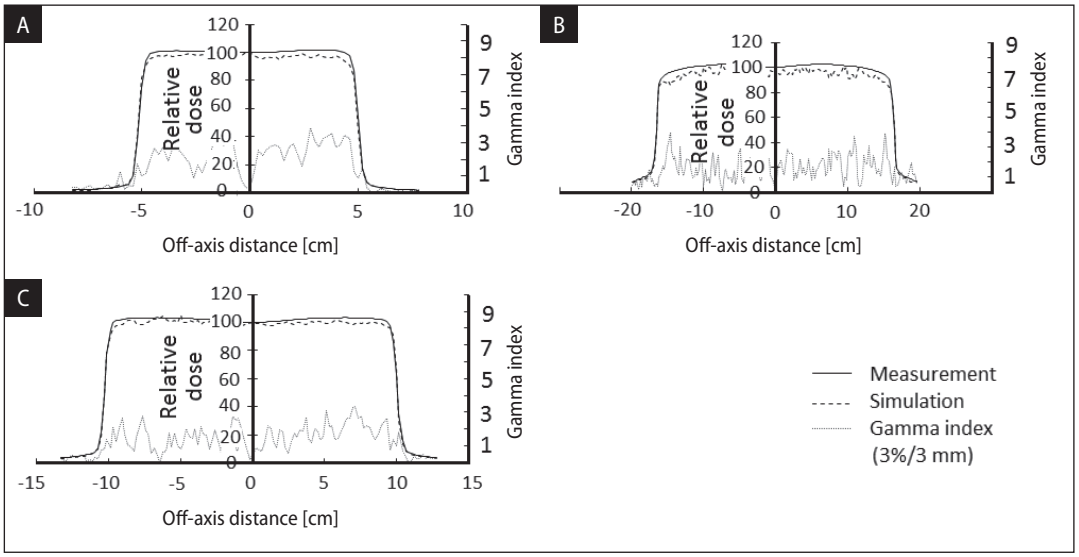

Figure 4. Comparison of simulated and measured dose profiles at 10 cm depths for the 10 cm × 10 cm (**A**), 20 ×20 cm (**B**), and 30 cm × 30 cm (**C**) field sizes with 3 %/3 mm criteria

Discussion

In this study, a 6 MV photon beam for the Varian Clinac 600C linac was simulated. As a standard procedure for validation of linac simulation by PRIMO, a linac photon beam was assumed and the optimum energy was obtained as 6.1 MV (Tab. 2). Dosimetric parameters from PRIMO code simulation and Eclipse and TPS were compared for five brain cancer patients. To compare dose distributions, from the two methods, the gamma-index analysis was used. Their gamma index passing rates with 3%/3 mm criteria were compared. Gamma-index values less than 1 are considered as a good agreement. Gamma passing rates for PDDs for the 10 × 10 cm^2, 20 × 20 cm^2 and 30 × 30 cm^2 field sizes and for dose profiles at different depths (d_{max}, 5 cm and 10 cm) for the 10 × 10 cm^2, 20 × 20 cm^2 and 30 × 30 cm^2 field sizes for the 6.1 MeV energy are listed in Table 3 and Table 4, respectively.

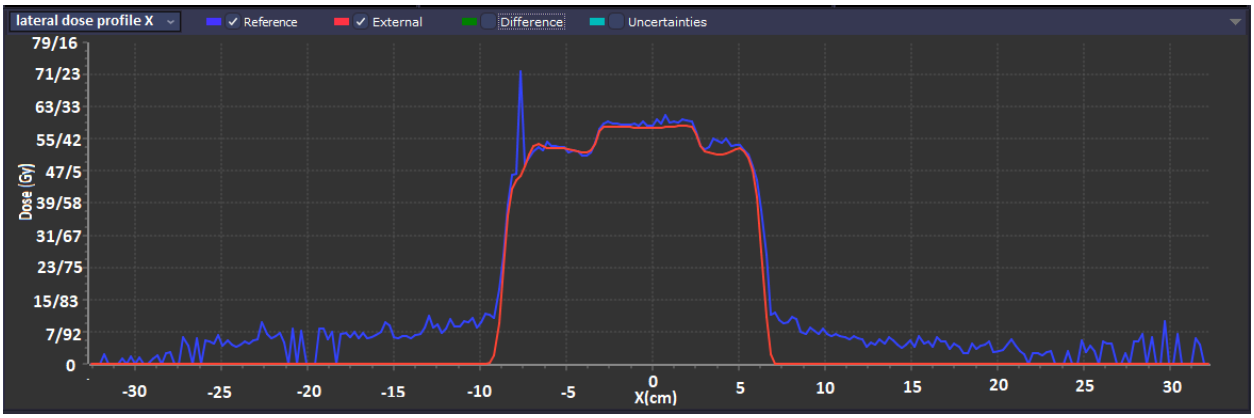

Figure 5. A sample for the simulated and Eclipse treatment planning system (TPS) calculated lateral dose profiles in the isocenter plane in the axial view

