

Clinical Implications of TiGRT Algorithm for External Audit in Radiation Oncology

Abstract

Background: Performing audits play an important role in quality assurance program in radiation oncology. Among different algorithms, TiGRT is one of the common application software for dose calculation. This study aimed to clinical implications of TiGRT algorithm to measure dose and compared to calculated dose delivered to the patients for a variety of cases, with and without the presence of inhomogeneities and beam modifiers. **Materials and Methods:** Nonhomogeneous phantom as quality dose verification phantom, Farmer ionization chambers, and PC-electrometer (Sun Nuclear, USA) as a reference class electrometer was employed throughout the audit in linear accelerators 6 and 18 MV energies (Siemens ONCOR Impression Plus, Germany). Seven test cases were performed using semi CIRS phantom. **Results:** In homogeneous regions and simple plans for both energies, there was a good agreement between measured and treatment planning system calculated dose. Their relative error was found to be between 0.8% and 3% which is acceptable for audit, but in nonhomogeneous organs, such as lung, a few errors were observed. In complex treatment plans, when wedge or shield in the way of energy is used, the error was in the accepted criteria. In complex beam plans, the difference between measured and calculated dose was found to be 2%–3%. All differences were obtained between 0.4% and 1%. **Conclusions:** A good consistency was observed for the same type of energy in the homogeneous and nonhomogeneous phantom for the three-dimensional conformal field with a wedge, shield, asymmetric using the TiGRT treatment planning software in studied center. The results revealed that the national status of TPS calculations and dose delivery for 3D conformal radiotherapy was globally within acceptable standards with no major causes for concern.

Keywords: *TiGRT, treatment planning system, radiation oncology, lung, phantom, dosimetry*

Introduction

Treatment planning system (TPS) is one of the key components of radiation therapy (RT) used widely in the practice of treatment planning and dose computation. Currently, there is a number of planning software with different algorithms to calculate the dose distribution.^[1,2] To take assurance of the treatment quality, the algorithms should be tested to verify its accuracy for dose calculation.^[3] Accuracy verification consists set of dosimetry tests, which their results will be compared to the measurements in the phantom.^[4-7] All these operations are defined as the quality assurance (QA) process which should be done after software installation by the TPS users. There is a long history of instruction recommended by the International Atomic Energy Agency (IAEA), in QA of radiotherapy, since 1969.^[4] For the purpose of acceptance audit tests, the IAEA

has published Technical Reports Series No. 430^[8] which provides the general framework and describes a number of tests and procedures to be considered by the TPS users. However, the implementation of all these tests is a costly and laborious procedure. To reduction of this extensive operation to a practical QA process, IAEA has recommended a technical document, TECDOC 1583, which is a set of dedicated practical tests, based on the TRS 430.^[8]

In recent years, researchers and TPS users applied different algorithms which have associated advantages and disadvantages in terms of speed of calculation, accuracy, and dealing with inhomogeneities in both tissue structure and density. Lalienna Bielsa *et al.* have used three-dimensional conformal radiotherapy (3DCRT) treatment planning software for photon energies 6 and 15 MV and reported the algorithm has a limitation on nonhomogeneous organs, but a good

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performance in heterogeneities for high energy X-ray beams is remarkable.^[9] Lopes *et al.* carried out the audit test in 24 centers in Portugal. They recognized known calculation limitations in nonhomogeneous areas such as bone and lung.^[10] They did not use the TiGRT TPS and algorithms. In another study, Rutojnsk *et al.* have been used simple fields and three simple treatment planning algorithms at radiotherapy centers in Serbia.^[11] They conducted that using simple TPS caused errors in delivered dose to the patients. Dunn *et al.* investigated systematic discrepancies between TPS calculated and measured audit doses in regions adjacent to and downstream from low-density material in anthropomorphic and slab phantom geometries using analytical anisotropic algorithm.^[12]

The authenticity of the TiGRT TPS calculation has been used by Mesbahi and Dadgar.^[13] In their study, only a small beamlet in IMRT is used, and special attention is put on fields that are in the lungs.

To the best of our knowledge, there is no evidence on the assessment of TiGRT in quality control tests in clinical practice, and this work is the first test on the application of this algorithm TPSs. In this study, the TiGRT with a linear accelerator (LINAC; Siemens ONCOR Impression Plus, Germany) to test 3D CRT is evaluated. Finally, this study aimed to report the results of QA process for a commercial TPS, TiGRT (1.0.8.451 Version, Linotech, USA, super convolution-based algorithm), for 3DCRT based on the protocols offered by TECDOC 1583^[2] for a variety of cases, with and without the presence of inhomogeneities and beam modifiers.

