Accuracy evaluation of dose calculation of ISOgray treatment planning system in wedged treatment fields

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ABSTRACT

Background*:** It is essential to evaluate the accuracy of dose calculation for treatment planning systems (TPSs). This study's primary goal was to evaluate the accuracy of dose calculation for ISOgray TPS in the presence of a wedges in the treatment fields. ***Materials and Methods: GATE (Geant4 Application for Tomography Emission) as a Monte Carlo (MC) code was utilized to model the 6 MV photon beam of an Elekta Compact linac. It did MC code verification for three different field sizes and three depths for open, and wedged fields with gamma index tool. Following the confirmation, the percentage depth dose (PDD) and dose profile were calculated using the TPS and compared with the simulation results. In the next step, the TPS dose calculations for the 10×10cm2 field with different wedge angles were compared by the result from analytical formula. ***Results:*** The PDD and dose profiles for open fields met the gamma index criteria. However, there was disagreement for large wedged fields. The dose profiles of wedge angles using Petti analytical equation were compared to ISOgray dose profiles. Results showed that dose profile points with all wedge angles meet the gamma index criteria except for the 45˚ wedge angle. ***Conclusions:*** The results indicated that the disagreement between MC and TPS dose calculations increases by increasing wedge angle and field size. The uncertainty is due to TPS dose calculation algorithm causing noticeable disagreement. A MC-based TPS for dose calculation is recommended to reduce the error in dose calculation or at least medical physicist consider this issue.

INTRODUCTION

Dose calculation in heterogeneous areas is a controversial topic in radiotherapy. The primary tool for dose distribution calculation is the treatment planning system (TPS) [(1)]. However, based on various studies, Monte Carlo (MC) simulation is account as the gold standard for calculation of dose distribution [(2, 3)]. Compared to TPS, the MC method has high accuracy for dose calculation in heterogeneous areas [(4, 5)]. The main disadvantage of the MC method is its time-consuming nature and this makes it to not be infrequently used in routine clinical practice [(2, 6-9)]. In general, this is a limiting factor because as accuracy increases, computational time also increases; therefore, it must make a compromise on this issue [(10)]. Considering the importance of TPS as the primary tool for dose calculation and treatment process [(4, 11, 12)], ensuring the accuracy of treatment plans is one of the main concerns of a medical physicist. Wedge filters are normally used as a treatment plan tool to adjust dose distribution and to improve the dose uniformity in the target volume. When a wedge filter is introduced into the beam path, the dose distribution is modified and the overall quality of the treatment is improved [(13, 14)]. In Elekta linacs, motorized wedges with a fixed angle of 60º are used, and a combination of open and wedged fields can achieve an effective isodose curve with a slope between 1-60º [(15-20)].

Several researchers have simulated and validated medical linacs using MC codes, compared MC results with experimental measurements, and discussed the factors affecting the simulation [(21-26)]. On the other hand, some studies have evaluated the simulations of wedge filters in treatment fields [(21-25, 27-31)]. Kinhikar *et al.* in 2007 [(29)] and Elhassan *et al.* in 2008 [(28)] assessed the accuracy of TPS for the motorized wedge of the tele-cobalt machine. Dawod *et al.* in 2014 [(16)] and Behjati *et al.* in 2018 [(15)] evaluated the accuracy of TPS for the motorized wedge of the Elekta Linac. Recently, Gamit *et al.* in 2020 [(17)] considered the effective isodose angles for Elekta

Versa HD motorized wedge. They were done by comparing dosimetry and Monaco TPS results. They announce that the maximum deviation is 9º for 6 MV, which is higher than the results of Kumar *et al.* in 2012 (32) and Petti *et al.* in 1985 (18) studies. According to the literature, the accuracy of ISOgray TPS (DosiSoft, France) dose calculations has not been investigated in full detail. Therefore, due to the wide use of ISOgray TPS in different radiotherapy departments, the evaluation of the accuracy of this TPS. The novelty of this work is the accurate investigation of several fields with different wedge angles.

The investigators in the current research simulated and validated Elekta compact linear accelerator (Elekta AB, Stockholm, Sweden) with MC for three field sizes and depths for open and wedged fields (60°). Then compared the PDD and the dose profile for wedged fields (5°, 10°, 15°, 20°, 30°, and 45°) in TPS and MC simulation to evaluate the accuracy of the TPS.

