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Original Article

Assessment of Dose Calculation Accuracy of TiGRT Treatment Planning System for Physical Wedged fields in Radiotherapy

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Abstract

Introduction
Wedge modifiers are commonly applied in external beam radiotherapy to change the dose distribution corresponding to the body contour and to obtain a uniform dose distribution within the target volume. Since the radiation dose delivered to the target must be within ±5% of the prescribed dose, accurate dose calculation by a treatment planning system (TPS) is important. The objective of the present study was to quantify the dose calculation accuracy of TiGRT TPS for physical wedged fields in radiotherapy.
Materials and Methods
A Semiflex™ ionization chamber was used for dose measurements in a water phantom; TiGRT TPS was also applied for dose calculations. The central axis (i.e., high dose-small dose gradient), build-up (i.e., high dose-large dose gradient), off-axis (i.e., high dose-small dose gradient), and out-of-field (i.e., low dose-small dose gradient) regions were evaluated in this study. Finally, the confidence limit values were obtained to quantify the dose calculation accuracy of TPS in these regions.
Results
The confidence limit values for the central axis, build-up, off-axis, and out-of-field regions were 1.01, 8.62, 1.79, and 55.24, respectively. Furthermore, the results showed that TiGRT TPS underestimated the dose of build-up and out-of-field regions for most points.
Conclusion
According to the results of the present study, it can be concluded that the dose calculation accuracy of TiGRT TPS for physical wedged fields in the central axis, build-up, and off-axis regions is adequate, while it is insufficient for out-of-field regions.

Keywords: Accuracy, Dose, Radiotherapy, Treatment Planning, Wedge

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1. Introduction

Radiotherapy is a modality applied for cancer treatment. Nearly 60% of patients require this type of treatment for curative or palliative purposes [1]. Wedge modifiers are commonly applied in external beam radiotherapy to change the dose distribution corresponding to the body contour and to obtain a uniform dose distribution within the target volume [2-10]. Wedges are commonly placed at a proper distance from the patient skin to avoid damage to the skin and spare the effect of megavoltage photon beams. Wedges are made of high-Z materials such as lead or copper [2, 11]. Dose distributions can be generated through using physical, motorized, and dynamic wedges [12].

In a treatment planning system (TPS), the most important software component is the dose calculation algorithm which is responsible for the precise delivery of dose to the target volume [13]. As the radiation dose must be delivered within ±5% of the prescribed dose [14, 15], TPSs should be able to precisely calculate the dose. There are several protocols which can provide information on the quality assurance (QA) of TPSs and the tolerance limit of the difference between dose measurements and dose calculations in different geometries and regions with various dose values and gradients [16, 17].

Several studies have assessed the dose calculation accuracy of different algorithms/TPSs in the wedged field technique. Venselaar and Welleweerd [18] evaluated the dose calculation accuracy of several TPSs and showed that for most systems, dose calculation accuracy in wedged fields was within the tolerance limit, while this finding was not reported for asymmetric wedged fields.

In this regard, Maqbool et al. [19] investigated the accuracy of the dose calculation algorithm used in Theraplan Plus (TPP) TPS when using wedge filters for 15 MV photon beams. They showed that the normalized wedge factor calculated by TPP TPS was in good agreement with the experimental values. Furthermore, they illustrated that negligence of the dependence of wedge factor on field size and depth leads to the underexposure of the tumor.

Additionally, Muhammad et al. [20] assessed the calculation accuracy of wedge factors of physical wedged fields by TPP TPS for 6 MV photon beams. They showed that ignoring the beam hardening and softening coefficients created a difference of approximately 7% between the calculated and measured normalized wedge factors (NFWs). However, after applying these parameters into the algorithm, the agreement between the calculated and measured NWFs improved by 2% for various depths.

Anjum et al. [12] evaluated the precision of Eclipse™ TPS on modeling dose distribution in wedged fields by using 45° and 60° enhanced dynamic wedges (EDWs). The results showed that the accuracy of Eclipse™ TPS with EDWs for symmetric and asymmetric fields is sufficient in clinical application. In addition, in 2015, Dawod carried out a study on the precision of Elekta Precise TPS in modeling dose distributions for motorized wedges [13]; the results were consistent with the findings reported by Anjum and colleagues.

