PHOTON BEAM MODELING: A Comparative Study of PRIMO and GATE Simulation Toolkits for the TrueBeam STx Linac

by

Hong Lam PHAM [1,2]***, Tien Dung PHAN*** [3]***,***
Thi Hoang Anh LE [4]***, and Quang Trung PHAM*** [5*]

[1] Military Hospital 103, Hanoi, Vietnam
[2] Graduate University of Science and Technology,
Vietnam Academy of Science and Technology, Hanoi, Vietnam
[3] Institute of Material Sciences, Vietnam Academy of Science and Technology, Hanoi, Vietnam
[4] School of Engineering Physics, Hanoi University of Sciences and Technology, Hanoi, Vietnam
[5] Radiation Oncology and Radiosurgery Department, 108 Military Central Hospital, Hanoi, Vietnam

Scientific paper
https://doi.org/10.2298/NTRP2401058P

This study compares the PRIMO and GATE Monte Carlo simulation toolkits for modeling photon beams from a TrueBeam STx Linac used in radiation therapy. Various beam configurations were evaluated against Varian's Golden Beam Data using the Gamma Index method. Both toolkits demonstrated good agreement overall, with GATE generally achieving higher gamma pass rates for percent depth dose curves than PRIMO.

Key words: photon beam, TrueBeam STx, Monte Carlo simulation, GATE, PRIMO

INTRODUCTION

Monte Carlo simulation is a mathematical technique to model and analyze complex scenarios involving uncertain events or systems. It involves repeatedly sampling random variables within specified parameters to simulate various possible outcomes. Unlike deterministic models, which rely on fixed input values, Monte Carlo simulations consider ranges of values to predict outcomes, providing insights into the likelihood of different scenarios [1].

The Monte Carlo method is widely utilized in radiotherapy for various purposes and holds significant importance by assisting in device simulations and dosimetry. It aids in evaluating physical properties, simulating radiation transport, and studying parameters that are challenging to measure experimentally [2]. Several simulation codes based on Monte Carlo methods are utilized in radiation therapy for dose calculation, treatment planning, and dosimetry. Examples include EGSnrc, Geant4, GATE, PENELOP, PRIMO, TOPAS, MCNP, and PHITS [3]. These diverse codes are available and actively supported for clinical or research applications [4]. Many studies on applying Monte Carlo simulation have been conducted, with several results published in recent years [5-7]. In the field of linear accelerator (Linac) beam simulation, there have also been some notable studies [8, 9].

The PRIMO is a computer software designed for simulating clinical linear accelerators and estimating absorbed dose distributions in phantom and patients. Utilizing Monte Carlo methods, PRIMO can simulate radiation therapy treatment plans, including intensity-modulated radiotherapy (IMRT) and volumetric-modulated arc therapy (VMAT) plans. The software supports importing DICOM RT Structure and Plan files for simulating and evaluating clinical treatment plans. The PRIMO, based on the PENELOPE computational engine, models electron, and photon transport using a mixed technique for electron and positron collisions. With a user-friendly graphical interface, PRIMO facilitates configuring simulations and analyzing results, providing researchers and clinicians with a convenient environment for assessing dose distributions, verifying treatment plans, and optimizing radiation therapy techniques [10, 11].

The GATE (Geant4 Application for Tomographic Emission) is a Geant4-based simulation toolkit known for its well-validated physics models, sophisticated geometry description, and powerful visualization capabilities designed to simulate the behavior of particles as they pass through matter. The GATE offered valuable contributions to photon beam modeling of radiotherapy linear accelerators, dose calculations, treatment planning, and research [12]. The GATE is built and developed using a

---

[*] Corresponding author, e-mail: qtphamhus@gmail.com

layer structure, including the core Geant4 simulation engine and three other layers: framework, application classes, and user interface.

Both PRIMO and GATE toolkits are widely utilized and highly accurate for radiotherapy dose calculation [13]. The PRIMO features a user-friendly interface tailored specifically for radiation therapy applications, while GATE offers advanced physical models and geometric descriptions, potentially enabling more comprehensive simulations.

The TrueBeam STx, an upgraded generation of the TrueBeam series, is an advanced linear accelerator system (Varian Medical Systems, USA) used in radiation therapy. It is particularly suitable for treating hard-to-reach tumors. The system offers a wide range of treatment modalities, including stereotactic radiosurgery (SRS), stereotactic body radiation therapy (SBRT), IMRT, VMAT, and image-guided radiation therapy (IGRT) [14]. The TrueBeam STx Linac has a multi-energy configuration that delivers photon and electron beams at different energy levels. In addition, apart from the flattened filtered (FF) photon beam, the Linac also has the flattened filtered-free (FFF) photon beam mode. Golden Beam Data (GBD) of the Linac model, including percentage depth dose (PDD) and profile of photon beam data, were collected and standardized from hundreds of TrueBeam worldwide.