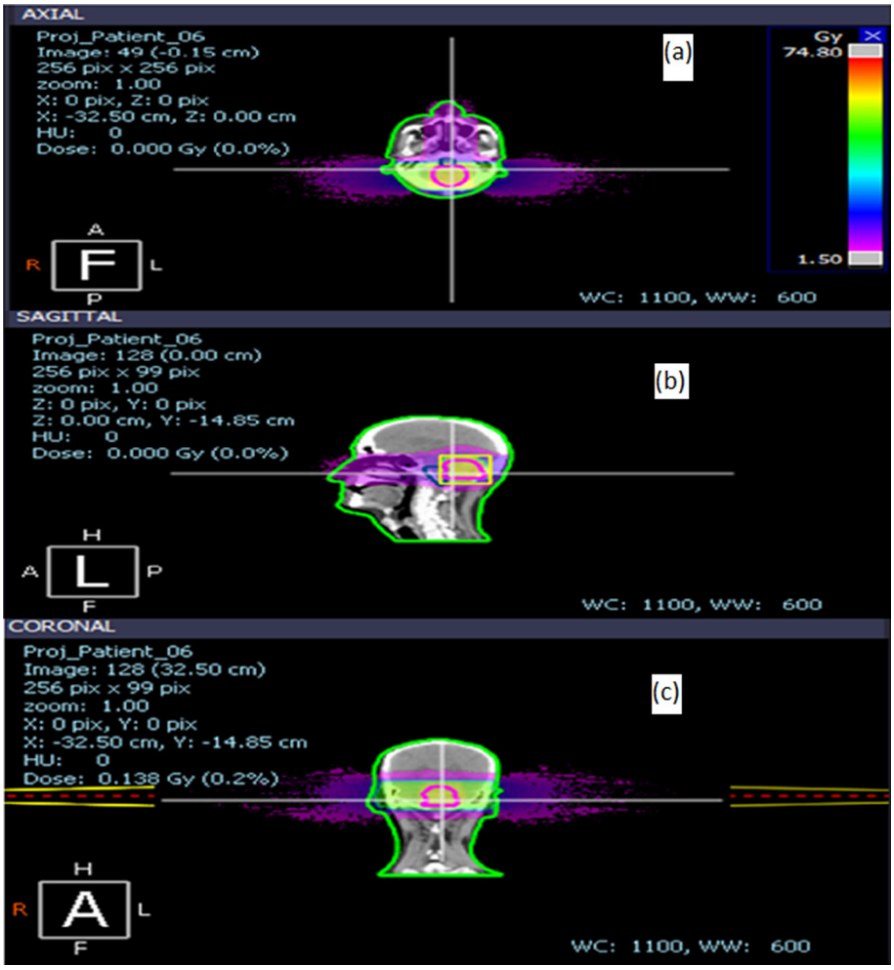

Figure 6. Simulated dose distribution in the axial (**A**), sagittal (**B**), and coronal (**C**) views in the isocenter planes for a sample brain cancer patient obtained by the PRIMO code

There is a good agreement between the simulated and measured values for PDDs and dose profiles.

The gamma function analysis for the PDD curves shows a minimum pass rate of 99.7 % for the 20×20 cm^2 field size (Tab. 3). The best agreement is presented in Figure 2 for the 10×10 cm^2 field size.

The results of gamma pass rates for dose profiles with the optimum energy of 6.1 MeV at dif-