To the best of our knowledge, no investigation has been carried out on the dose calculation accuracy of TiGRT TPS in physical wedged fields. Therefore, in this study, we aimed to assess the accuracy of dose calculations in TiGRT TPS for physical wedged fields.

2. Materials and Methods

2.1. Geometric Specifications of the Wedged Field

According to TECDOC 1540 protocol, which provides information on the QA of TPSs [16], a field size of 9×9 cm^2 at the isocenter, surface-to-source distance (SSD) of 100 cm, wedge angle of 60°, and gantry and collimator angles of 0° were considered for testing the wedged fields. This test was carried out with the MP3-M water phantom (PTW, Freiburg, Germany). Figure 1 shows the graphical representation of wedge tests.

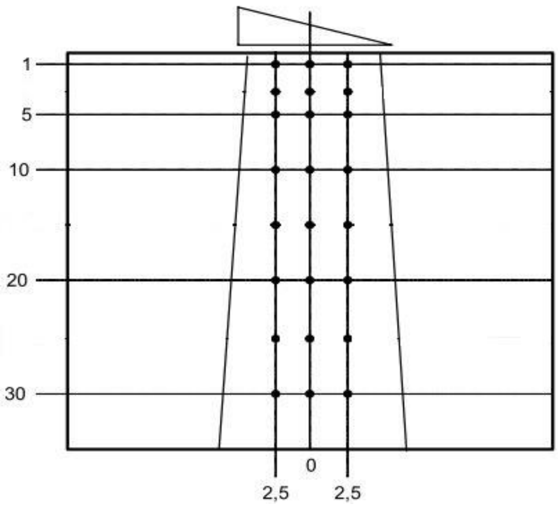

Figure 1. The graphical representation of the wedge tests

2.2. TPS and Dosimetric Method

In this study, Siemens Primus Accelerator (Siemens AG, Erlangen, Germany) with 6 MV X-rays was applied. For dose measurements, a Semiflex™ ionization chamber with a sensitive volume of 0.125 cm^3 (PTW, Freiburg, Germany) was used. Also, for dose calculations, TiGRT TPS version 1.2 (LinaTech, Sunnyvale, CA, USA) was employed. TiGRT is a radiotherapy TPS for dose planning of patients undergoing treatment with external beams in clinical oncology. This TPS is applied to plan radiation treatments with linear accelerators and other similar radiation therapy devices with X-ray energies of 1-25 MV, cobalt-60, and electron energies of 1-25 MeV.

TiGRT TPS uses a three-dimensional (3D) photon dose calculation algorithm, based on the full scatter convolution. According to the user's manual of TiGRT TPS, this system uses an exclusive algorithm, known as full scatter convolution (FSC), developed to facilitate accurate and fast calculations. The FSC algorithm applies basic beam data, collected during commissioning (e.g., beam profile, tissue maximum ratio, collimator parameters, and total scatter factors). The dose calculation time per beam for conventional and 3D conformal techniques is under 10 sec. According to the manual, this algorithm separates the absorbed dose (*D*) in a given point into the primary dose (D_p) and the scatter dose (D_s):

$$D = D_p + D_s \quad (1)$$

The primary dose D_p ($\vec{r}$) is obtained based on the convolution algorithm, using the following formula:

$$D_p(\vec{r}) = \iiint \phi_p(\vec{r}')k_p(\vec{r}-\vec{r}')dV' \quad (2)$$

where $\phi_p(\vec{r}')$ is the photon fluence at the surface of a ray passing through the surface to point $\vec{r}'$ and $k_p(\vec{r}-\vec{r}')$ denotes the electron transport kernel, explaining the dose distribution around the primary interaction site of the photon. This demonstrates that the electron transport modeling by this algorithm has been taken into account, and the electron dose deposition kernel can be scaled for heterogeneities such as lung, bone, and air cavities. Finally, V' states the differential calculation volume at point $\vec{r}'$. The scatter dose $D_s(\vec{r}')$ is derived from the following convolution equation:

$$D_s(\vec{r}) = \iiint \phi_p(\vec{r}')k_s(\vec{r}-\vec{r}')dV' \quad (3)$$

In the FSC algorithm, multiple scattering of photons is discarded and $k_s(\vec{r}-\vec{r}')$ is the first scatter fluence kernel. This kernel can be derived from the electron transport kernel.