Some studies have utilized GATE or PRIMO tools independently to model photon beams of Linac in general, including the TrueBeam STx. Additionally, several comparative studies have analyzed and compared these two toolkits for simulating photon beams on a radiotherapy linear accelerator. Aamri *et al.* [15] simulated a 6 MV FFF photon beam of a TrueBeam using the PRIMO and EGSnrc code, comparing the result of PDD and cross-beam profiles. Similarly, Sadoughi *et al.* [16] compared the PDD and beam profiles of 6 MV FF Elekta Compact Linac using electromagnetic (EM) physics packages of GATE versus Monte Carlo N Particle eXtended (MCNPX) in simulation. However, to date, no studies have compared photon beam simulation results of the TrueBeam STx Linac between the two toolkits of PRIMO and GATE.

In this study, the accuracy of the PRIMO and GATE simulation toolkits is compared by evaluating their simulation results of PDD and cross-profiles of TrueBeam STx Linac photon beams in comparison with GDB.

MATERIALS AND METHODS

Simulation setup

The TrueBeam STx Linac photon beams are modeled, including four FF beams with energies of 6 MV, 8 MV, 10 MV, and 15 MV, and two FFF beams with energies of 6 MV and 10 MV.

The simulation was conducted with a field size of 10 cm × 10 cm and a source surface distance (SSD) of 100 cm. The PDD profiles were recorded on the central axis of the beam, while cross profiles were obtained at a depth of 10 cm in a virtual water phantom. The voxel resolution for dose recording was set to 2 cm × 2 cm × 2 cm. The phantom size used for dose calculation was 30 cm × 30 cm × 35 cm ($x \times y \times z$).

For convenience, phase-space files located upstream of the secondary collimator were utilized. These files, provided by the manufacturer Varian via the MyVarian website, are written in IAEA-format codes and can be simulated using PRIMO or GATE [15].

THE PRIMO simulation toolkit

The PRIMO was installed on the Windows operating system and incorporates a detailed model for simulating linear accelerators. It integrates numerous Linac models commonly used worldwide by manufacturers such as Varian and Elekta. The PRIMO combines these models with source models, tallies, techniques for reducing variance, and the ability to evaluate both, quadric and voxelized geometries [11]. These Linac series are either pre-built in terms of geometric structure and materials or are hypothetically constructed according to design specifications. Many studies have validated the accuracy of dose distribution produced by these Linac models, demonstrating highly accurate simulation results compared to experimental data. As a result, users only need to make simple declarations on the software interface to initiate a simulation.

This study utilizes PRIMO version 0.3.64.1814 with the physical PENELOP low-energy electromagnetic model, which incorporates various processes to simulate the interaction and transport of electrons, positrons, and photons in different materials. These processes include Rayleigh scattering, Compton scattering, photoelectric effect, pair production, ionization, bremsstrahlung, and positron annihilation [17].

The Varian CLinac 2100 model is utilized to derive the FF beam of the TrueBeam STx Linac, whereas the FakeBeam model is employed for the FFF beams.

The simulation was executed on a Dell Precision 351 computer system with an Intel (R) Core (TM) i7-10875H CPU, featuring 8 cores, 16 logical processors, and 32 GB RAM.

THE GATE simulation toolkit

The GATE is an open-source software package designed to run on the LINUX operating system. This study utilizes GATE version v9.1, which operates on Geant4.10.7, and employs the physical interaction model G4EmStandardPhysics_option3 [18-20].

The G4EmStandardPhysics_option3 model encompasses various physical interaction processes for simulating electromagnetic interactions of various types of particles (including gamma, leptons, mesons, baryons, and ions) with matter, as well as electromagnetic interactions for gamma and electrons; nuclear stopping, multiple scattering, and bremsstrahlung and pair production for muons and hadrons [20]. The model accurately accounts for energy deposition, scattering, and secondary particles generation, precisely simulating particle behavior in detectors or materials [21].

For this study, GATE was installed on Ubuntu 18.04, running on a Dell Precision M4700 computer system featuring an Intel (R) Core (TM) i7-3740QM CPU with 4 cores, 8 logical processors, and 16 GB RAM.

A number of events of 2×10^9 were set in the code. Variance reduction techniques were employed, and photon and electron cut-off energies were adjusted to 0.05 MeV and 0.1 MeV, respectively. Additionally, efforts were made to maintain the statistical uncertainty of Monte Carlo results at less than 1 %.

Golden beam data

Manufacturers typically provide GBD for specific Linac models. The GBD refers to a set of benchmark measurements or reference data representing the ideal or expected performance of a Linac's photon beams. These data are usually obtained during the commissioning process of the Linac and serve as a standard for comparison in quality assurance and treatment planning systems [22].

The GBD encompasses parameters such as PDD curves, output factors, and profiles. These parameters characterize the energy spectrum, beam quality, and dose distribution of the photon beams produced by the Linac. Crucially, these data ensure dosimetry accuracy in radiation therapy treatments [23].