MATERIALS AND METHODS

In the current study, an Elekta Compact (with 6 MV photon beam) linear accelerator which was installed in the radiotherapy department at Imam Ali hospital of Bojnurd, Iran, was simulated and validated. To achieve this goal a water phantom with 60×60×60 cm^3 size (PTW, Freiburg, Germany), Semiflex ionization chamber 31010 (PTW-Freiburg, Freiburg, Germany) and ISOgray TPS in the mentioned department was used. The simulations were done with Gate 7.2 (Ubuntu 16.04, Geant4 10.2) and MC codes were run on a personal computer with the following performances: Intel Core i7 CPU with 3.2 GHz and 8GB RAM. MATLAB R2015b (MathWorks Inc., MA) was used to read and extract the data from MC output files. Validation of simulated code were done with the Gamm Index code, which it wrote in MATLAB m-file. Three parts as below done the study:

Experimental measurement

The selected PDD and dose profiles for three field sizes (including 5×5, 10×10 and 20×20 cm^2) at three depths (5, 10, and 20 cm) were measured for the open and wedged fields. The typical quality control tests were performed for the linac before measurements. To increase the accuracy of dosimetry, relative dosimetry was done according to the TG-106 protocol (33).

MC simulation

The geometrical details and the composition of each linac's components were modeled and simulated at source to skin distance (SSD) of 100 cm.

The electron beam characteristics used in the simulation included two half Gaussian curves with average energy of 6.05 MeV. The standard deviations (sigma) for each half Gaussian curve were 0.15 and 0.35 MeV. A one-dimensional beam (beam1d) with 1.98° standard deviation (sigma_r) was defined for the source. The PDD and dose profile for 10×10 cm^2 field size in 10 cm depth were simulated and then compared with the corresponding data from experimental measurement. The gamma index (with 2%–2mm criteria) was used to verify the energy of the electron and linac head simulation. The gamma index results for all three field sizes' PDDs and the dose profiles for all investigated field sizes and depths for the open and wedged fields were presented in table 1. After verification of the reference field size (namely10×10 cm^2), to increase the accuracy of simulation and validation, two small and large field sizes (5×5 and 20×20 cm^2) were simulated and verified at 10 cm depth. The results presented in table 1 demonstrates that the pass rates for PDDs were more than 98% and for dose profiles 100% of points passed the gamma index for all the open and wedged fields.

Table 1. Gamma index (2%-2mm criteria) pass rates for experimental measurement and MC's PDDs and dose profile comparison for open and wedged fields. *Percentage Depth Dose

Field size (cm^2)	5×5	10×10	20×20
PDD*			
Open field	98.68%	98.68%	98.68%
Wedge field	98.68%	98.68%	98.68%
Dose Profile (Open Field)			
Depth (cm)			
5	100%	100%	100%
10	100%	100%	100%
20	100%	100%	100%
Dose Profile (Wedged field)			
Depth (cm)			
5	-	100%	-
10	100%	100%	100%
20	-	100%	-

In the following steps, the Elekta motorized wedge with a 60º angle was modeled, simulated, and then verified for the exact field sizes and depths. Verification for open and wedged fields was done using a gamma index tool with 2%–2mm criteria and experimental measurement data for comparison.

The phase-space method was utilized to increase the simulation speed and placed after the ionization chamber just before the X-Jaw. In the wedged field model, the phase space was located before the wedge to achieve the proper dose profile. It runs the first part of the phase space code for $2×10^9$ particles. The second part of the code considered the phase space a source, and it tracked $4×10^{10}$ and $6×10^{10}$ particles for open and wedged fields. The dose distribution and dosimetric quantities were calculated, respectively.

ISOgray TPS evaluation

The PDDs and the dose profiles for the exact three field sizes and depths for the open and wedged (60º) fields for MC and TPS results were compared and the accuracy of dose calculation of ISOgray TPS were

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evaluated.