For the assessment of dose calculation accuracy, doses delivered to points on the central axis and vertical lines at a 2.5 cm distance from the right and left sides of the central beam axis (in the direction of the wedge), as well as profiles at depths of 1, 5, 20, and 30 cm, were measured. Then, for making a virtual phantom by TiGRT TPS, the geometric specifications of the wedged field were planned, and the dose was calculated by TPS in the corresponding points with the measured dose.

2.3. Data analysis

For the analysis of the results, TRS 430 and TECDOC 1540 protocols were applied. These protocols provide information on the QA of TPSs. According to these protocols, the difference between the calculated and measured doses is defined as follows:

$$\delta[\%] = 100 \times (D_{cal} - D_{meas})/D_{meas} \quad (1)$$

where D_{meas} and D_{calc} are the measured dose by the ionization chamber and the calculated dose by TPS, respectively. Therefore, the confidence limit value is determined as follows:

$$\Delta = |\text{average deviation}| + 1.5 \times SD \qquad (2)$$

The confidence limit value is determined by calculating the average deviation between the measured and calculated dose values for several data points in comparable positions and the standard deviation of the differences (1 SD of the average). Finally, the confidence limit values were obtained for in-field (including the central axis, build-up, and off-axis regions) and out-of-field regions and were compared with the tolerance limits, suggested in TRS 430 and TECDOC 1540 protocols.

For the evaluation of the dose calculation accuracy of TPS in the central axis, build-up, and off-axis regions, data related to percentage depth doses (PDDs; central beam axis at a 2.5 cm distance from the right and left sides of the central beam axis) were applied. Also, to evaluate the dose calculation accuracy of TPS in the out-of-field region, data related to the profiles were applied.

In addition, for high dose-small dose gradient regions (i.e., central axis and off-axis regions), data related to depths more than 16 mm were used. For the high dose-large dose gradient regions (i.e., build-up regions), data related to the depths of 0-16 mm were applied. Finally, for the low dose-small dose gradient regions (i.e., out-of-field regions), data related to distances of about 5-10 mm from the field edge were used.

3. Results

Dose values of points on the central beam axis at a 2.5 cm distance from the right and left sides of the central beam axis (in the direction of the wedge), as well as profiles in depths of 1, 5, 20, and 30 cm, were evaluated. In these points, doses measured by the ionization chamber were compared with the corresponding values calculated by TiGRT TPS; these results are illustrated in Figures 2 and 3. It is notable that TPS could not calculate the dose at a depth of 0 or on the phantom surface. Therefore, data related to this depth were not used in the calculation of the confidence limit values. Furthermore, dose values in the profiles were normalized to dose values on the central axis at a 1 cm depth.