Gamma index method

The dose distribution of the PDD and beam cross-profiles was simulated and compared to the GBD using the Gamma Index method. The Gamma Index uses two separate criteria: the dose difference (*DD*) at a certain point and the distance-to-agreement (*DTA*) value that was expressed in eq. (1) [24]

$$\gamma = \sqrt{\frac{\Delta x^2}{DTA^2} + \frac{\Delta D^2}{DD^2}} \qquad (1)$$

where Δx is the distance between the reference point and the closest calculated point and ΔD – the dose difference. In this work, a code *DEV*++C-based run to evaluate the Gamma index, the passing criterion used 1 %/1 mm, 2 %/2 mm, and 3 %/3 mm for the dose difference and the distance to agreement, respectively. The percentage of pass points evaluates the final result passed the test gamma pass rate (GPR).

Relative dose difference (*dd*) is also used to compare the simulation results to GDB, donated by eq. (2)

$$dd = 100\,\frac{D_{\mathrm{MC}} - D_{\mathrm{GBD}}}{D_{\mathrm{GBD}}}\ [\%] \qquad (2)$$

where *dd* is the deviations, expressed as %, D_{MC} – the calculated dose by Monte Carlo (PRIMO or GATE) at a particular point, and D_{GBD} – the dose from GBD at the same point in the phantom.

RESULTS AND DISCUSSION

Compare the percentage depth dose

Figure 1 illustrates the photon beam PDD simulation results using the PRIMO and GATE toolkits, compared to GBD. All PDD distribution curves were normalized to the depth of the maximum dose (d_{max}). Table 1 provides a comprehensive comparison of the simulation results obtained from PRIMO and GATE codes with the GBD. The results reveal nuanced differences in the performance of the two Monte Carlo toolkits under *vs*. evaluation criteria. Notably, when assessed using the widely adopted 3 %/3 mm criterion, the GPR of GATE surpasses that of PRIMO across most energy levels and beam configurations. Specifically, GATE demonstrates a superior performance with a pass rate reaching 100 % for certain beam configurations, such as 8 MV FF and 10 MV FFF, compared to PRIMO's slightly lower pass rate of 99 % for 10 MV FFF. However, a shift in perspective emerges when employing the stricter 1 %/1 mm criterion, wherein GATE's overall GPR tends to decline, particularly evident at higher energy levels where it falls below 90 %, exemplified by the 15 MV FF energy level where GATE only achieves an 87 % pass rate.

On the other hand, by adopting the more stringent criterion recommended by the American Association of Physicists in Medicine (AAPM) at 2 %/2 mm, both PRIMO and GATE exhibit comparable performance, with GPR exceeding 95 % across all PDD and cross-profile comparisons. This observation underscores the sensitivity of GPR to evaluation criteria, highlighting the importance of selecting appropriate criteria based on the clinical context and desired level of precision.

Furthermore, the detailed analysis depicted in fig. 1 sheds light on the *dd* observed at various depths, revealing a pronounced discrepancy, particularly at the surface and depths around 30 cm. This phenome-