Materials and Methods

To assist national auditing center, IAEA has been offered a set of guidelines (based on the IAEA TECDOC 1583),^[4] specific dosimetry equipment, and intellectual services for medical physicists in RT centers. The audit process was included calculating the dose distribution in phantom by TiGRT treatment planning software and comparing its results with measured values obtaining through a set of clinical test cases. To ensure the accuracy of measurements, the local dosimetry equipment including Farmer ionization chamber and electrometers (Sun Nuclear, USA) was calibrated by the international Secondary Standard Dosimetry Laboratories (SSDLs) before starting the process. Duration test was about 12–14 h and 3 h for all equipment and data processing in the RT centers and only for LINAC, respectively.

Phantom

According to the IAEA-TECDOC 1583, all measurements of clinical test cases were performed on a semi-anthropomorphic thorax phantom named TiGRT quality dose verification or QDV phantom. The phantom is commercially available which is shown in Figure 1. It comprised a thoracic body made of different materials

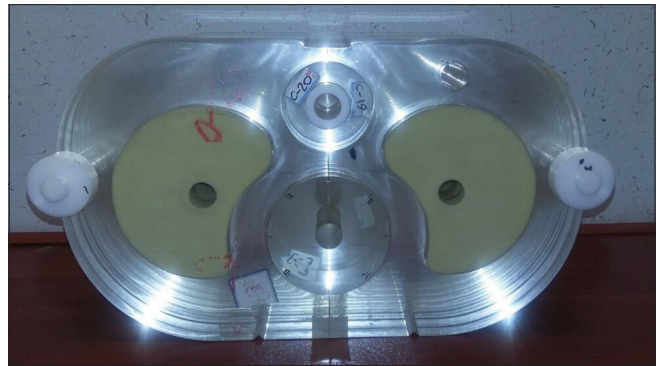


Figure 1: TiGRT quality dose verification thorax phantom

associated with thorax components, plastic water-equivalent material (plastic-to-water relative electron density [RED] of 1.003), lung-equivalent material (RED of 0.207), and bone-equivalent material (RED of 1.506), with a marker on the top of it.^[12] The phantom contained nine cylindrical holes which were positioned at different locations and were initially filled with solid plugs. For each case of clinical measurements, the corresponding holes were replaced with ionization chambers. The position of the labeled holes is given in Figure 2.

Computed tomography examinations

The phantom underwent computed tomography (CT) imaging in two times, according to the protocol applied in the local center for a typical thoracic scanning. The CT imaging acquisition parameters such as slice thickness and field of view were kept the same throughout both examinations. The purpose of the first scan was obtaining the CT-to-RED conversion curve of TPS. In this scan, all holes were filled with the reference solid plugs. The local CT-to-RED conversion curve was used for dose calculations. The tolerance value of ± 20 Hounsfield unit was accepted throughout this study.^[14] The second scan was done to plan clinical test cases. For this purpose, all reference plugs were replaced with plugs of material corresponding to the regions. After completion of data acquisition from CT workstation, all images in DICOM format were imported to the TiGRT TPS for dose calculation.

Clinical test cases

In total, seven different test cases were accomplished for dose measurements. The goal of these tests was measuring dose value received by holes through the multiple treatment methods which are used in the clinical examination. The explanation for all test cases has described in IAEA-TECDOC 1583.^[3] In addition, all these test cases are summarized in Table 1. Each clinical test was performed using specific parameters, in which the dose value of certain points needed to be measured. In total, 15 points were measured in whole seven test cases and for each one of them was selected as the reference point. To obtain the value of dose measurement points, the chamber

Table 1: Seven different test cases were accomplished for dosimetric measurement, which is used in the clinical trials

Case	Test geometry	Beams number	Set-up	Measurement points	Field size	Gantry angle	Collimator angle	Accessory	Agreement criteria (%)
1	Single field	1	SSD	2 (ref)* 5 6	10×10	0	0	None	2 4 3
2	Tangential field, oblique incidence, and lack of scattering	1	SAD	1 (ref)	10×15	90	0	W30	3
3	Significant blocking of the field corners	1	SSD	2 (ref)	Field size 14 cm×14 cm blocked to a 10 cm×10 cm	0	45	None	3
4	Four field box	4	SAD	3 (ref) 5 6	15×10 anterior 15×10 posterior 15×8 RL 15×8 LL	0 180 90 270	0 0 0 0	None	2 3 3 3
5	Oblique incidence with irregular L-shaped field (blocking off the center of the field)	1	SAD	2 (ref) 5 6	L-shaped 12×21	50	0	Custom block or MLC	3 5 5
6	Plan with asymmetrically wedged fields	3	SAD	1 2 3 (ref)	12×10 6×10 assym 6×10 assym	0 90 270	0 90 270	None W30, half beam W30, half beam	2 4 4
7	Plan with non-coplanar field	3	SAD	3 (ref)	4×4 [table 90] 4×16 LL 4×16 RL	30 90 270	0 6 300	None None None	3 3 3