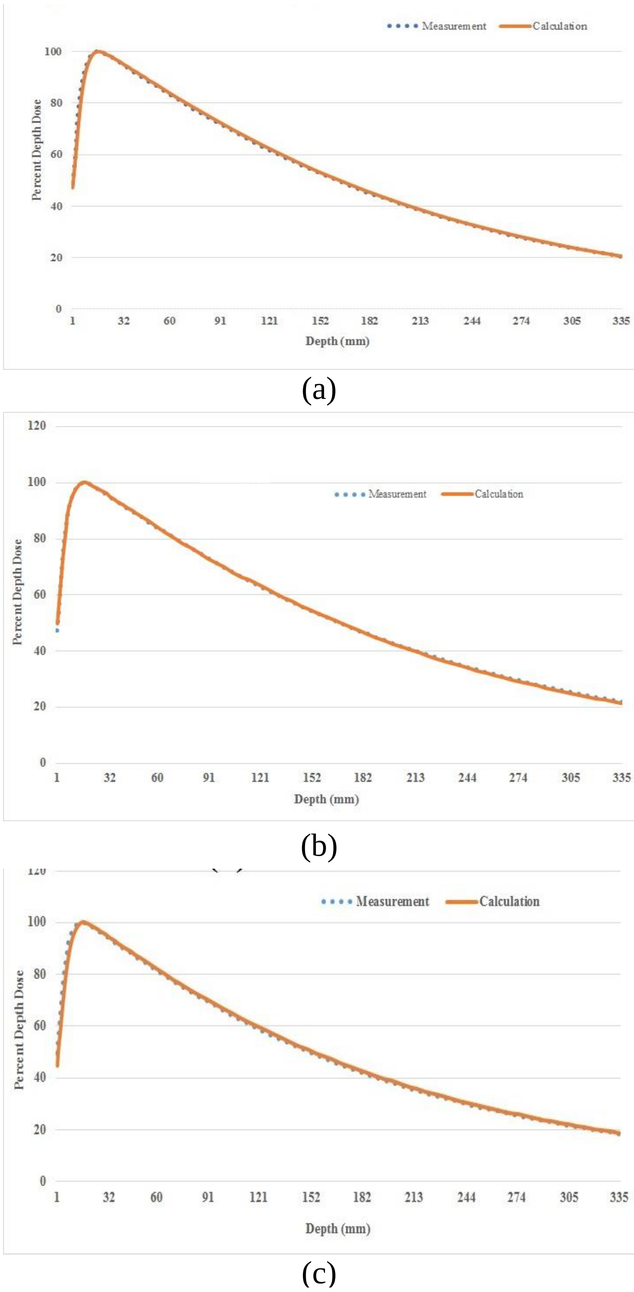

Figure 2. The measured and calculated percentage depth doses (PDDs) on the central axis (a), at a 2.5 cm distance from the right (under the thick edge of the wedge) and left (under the thin edge of the wedge) sides of the central beam axis 1 cm depth.