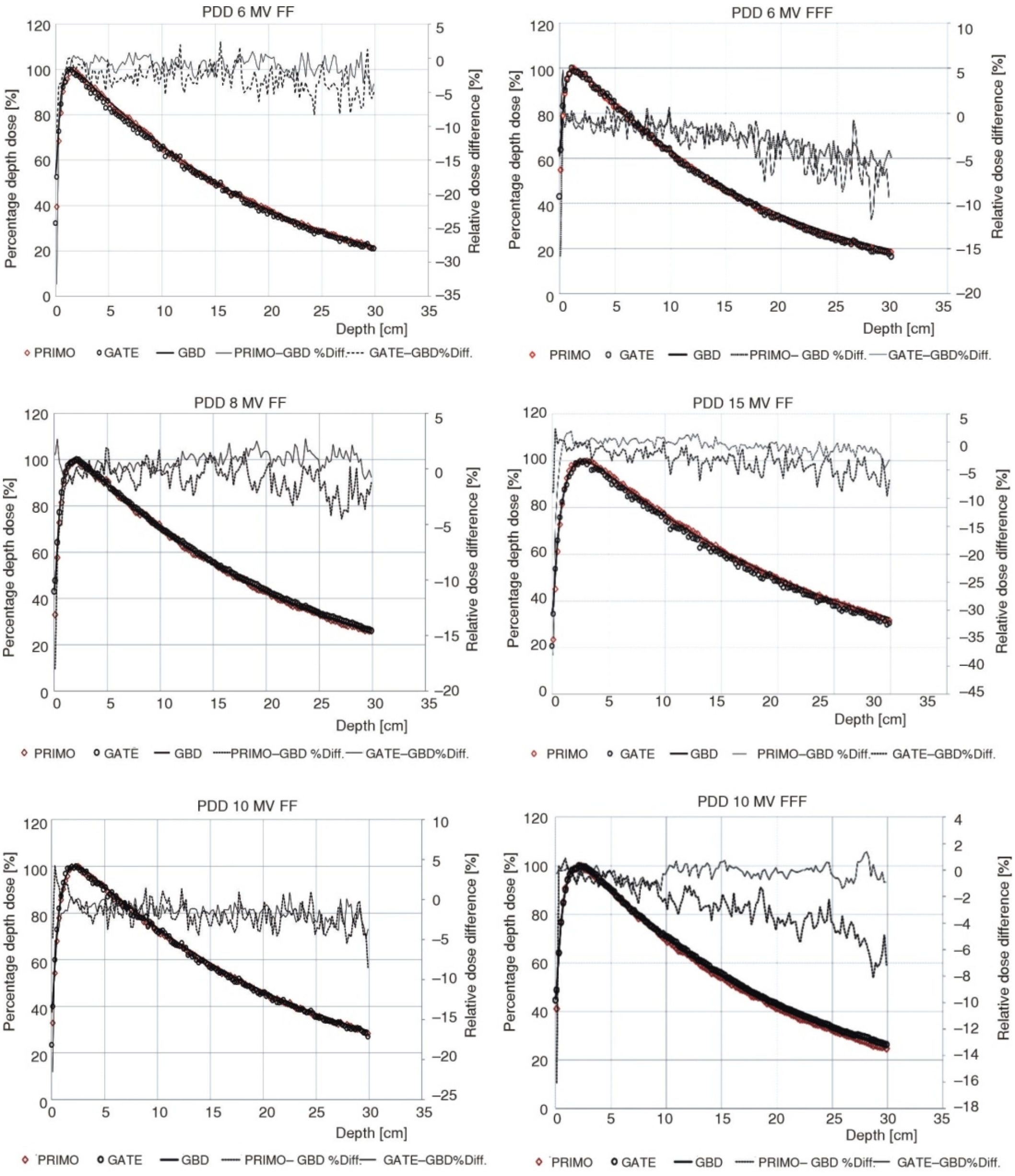

Figure 1. Comparison of the PDD simulation results of the TrueBeam STx photon beam using PRIMO and GATE code with GBD

Table 1. The GPR in comparison of PDD between PRIMO, GATE simulations with GBD for the TrueBeam STx photon beam

Photon beams PDD		GPR [%]		
		3 %/3 mm	2 %/2 mm	1 %/1 mm
PRIMO *vs*. GBD	6 MV FF	98	98	97
	6 MV FFF	98	98	97
	8 MV FF	96	96	95
	10 MV FF	97	96	95
	10 MV FFF	99	99	94
	15 MV FF	97	96	96
GATE vs. GBD	6 MV FF	98	98	93
	6 MV FFF	98	98	95
	8 MV FF	100	98	95
	10 MV FF	98	97	94
	10 MV FFF	100	99	96
	15 MV FF	99	98	87

non resonates with findings from previous studies, such as those by Mesbahi A. *et al.* [25], which underscore the challenges encountered in accurately modeling dose distributions, especially at narrow depths. These findings emphasize the need for continuous refinement and validation of Monte Carlo simulation methodologies to ensure their reliability and accuracy in clinical practice.

Compare the cross-profile

Figure 2 illustrates the cross-profile simulation results using the PRIMO and GATE toolkits, compared to GBD.

Table 2 provides a comprehensive overview of the GPR results for the cross-profiles obtained from PRIMO and GATE simulations, juxtaposed against GBD. Notably, GATE demonstrates a slightly higher