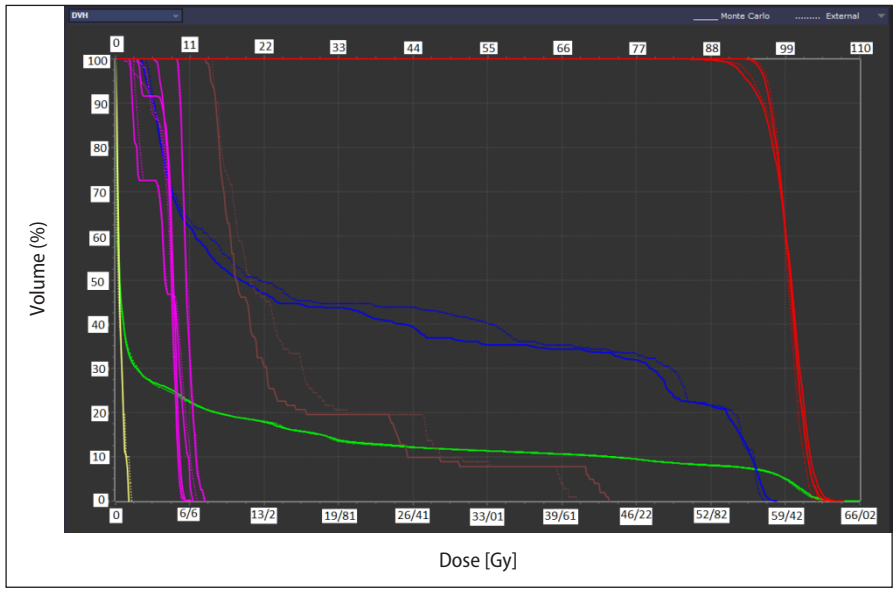

Figure 7. Dose-volume histograms (DVHs) for planning target volume (PTV), and organs at risk (OARs) which were obtained by simulation with the PRIMO code for a sample brain cancer patient. The Monte Carlo data appear in the form of solid curves, and the Eclipse treatment planning system (TPS) data appear in the form of a dotted curves

Table 5. Dosimetric parameters for planning target volume (PTV) (D_{min}, D_{mean}, D_{max}, HI and CI) and organ at risk (OAR) (D_{min}, D_{mean}, and D_{max}) obtained by the PRIMO code and Eclipse treatment planning system (TPS) for brain cancer patients. The OARs including the brain stem, chiasm, right optic nerve, left optic nerve, right eye, and left eye

Average for 5 patients	Dosimetric parameter	PRIMO code	Eclipse TPS	Difference (%)
PTV	D_{min} [Gy]	31.88	38.11	6.23
	D_{mean} [Gy]	63.25	60.11	3.14
	D_{max} [Gy]	68.98	64.60	4.38
	HI	0.21	0.24	0.03
	CI	0.92	0.95	0.02
Brain stem	D_{min} [Gy]	2.20	2.14	0.06
	D_{mean} [Gy]	21.29	25.11	3.82
	D_{max} [Gy]	65.11	58.24	6.87
Chiasm	D_{min} [Gy]	9.50	11.36	1.86
	D_{mean} [Gy]	20.13	20.40	0.01
	D_{max} [Gy]	26.77	29.27	2.50
Right optic nerve	D_{min} [Gy]	4.16	4.10	0.06
	D_{mean} [Gy]	6.47	6.50	0.03
	D_{max} [Gy]	12.90	16.32	3.42
Left optic nerve	D_{min} [Gy]	1.34	3.01	1.67
	D_{mean} [Gy]	4.66	6.45	1.79
	D_{max} [Gy]	10.27	11.59	1.32
Right eye	D_{min} [Gy]	0. 21	1.18	0.97
	D_{mean} [Gy]	1.58	2.62	1.04
	D_{max} [Gy]	4.22	6.78	2.56
Left eye	D_{min} [Gy]	0.07	1.36	1.29
	D_{mean} [Gy]	1.39	2.28	0.98
	D_{max} [Gy]	12.38	10.40	1.98

PTV — planning target volume; HI — homogeneity index; CI — conformity index

ferent depths for the 10 × 10 cm^2, 20 × 20 cm^2 and 30 × 30 cm^2 field sizes are listed in Table 4. At this level, a good agreement was seen with a minimum passing rate of 86.7 % for the 10 × 10 cm^2 field at d_{max} with 3 %/3 mm criteria. The agreement is presented in Figure 3 for the 30 × 30 cm^2 field at 5 cm depth and rate of 100% for the gamma analysis.

To simulate dosimetric parameters of PTV and OARs, the files of 5 patients were entered in the PRIMO code and the comparison was performed separately for each patient. In this step, these files were obtained from the Eclipse TPS for the patients who had been treated. It has relied on the comparison using dose difference as a tool for comparison of D_{min}, D_{mean} and D_{max} and these results are listed in Table 5. The lateral dose profiles comparison for target structures also showed good agreement between the PRIMO code and Eclipse TPS. The results are illustrated in Figure 6. The results of the gamma analysis were up to 97% between the PRIMO code and TPS, which is a good agreement. Isodose distribution was first compared visually on axial, sagittal, and coronal slices for a degree of conformity of the prescribed dose to the PTV and then for any inclusion of OAR within high dose and low dose levels. Direct comparison was also made for the cumulative DVH curves for PTV and OARs (Fig. 7). Dose to OAR was also evaluated. Plan comparison was also made quantitatively by comparing DVH parameters and by computing and comparing relevant metrics for target coverage, target conformity, dose heterogeneity within the target, and OAR sparing.