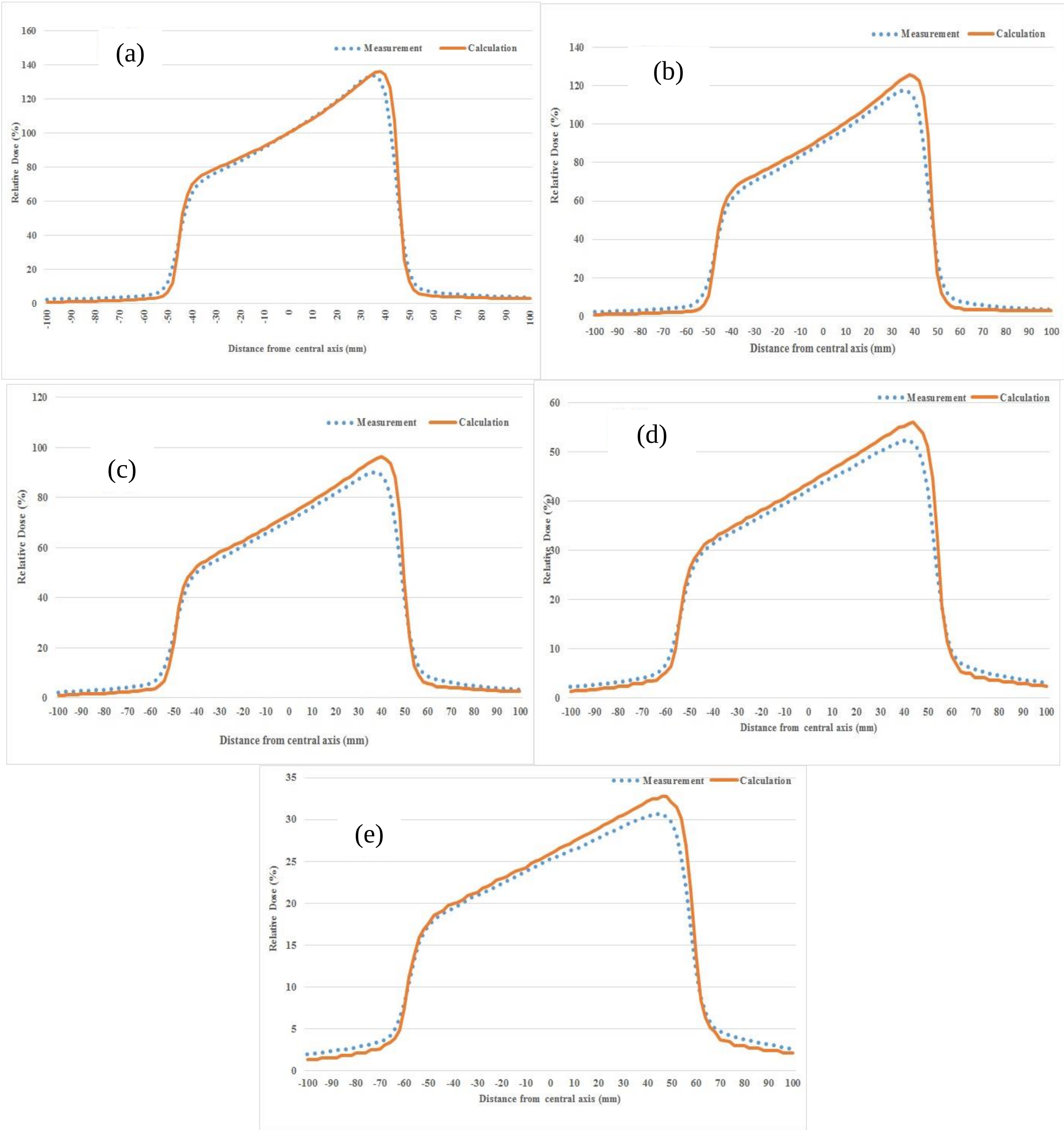

Figure 3. The measured and calculated profile doses for depths of 1 cm (a), 5 cm (b), 10 cm (c), 20 cm (d), and 30 cm (e) from the surface phantom

Figure 2 (a-c) represents the measured and calculated PDDs on the central axis (a) at a 2.5 cm distance from the right (under the thick edge of the wedge) and left (under the thin edge of the wedge) sides of the central beam axis. Figure 3 (a-e) shows the measured and calculated profile doses for depths of 1 cm (a), 5 cm (b), 10 cm (c), 20 cm (d), and 30 cm (e) from the surface phantom.

Finally, the confidence limit values were obtained. The corresponding values for the central axis, build-up, off-axis, and out-of-field regions were 1.01, 8.62, 1.79, and 55.24, respectively. It is notable that the data related to PDDs (central beam axis at a 2.5 cm distance from the right and left sides of the central beam axis) were applied to obtain the confidence limit values in the central axis, build-up, and off-axis regions. Also, the data related to the profiles were applied to obtain the confidence limit values in the out-of-field regions.

4. Discussion

In this study, the accuracy of dose calculations by TiGRT TPS for physical wedged fields was evaluated, and different regions, i.e., central axis, build-up, off-axis, and out-of-field regions, were evaluated. According to TECDOC 1540 and TRS 430 protocols, which provide information on the QA of TPSs, the tolerance limit values for the wedged field (i.e., complex geometry) in the central axis (i.e., high dose-small dose gradient), build-up (i.e., high dose-large dose gradient), off-axis (i.e., high dose-small dose gradient), and out-of-field (i.e., low dose-small dose gradient) regions are 3, 15, 3, and 40, respectively.

The present results showed that the confidence limit value for the high dose-small dose gradient regions (i.e., central axis and off-axis regions) was within the tolerance limit. For the central axis region, the difference between D_{meas} and D_{calc} was in the range of 0.02-1.05%. Also, for regions at a 2.5 cm distance from the right (under the thick edge of the wedge) and left (under the thin edge of the wedge) sides of the central beam axis, the differences between D_{meas} and D_{calc} were in the range of 0.02-1.98% and 0.04-1.88%, respectively.