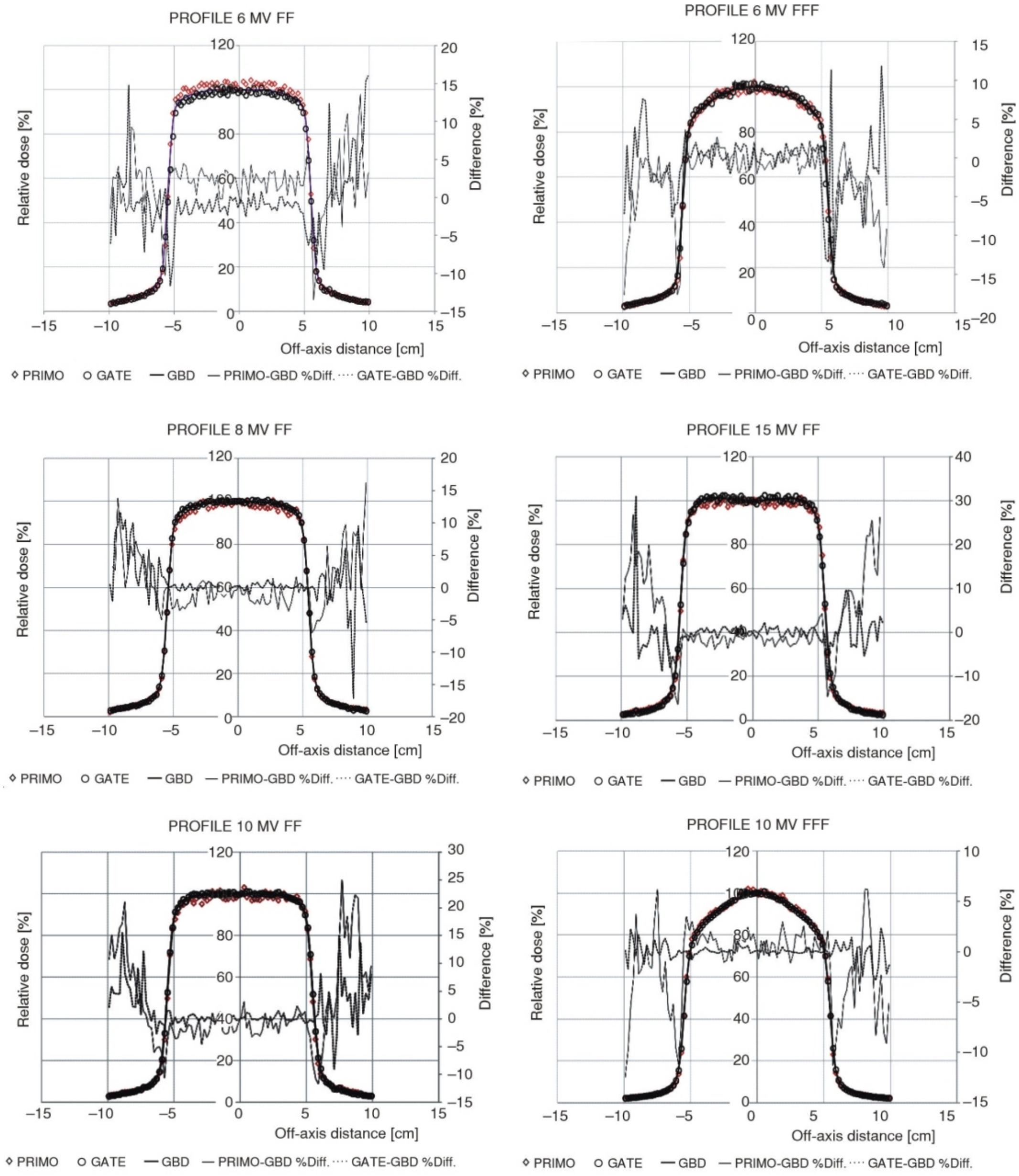

Figure 2. Comparison of the cross-profile simulation results of the TrueBeam STx photon beam using PRIMO and GATE code with GBD

Table 2. GPR in comparison of cross-profile between PRIMO, GATE simulations with GBD for the TrueBeam STx photon beam

Photon beams PDD		GPR [%]		
		3 %/3 mm	2 %/2 mm	1 %/1 mm
PRIMO *vs*. GBD	6 MV FF	92	90	85
	6 MV FFF	94	92	87
	8 MV FF	98	97	91
	10 MV FF	94	92	87
	10 MV FFF	95	93	87
	15 MV FF	91	90	86
GATE vs. GBD	6 MV FF	94	93	92
	6 MV FFF	94	93	87
	8 MV FF	99	97	92
	10 MV FF	97	96	93
	10 MV FFF	100	97	94
	15 MV FF	98	95	92

GPR compared to PRIMO across all three passing criteria evaluated. Under the 3 %/3 mm and 2 %/2 mm criteria, the GPR for all beam configurations exceeds 90 %, indicating a robust agreement between the simulated cross profiles and the reference GBD. However, when employing the stricter 1 %/1 mm criterion, the GPR ratios for certain beams, particularly those simulated by PRIMO, fall below the 90 % threshold.

A potential contributing factor to these discrepancies, especially notable in PRIMO's results, could be the reduced number of particles in the phase space file for the 6 MV FF beam configuration, leading to increased statistical uncertainty. Consequently, the observed relative error between the simulation toolkits and GBD becomes more pronounced, particularly at the edges of the beams and in the out-of-field regions.

These findings underscore the importance of meticulous attention to detail and careful consideration of statistical uncertainties when interpreting simulation results, especially in regions susceptible to higher uncertainties. Further refinement and optimization of simulation parameters and methodologies are warranted to mitigate these discrepancies and enhance the accuracy and reliability of cross-profile simulations for clinical applications.