*The reference level point. SAD: Source-axis distance, SSD: Secondary standard dosimetry, MLC: Multi-leaf collimator, RL: Right lateral, LL: Left lateral

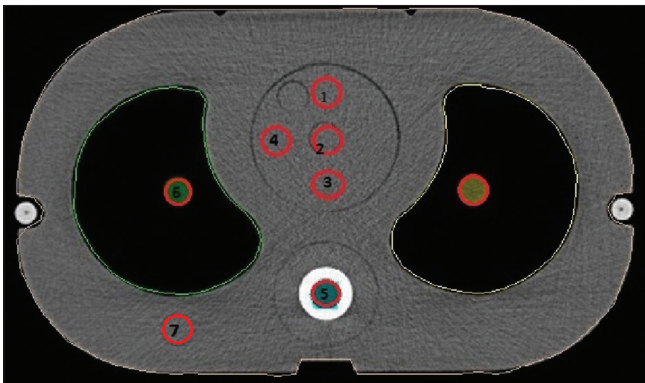


Figure 2: Position of measurement points in thorax phantom

was inserted into the corresponding hole. These points should be out of penumbra region to avoid measurement in high-dose gradients.^[3]

Furthermore, additional measurement points were selected in the build-up region behind the lung material and at an out of field position in the lung. After audit operation, test cases were planned with 6 and 18 MV photons through the radiation TPS (RTPS). All plans were designed relatively simple, based on asymmetric fields with the use of wedges and inhomogeneities. The monitor unit calculation was done for delivering the prescribed dose of 2 Gy to the

reference point. The dose calculations were performed based on the grid size routinely used in the center methods. In this research, the TPS calculation algorithm was model based, similar to the method used by Knöös *et al.*^[14] Model-based algorithms calculated the dose distribution in 3D using convolution kernels and also modeling the indirect natural of dose deposition from photon beams. Changes in lateral electron and photon transport are approximately modeled (with lateral transport).

Measurements

Dosimetric equipment includes Farmer ionization chambers and PC-electrometer (Sun Nuclear, USA) reference class electrometers with the calibration traceable to the international SSDL which employed throughout the audit. Dose measurements were accomplished using the IAEA TRS398 protocol and calculated in the absorbed dose to water.^[15] The measurements of lung and bone equivalent substances were done on the opinion that dose values were measured in small equivalent water phantom cavities. To boost measurement accuracy, relative output factors as well as wedge factors in TPSs were measured. Based on the published results, the mean wedge transmission data were a Gaussian distribution with a standard deviation (SD) value of $\pm 2\%$ in the most models of accelerators. According to these data, a $\pm 4\%$ action level corresponding to two SDs

of the mean value was chosen to evaluate the outliers for relative output factors and wedge factors.^[16]

Analysis of the results

To compare the values obtained through measurements (D_{meas}) and TPS calculations (D_{cal}), the same criteria specified in the IAEA TRS 430 were done.^[5] However, due to the limited number of available positions for the dose measurements in the semi-anthropomorphic phantom, dose differences were normalized to the dose measured at the reference point for each test case (rather than to the measurement point – local difference), i.e., the following equation was used:^[3,7]

$$\Delta(\%) = 100 \times \left(\frac{D_{cal} - D_{meas}}{D_{meas,ref}} \right) \quad (1)$$

Which $D_{meas,ref}$ indicates dose value measured at the reference point. The agreement criteria for each test case are listed in Table 1 which depends on the complexity of the test case geometry.

Results

Clinical test cases

The system is used in this audit had supplied CT to RED conversion curves which used for the further procedure.

The differences between the measured and calculated doses for the various measurement points and test cases for studied radiotherapy center and accelerator are presented in Figures 3 and 4.

The verification of basic dosimetry data input into TiGRT TPS was done.

To create conditions fully comply with treatment requirements and to compare the measured and calculated results in clinical conditions, all test cases were done in the RT centers. However, LINAC output parameters, percentage depth dose, dose profile, and the head scatter factors were kept constant. The percentage differences between the measured and calculated doses for the various measurement points and test cases are presented in Figures 3 and 4.