By following the data in Table 5 in terms of average values for five patients for the D_{min}, D_{mean}, D_{max}, HI and CI for PTV from PRIMO code and Eclipse TPS, a good agreement was observed between the values from the simulations and TPS. By calculating the D_{min}, D_{mean} and D_{max} for organs such as the optic nerve, brain stem, chiasm, right eye and left eye and comparing them with the Eclipse TPS, a convergence was noticed in the dose distributions for these organs between the PRIMO code and Eclipse TPS.

By comparing target coverage (D_{min}, D_{mean}, D_{max}, HI and CI) obtained from simulations by the PRIMO code and Eclipse TPS, the dosimetric analysis confirmed that there was a good agreement in target coverage between the PRIMO and Eclipse TPS (Tab. 5). The percentage difference in the distribution of the three doses is up to 4.32% for PTV. This difference is due to PRIMO accuracy in distributing the dose. As for the CI and HI, there is a good agreement, and the percentage difference reaches 0.02%. The brain stem dose distribution had a good agreement, with the mean difference of 3.68%. The distribution of doses for the region of the chiasm had good agreement with the difference of 1.21%. Right and left optic nerve had good agreement with the difference of 1.15%. Right and left eyes had good agreement with the difference of 1.46%.

As stated before, various studies have focused on accuracy and validation of the PRIMO code and its comparison with dosimetric parameters obtained by phantom [9–12]. In a study by Bacala et al. [11], a Varian Clinac 2100 for 6 MV and 10 MV beams was simulated using the PRIMO code. PDDs and lateral dose profiles for each nominal energy were compared with the data obtained by a water phantom using the gamma-index. A good agreement was seen between the simulated data and measurements by phantom. In another study by Efendi et al. [27] validation of the PRIMO code for quality assurance of linac beam was evaluated. For this purpose, the PDD and beam profile of the 6 MV photon beam were simulated and compared to the experimental data obtained by a water phantom. The results showed a good agreement between the simulated PDD and dose profiles. The best agreement was seen for the 10 × 10 cm^2 field size with 98.33% passing criteria which is close to the calculated value in this study (100% passing rate). Additionally, Sarin et al. [28] studied the PRIMO code and its validation against Eclipse TPS. The difference between the simulated and measured PDD was calculated at 0.7% with a minimum gamma pass rate of 99.0%.

According to Emami [29] study, normal tissue tolerance for standard fractionation for the brain stem was reported less than 64 Gy for D_{max}. The corresponding value for the optic nerves and chiasm were less than 55 to 60 Gy and the mean dose (D_{mean}) of < 55 Gy. The calculated doses in this study using the PRIMO code and Eclipse TPS were less than normal tissue tolerance (Tab. 5). D_{max} for the brain stem, chiasm and optic nerves were 58.21 Gy, 29.27 Gy and 13.95 Gy, respectively.

PRIMO code is a user-friendly interface for simulation of medical linear accelerators which can be

used as a tool for validation of TPS dose calculation, especially for brain cancer. Brain contains many vital organs, such as the chiasm, nerves, hippocampus and eyes, and protecting them against radiation exceeding their tolerance limit would help patients maintain their quality of life. Since there was a good agreement between the simulations and TPS values, it is suggested that the PRIMO code should be validated and used as a tool to evaluate treatment plans in brain cancer patients.

Conclusion

Based on the results of this study, it became evident that the PRIMO code has a good graphical interface for Varian linac and is a suitable tool with a usersociable interface to simulate medical linear accelerators. In this study, optimum energy value and initial stimulation parameters for the 6 MV photon beam from Varian Clinac 600C linac were determined, and the MC model of the Varian Clinac 600C linac beam was benchmarked against the measured data. Based on this study, the default values of the PRIMO code for beam parameters were not suitable for this work to reach the best agreement of PDD and dose profile obtained from PRIMO code simulation and measurements. Therefore, an optimum beam parameter was determined and the results of this study showed a good agreement between the PDD and dose profiles obtained by simulations by the PRIMO code and in phantom measurements. This point indicates that the Monte Carlo simulations of the Varian Clinac 600C linac are validated.

There was also a good agreement between the dosimetric parameters in the PTV and OARs obtained by the PRIMO MC code and Eclipse TPS for brain cancer patients. PRIMO code can be used for evaluating treatment planning for brain cancer patients but validation of the code simulation is needed.

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Conflict of interest

There is not any relationship that might lead to a conflict of interest.

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