Compared with findings from other studies, our investigation reveals a notable fluctuation in the agreement between simulation and experimental data, highlighting the inherent variability in Monte Carlo simulations and the sensitivity of results to simulation parameters and methodologies. For instance, Efendi *et al*. [26] simulated a 6 MV FF photon beam of the TrueBeam STx using the PRIMO code with stringent acceptance criteria of 1 %/1 mm. Their study reported a passing criterion of 98.53 % for 10 cm × 10 cm open field PDD, with the passing criterion for profiles at 10 cm depth slightly lower at 88.96 %. Similarly, Rodriguez *et al*. [27] utilized the PRIMO code to simulate 6 MV, 8 MV, 10 MV, and 15 MV FF beams of the TrueBeam, achieving a GPR exceeding 99 % for all beams with a 2 %/2 mm criterion when compared to GBD.

Additionally, Belosi *et al*. [28] conducted a comparative analysis of 6 MV and 10 MV FFF beams using the PRIMO code against experimental data, reporting gamma agreements of 98.8 % and 96.3 % for 6 MV and 10 MV FFF beams, respectively, with a 1 %/1 mm criterion. Furthermore, Ton *et al*. [29] simulated 6 MV FF beams of the TrueBeam STx Linac and compared them to experimental data, achieving a GPR greater than 98 % and 94 % for PDD and profiles, respectively, with a 2 %/2 mm criterion and a 10 cm × 10 cm field size at a depth of 1.5 cm.

These findings collectively underscore the variability in simulation outcomes across different studies, emphasizing the importance of thorough validation and careful consideration of simulation parameters to ensure accurate and reliable results in radiation therapy treatment planning and quality assurance practices.

The accuracy of Monte Carlo simulations in radiotherapy hinges upon numerous factors, each playing a crucial role in determining the fidelity of the simulated dose distributions. These factors include the characteristics of the primary beam, encompassing parameters such as energy spectrum, beam profile, and angular distribution. Additionally, the choice of physics models governing particle interactions with matter, as well as the fidelity of the Linac head geometry representation, profoundly impacts simulation accuracy. The effectiveness of variance reduction methods employed to optimize computational efficiency while preserving accuracy is also paramount. Moreover, factors such as tissue heterogeneities, patient anatomy, and the presence of treatment accessories further contribute to the complexity of the simulation process and its accuracy. Thus, meticulous attention to detail and comprehensive validation against experimental data are essential to ensure the reliability and precision of Monte Carlo simulations in guiding radiation therapy treatment planning and quality assurance protocols.

In this work, it's imperative to note that the same Phase-Space Files (PSF) were utilized as input data for both Monte Carlo codes. By ensuring consistency in the input data, particularly about the primary beam characteristics, any observed differences in simulation results between the two codes cannot be attributed to variations in the initial beam properties. This approach helps isolate the impact of other factors, such as variance reduction methods, physics models, and Linac head geometry representations, on the differences observed in the simulation results. By employing identical PSF for both codes, the focus shifts towards understanding the influence of these factors on simulation accuracy and consistency, facilitating a more robust comparison and interpretation of the simulation outcomes.

In contrast to GATE, where users must manually construct and declare input data for the Linac head geometry and material structure components through commands, PRIMO provides pre-built and verified information readily available to users. This crucial distinction reduces the uncertainty stemming from subjective reasons in building the geometric structure and declaring the material components of the Linac head, potentially minimizing discrepancies in simulation results. By leveraging pre-existing and validated geometric and material data in PRIMO, users can benefit from enhanced consistency and reliability in simulation outcomes. This streamlined approach in PRIMO not only simplifies the simulation process but also contributes to reducing the likelihood of errors associated with manual data construction and declaration. Consequently, PRIMO offers a more user-friendly and reliable solution for accurately modeling Linac head geometry and material structure components in Monte Carlo simulations, by facilitating robust and consistent dose calculations in radiotherapy planning and quality assurance practices.

The GATE utilizes the standard EM package of Geant4, namely the G4EmStandardPhysics physics list, originally designed for high-energy physics simulations, covering the energy range from 1 keV to 10 PeV [20]. In contrast, PRIMO employs the physics models of PENELOP, optimized specifically for low-energy electromagnetic physics simulations, with validation spanning the energy range of 250 eV to 100 GeV [30]. This distinction in physics packages is underscored by the findings of Sadoughi *et al*. [16] who compared the Standard and Penelope EM physics packages of Geant4 in the simulation of a 6 MV photon Elekta Compact Linac, revealing significant discrepancies in the simulation results.

Furthermore, in PRIMO, the number of particle histories employed in simulations varies depending on the phase space of each beam, ranging from 560-900 million particles. Consequently, the statistical uncertainties in PRIMO simulations may be higher, potentially impacting the accuracy of recorded results compared to GATE. Additionally, variance reduction techniques utilized in both platforms, while essential for reducing computation time, may introduce complexities and trade-offs that could affect the overall accuracy of simulation results.

These factors, collectively, underscore the nuanced considerations and potential challenges associated with Monte Carlo simulations in radiotherapy. While each platform offers unique advantages and capabilities, careful attention to simulation parameters, validation methodologies, and interpretation of results is essential to ensure the reliability and accuracy of Monte Carlo simulations in guiding clinical decision-making and treatment planning processes.