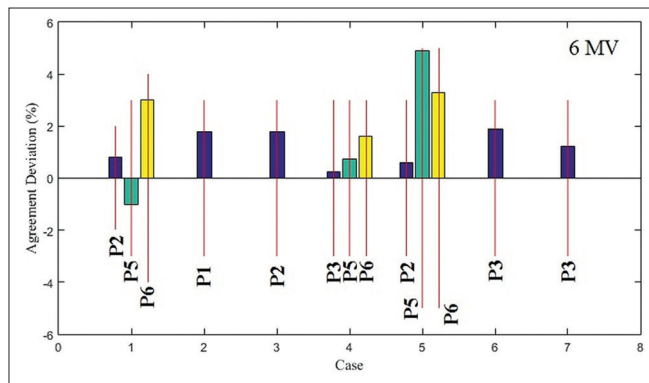


Figure 3: Measurement points for Siemens ONCOR for 6 MV photon beam

Discussion

Before testing audit, some experiments such as compliance light, radiation field, and mechanical test consist of the accuracy of the isocenter in the rotations of gantry, collimators, and couch will be done. The accuracy of the optical ruler with a mechanical device was also examined.

The main advantage of audit test is identifying issues and problems which are not related to algorithm restrictions, whereas the main problem with TPSs is incorrect data entry to the software and is a lack of quality for beam modeling. The errors that occur in the accelerator and the lack of proper calibration software are another problem which causes a deviation between the measured and calculated dose.

In this study, the quality control of multileaf collimators (MLCs) is not performed and hence related errors not accounted. Figures 3 and 4 showed that at low energies, the power of calculation software for lung and points out of the field is relatively less. The power of software for computing of higher energies and nonhomogeneous areas is suitable for points out of the field. Efficiency of the TPS for both high and low energies and for homogeneous region was acceptable. Indeed, no change was observed in the accuracy and sensitivity of the TPS. All calculations have been performed in clinical conditions.

The CT-to-RED calibration curves which are good conformity between measured and calculated dose must be updated in all radiotherapy centers. The used phantom includes three nonhomogenized regions that can help to confirm the calculation of the TPS for nonhomogeneous regions, in particular for lung.

The difference between the planned dose and the dose delivered to the patient is very useful and will lead to improve treatment planning methods in the centers.^[6] Any significant difference between calculated and measured dose may be related to the promotion of correction accelerator dosimetry data entry software, redundancy calibration curve of CT-to-RED, correct modeling of radiation, and expertise of the limitations of the dose calculation algorithm treatment planning software.

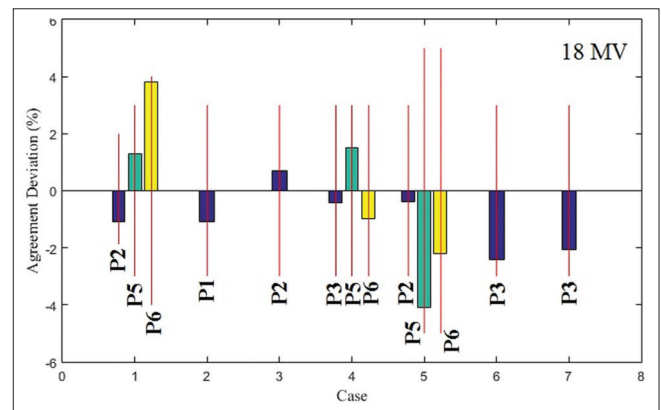


Figure 4: Measurement points for Siemens ONCOR for 18 MV photon beam

In this study, as all accessories (MLC, wedge, block) used a significant difference between calculated and measured dose was observed compared to unused accessories. For reducing the errors, several approaches such as loose placement of the wedge, attenuation coefficient accelerator table, inaccuracies in placing the patient thermoplastics, and inaccuracies in the correct location reference point for patient are recommended. In experiments that radiation passes through the table in both high and low photon energies, range of motion secondary particles is much wider, and so the collected dose for algorithm may be confusing.

As recommended by IAEA-TECDOC 1583, CIRS phantom needs to eight test cases, but in this study, there was no possibility for measuring case 5 due to using of semi CIRS phantom. Several researchers such as Laliena Bielsa *et al.*^[9] used plastic water phantom with 10 point holes which are different from solid phantom which used in this work. For this reason, comparing the results of this work, no was done with their results.

A few errors which observed here is due to lack of using standard or internal center protocols, no enough phantom setting, lack of performing quality control tests routinely, deviations in the dose calculation TPS for wedges, especially in off-axis situations, and the possibility of errors in the correct place shield. Using of audit test may be reduced errors relevant to mentioned criteria. For this reason, recommendation of doing audit test is a vital in all RT centers.

As new radiotherapy equipment invented and introduced to the community, new treatment methods are developed. Further study including the physics of radiation, and planning will be required. When the dose delivery methods are becoming increasingly more complex, it is possible that health centers may not pass the limits of assurance for radiotherapy treatment.

The audit could also help the users to appreciate the properties, qualities, and operational characteristics of TPSs and to better understand their limitations.

The overall results revealed that the national status of TPS calculations and dose delivery for 3DCRT was globally within acceptable standards with no major causes for concern.

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Conflicts of interest

There are no conflicts of interest.

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