Bahreyni Toossi et al. evaluated the accuracy of dose calculations by TiGRT TPS in breast regions. The results showed that the accuracy of dose calculation in this TPS for most in-field regions was within the tolerance limit. [21] The results of the present study were consistent with the findings of the mentioned study. In addition, Venselaar and Welleweerd evaluated the dose calculation accuracy of several TPSs (LPS-2, Theraplan, Plato-RTS, UM-Plan, CadPlan, Pinnacle, and RenderPlan TPSs) and showed that for all TPSs, dose calculation accuracy in the wedged fields was within the tolerance limit, while dose calculation accuracy in asymmetric wedged fields was not within the tolerance limit (except for LPS-2 TPS). [18]

Petrovic et al. compared the linear array measurements of EDW with the calculations of electronic portal imaging device (EPID) and TPS for 15 MV photon energy. The results showed that EDW linear array measurements of profiles differed by nearly 0.5% from XIO CMS TPS calculations. PDDs for all EDW measurements showed a difference of not more than 0.2%. Also, the results demonstrated that EPID could not be applied for reference measurements [22].

Additionally, the results showed that the confidence limit value for the high dose-large dose gradient regions (i.e., build-up regions) was within the tolerance limit. For build-up regions at the central axis, the difference between D_{meas} and D_{calc} was in the range of 0.15-6.17%. Also, for build-up regions at a 2.5 cm distance from the right (under the thick edge of the wedge) and left (under the thin edge of the wedge) sides of the central beam axis, differences between D_{meas} and D_{calc} were in the range of 0.03-6.27% and 0.02-12.46%, respectively. The differences between D_{meas} and D_{calc} were greater in regions near the surface, compared to regions near the depth of the maximum dose.

In 2016, Farhood et al. evaluated the accuracy of dose calculations by TiGRT TPS in the build-up region. They showed that the confidence limit values for small and moderate gantry angles (15° and 30°) were within the tolerance limit. [23] The present results were consistent with the findings of the mentioned study. Finally, the present results showed that the confidence limit value for the low dose-small dose gradient regions (i.e., out-of-field regions) was not within the tolerance limit. For these regions, the difference between D_{meas} and D_{calc} was in the range of 16.18-69.34%.

It is notable that for most TPSs, dose calculation accuracy in out-of-field regions is not adequate, which might be due to the inaccurate dose modeling in these regions. In addition, since the local dose in these regions was low and the difference between D_{meas} and D_{calc} was normalized to the local dose, a small difference between D_{meas} and D_{calc} majorly increased the values obtained from Equation 1 (δ).

Furthermore, the results showed that for most points, TiGRT TPS underestimated the dose compared to the measured dose (Figure 3). Consistent with our previous studies [23, 24], the present results indicated that TiGRT TPS generally underestimates the dose of out-of-field points. For pregnant patients or those with implanted electronic devices, it is important to accurately evaluate the dose to the fetus or the device to guide clinical management. Therefore, dose assessment in such regions (low-dose regions) should not merely rely on TPS calculations.

Similarly, for research studies or clinical investigations on the potential of radiation for the development of secondary cancer, we should not generally rely on TPSs to evaluate the risks associated with out-of-field regions. Therefore, underestimation of the dose received by a radiosensitive organ, using the TPS calculated dose, leads to risk underestimation.

5. Conclusion

In this study, we evaluated the accuracy of dose calculations by TiGRT TPS for physical wedged fields. Based on the results of the present study, the dose calculation accuracy of TiGRT TPS for the physical wedged field in the central axis, build-up, and off-axis regions was adequate, while it was not sufficient for out-of-field regions. Furthermore, the results showed that TiGRT TPS underestimated the dose of build-up and out-of-field regions for most points. Overall, the accuracy of TiGRT TPS dose calculations for the physical wedged field was adequate, similar to other TPSs (e.g., Pinnacle and CadPlan). Finally, it can be concluded that the out-of-field data for this TPS should be only used with a certain understanding of the accuracy of the calculated dose outside the treatment field.

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