CONCLUSIONS

Overall, both PRIMO and GATE simulations demonstrated good agreement with the GBD. Utilizing the criteria recommended by the American Association of Physicists in Medicine (AAPM) of 2 %/2 mm, GPR exceeded 95 % and 90 % for GATE and PRIMO, respectively.

Upon comparing PRIMO and GATE results, GATE simulations exhibited slightly higher GPR for PDD and cross-profiles across all three accepted criteria (3 %/3 mm, 2 %/2 mm, and 1 %/1 mm). However, it is noteworthy that PRIMO demonstrated less discrepancy, compared to GATE, particularly when employing the 1 %/1 mm criterion for PDD, showcasing its robustness in matching the GBD.

These findings underscore the reliability and accuracy of both PRIMO and GATE simulations in replicating the dose distributions of TrueBeam STx Linac photon beams. While GATE demonstrates a slightly superior performance of GPR, PRIMO exhibits commendable consistency and reliability, particularly when stringent acceptance criteria are applied. These results highlight the importance of selecting appropriate simulation tools and criteria based on the desired level of accuracy and clinical requirements in radiation therapy treatment planning and quality assurance practices.

AUTHORS' CONTRIBUTIONS

H. L. Pham and Q. T. Pham: wrote the manuscript and performed simulations on GATE. H. L. Pham and T. H. A. Le: performed simulations on PRIMO. T. D. Phan and Q. T. Pham: visualization, investigation, writing-reviewing and editing.

ACKNOWLEDGMENT

We express our gratitude to the Graduate University of Science and Technology for their support. We thank the medical physicists of the Department of Radiation Oncology and Radiosurgery at the 108 Military Central Hospital for their valuable comments that contributed to this work.

ORCID NO

Quang Trung Pham:
https://orcid.org/0009-0003-4941-0836
Tien Dung Phan:
https://orcid.org/0009-0004-9083-1701
Hong Lam Pham:
https://orcid.org/0009-0009-7549-9719
Thi Hoang Anh Le:
https://orcid.org/0009-0007-7210-8132

REFERENCES

[1] Mooney, C. Z., Monte Carlo Simulation, Sage Publications, Thousand Oaks, 1997

[2] Seco, J., Verhaegen, F., *Monte Carlo Techniques in Radiation Therapy*, CRC Press, Boca Raton, Fla., USA, 2013

[3] Andreo, P., Monte Carlo Simulations in Radiotherapy Dosimetry, *Radiation Oncology, 13* (2018), 121, pp. 1-15

[4] Fielding, A. L., Monte Carlo Techniques for Radiotherapy Applications I: Introduction and Overview of the Different Monte Carlo Codes, *Journal of Radiotherapy in Practice, 22* (2023), e80

[5] Krstić, D. Ž., *et al*., Dose Assessment with MCNP5/X Code for Boron Neutron Capture Therapy of Pancreas Cancer, *Nucl Technol Radiat, 36* (2021), 3, pp. 294-298

[6] Kye, Y.-U., *et al*., Measurement of Absorbed Dose Rate in Water Phantom Maintained at Body Temperature by ^{60}Co Irradiator-Comparison of Experimental Results and Monte Carlo Simulation, *Nucl Technol Radiat, 36* (2021), 3, pp. 289-293

[7] Sahmaran, T., Tugrul T., Investigation of Radiological Properties of Imaging Agents Used in Nuclear Medicine with Different Methods and GATE/Geant4 Simulation Program, *Nucl Technol Radiat, 38* (2023), 2, pp. 116-124

[8] Ma, C.-M., Jiang, S. B., Monte Carlo Modelling of Electron Beams from Medical Accelerators, *Physics in Medicine & Biology, 44* (1999), 12, R157-R189

[9] Verhaegen, F., Seuntjens, J., Monte Carlo Modelling of External Radiotherapy Photon Beams, *Physics in Medicine and Biology, 48* (2023), 21, R107-R164

[10] Esposito, A., *et al*., Primo Software as a Tool for Monte Carlo Simulations of Intensity Modulated Radiotherapy: a Feasibility Study, *Radiation Oncology, 13* (2018), 91, pp. 1-13

[11] Li, Y., *et al*., Monte Carlo Simulation of Linac Using PRIMO, *Radiation Oncology, 17* (2022), 1, 185

[12] Sarrut, D., *et al*., A Review of the Use and Potential of the GATE Monte Carlo Simulation Code for Radiation Therapy and Dosimetry Applications, *Med Phys, 41* (2014), 6, 064301

[13] Altuwayrish, A., *et al*., Comparison of PRIMO Monte Carlo Code and Eclipse Treatment Planning System in Calculation of Dosimetric Parameters in Brain Cancer Radiotherapy, *Reports of Practical Oncology and Radiotherapy, 27* (2022), 5, pp. 863-874

[14] Oliveira, J. E. N., Clinical Implementation of Monte Carlo Simulations of a Varian TrueBeam Unit, Universidade Do Porto, 2017

[15] Aamri, H., *et al*., Comparison Between PRIMO and EGSnrc Monte Carlo Models of the Varian True Beam Linear Accelerator, *Radiation Physics and Chemistry, 178* (2021), 109013

[16] Sadoughi, H.-R., *et al*., A Comparison Between GATE and MCNPX Monte Carlo Codes in Simulation of Medical Linear Accelerator, *Journal of Medical Signals and Sensors, 4* (2014), 1, pp. 10-17

[17] Asai, M., *et al.*, The PENELOPE Physics Models and Transport Mechanics, *Implementation into Geant4," Frontiers in Physics, 9* (2021), 738735

[18] Jan, S*., et al*., GATE: a Simulation Toolkit for PET and SPECT, *Physics in Medicine and Biology, 49* (2004), 19, pp. 4543-4561

[19] Sarrut, D., *et al*., A Review of the Use and Potential of the GATE Monte Carlo Simulation Code for Radiation Therapy and Dosimetry Applications, *Medical Physics, 41* (2014), 6, pp. 064301-14

[20] Agostinelli, S., *et al*., GEANT4-a Simulation Toolkit, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, *Detectors and Associated Equipment, 506* (2003), 3, pp. 250-303

[21] Gibaru, Q., *et al*., Geant4 Physics Processes for Microdosimetry and Secondary Electron Emission Simulation: Extension of MicroElec to Very Low Energies and 11 Materials (C, Al, Si, Ti, Ni, Cu, Ge, Ag, W, Kapton and SiO_2), *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 487* (2021), pp. 66-77

[22] Zheng, C., *et al*., Commissioning and Dosimetric Characteristics of TrueBeam System: Composite Data of Three TrueBeam Machines, *Med Phus. 39* (2012), 11, pp. 6981-7018

[23] Yousif, Y. A., *et al*., Golden Beam Data Provided by Linear Accelerator Manufacturers Should be Used in the Commissioning of Treatment Planning Systems, *Physical and Engineering Sciences in Medicine, 45* (2022), 2, pp. 407-411

[24] Low, D. A., *et al*., A Technique for the Quantitative Evaluation of Dose Distributions, *Medical Physics, 25* (1998), 5, pp. 656-661

[25] Mesbahi, A., *et al*., Monte Carlo Calculation of Varian 2300C/D Linac Photon Beam Characteristics: a Comparison Between MCNP4C, GEANT3 and Measurements, *Applied Radiation and Isotopes, 62* (2005), 3, pp. 469-477

[26] Efendi, M. A., *et al*., Monte Carlo Simulation of 6 MV Flattening Filter Free Photon Beam of Truebeam STx Linac at Songklanagarind Hospital, *Sains Malaysiana, 46* (2017), 9, pp. 1407-1411

[27] Rodriguez, M., et al., Monte Carlo simulation of the Varian TrueBeam flattened-filtered beams using a surrogate geometry in PRIMO, Radiation Oncology, 19 (2024), 14, pp. 1-10

[28] Belosi, M. F., *et al*., Monte Carlo Simulation of TrueBeam Flattening Filter Free Beams Using Varian Phase Space Files: Comparison with Experimental Data, *Medical Physics, 41* (2014), 5, 051707

[29] Ton, N., *et al*., Dosimetric Characteristics of 6 MV Photons from TrueBeam STx Medical Linear Accelerator: Simulation and Experimental Data, *Nuclear Science and Technology, 9* (2019), 2, pp. 37-44

[30] Ivanchenko, V., *et al*., Recent Improvements in Geant4 Electromagnetic Physics Models and Interfaces, *Progress in Nuclear Science and Technology, 2* (2011), pp. 898-903

Received on May 24, 2024
Accepted on June 25, 2024

Хонг Лам ФАМ, Тиен Дунг ФАН, Ти Хоанг Анх ЛЕ, Куанг Трунг ФАМ

МОДЕЛОВАЊЕ ФОТОНСКОГ СНОПА – ПОРЕЂЕЊЕ PRIMO И GATE СИМУЛАЦИЈСКИХ АЛАТА ЗА TrueBeam STx ЛИНЕАРНИ АКЦЕЛЕРАТОР

У раду су упоређени PRIMO и GATE Монте Карло алати за симулацију моделовања снопа фотона из TrueBeam STx линеарног акцелератора који се користи у терапији зрачењем. Различите конфигурације снопа процењене су у односу на Варианове податке златног снопа коришћењем гама индексне методе. Оба комплета алата у целини показала су добро слагање, при чему је GATE генерално исказао веће пролазне гама јачине за криве доза у процентима по дубини, него PRIMO.

Кључне речи: сноп фотона, TrueBeam STx, Монте Карло симулација, GATE, PRIMO