For the other wedge angles, the effective doses with the combination of MC open and wedged fields using the Petti equation (1) [18] for 5, 10, 15, 20, 30, and 45º wedge angles in 10×10 cm² field size and 10 cm depth were calculated.

$$B = \frac{f}{\frac{\tan\theta_W}{\tan\theta_E} + f - 1} \qquad (1)$$

B is the wedged field weighting factor normalized to one by open field weighting factor (A), θ_W and θ_E are nominal and effective wedge angles, respectively, and the f factor is the ratio of the slopes of the PDD curves for the open and wedged fields. The following formula presents the effective wedge distribution (D): $D = (A \times D_0) + (B \times D_w)$ (2)

In this formula A and B are the proportions of the open (D_0) and wedged (D_w) fields, respectively (A+B=1) [18].

In the last step, the effective isodose curves that resulted from the equation (1) were compared with ISOgray results. TPS's accuracy was evaluated using the gamma index tool with 2%–2 mm criteria.

Statistical analysis

In this study, R Software (version R-3.4.1, by the Foundation for Statistical Computing Company, Vienna, Austria) was used to perform the statistical analyses. Statistical significance was evaluated using the *t*-test and a *p*-value of less than 0.05 was accounted as a statistical significance.

RESULTS

ISOgray TPS evaluations

The authors in the current study performed a two-stage evaluation of the TPS for the open and wedged fields. First, the PDDs for three field sizes (including 5×5, 10×10, and 20×20 cm² fields) were compared, and then investigated the dose profiles at three depths (5, 10, and 20 cm). In all evaluations, the gamma index with 2%-2 mm criteria were used.

Figure 1 illustrates the PDDs for open and wedged fields of 5×5, 10×10, and 20×20 cm² field sizes. The corresponding gamma index values are listed in table 2. Based on table 2, the PDDs for all the open and wedged fields meets the criteria, with a pass rate of 100%. The investigators did not observe any statistically significant differences in these fields. The p-values for the open fields were 0.824, 0.773, and 0.995 for the 5×5, 10×10, and 20×20 cm² field sizes, respectively. Similarly, for the wedged fields, the p-values were 0.788, 0.859, and 0.941 for the same field sizes.

In figure 2, the dose profiles for open and wedged fields at depth of 10 cm are displayed for field sizes of 5×5, 10×10, and 20×20 cm². The corresponding gamma index results are listed in Table 2. Based on the results in table 2, the gamma index values for the dose profiles of open fields meet the criteria, indicating no statistically significant difference between the MC and TPS dose profiles. The *p*-values for the open fields are 0.804, 0.929, and 0.922 for the 5×5, 10×10, and 20×20 cm² field sizes, respectively. However, the dose profile points for the wedged fields fail to meet the gamma index criteria for the 20×20 cm² field size, although there is no statistically significant difference. The *p*-values for the wedged fields are 0.947, 0.789, and 0.996 for the 5×5, 10×10, and 20×20 cm² field sizes, respectively.

Evaluation of TPS's effective wedge angle

In the final stage, the researchers compared the dose profiles of the investigated wedge angles, calculated using the Petti analytical equation (equation 1), with the ISOgray dose profiles. The gamma index was used for this comparison. Figure 3 illustrates the MC and TPS dose profiles, as well as the gamma index results for the effective wedge angles (5, 10, 15, 20, 30, and 45°) at the reference field size and depth.

The gamma index results for the effective wedge angles, using a 2%-2mm criteria for MC and TPS comparison (10×10 cm² field size) for 5, 10, 15, 20, 30, and 45º wedge angles, are presented in Table 3. According to the Table 3, dose profile points with all wedge angles meet the gamma index criteria, except for the 45º wedge angle. But also, there was not any statistically significant difference and the *p*-values for the wedge angles of 5, 10, 15, 20, 30, and 45º are 0.965, 0.976, 0.986, 0.998, 0.976, and 0.928, respectively.

The nominal wedge angles and corresponding effective wedge angles, determined through experimental measurement, MC, and TPS isodose curves, are presented in table 4. The effective wedge angles were obtained by fitting a line to the isodose curves following the guidelines of the ICRU24 protocol [34].

Table 2. Gamma index (with 2%-2mm criteria) pass rates for TPS and MC's PDDs and dose profiles comparison (three open and wedge field). *Percentage Depth Dose

Field size (cm²)	5×5	10×10	20×20
	PDD*		
Open field	100%	100%	100%
Wedged field	100%	100%	100%
	Dose Profile		
Depth (cm)			
Open field	100%	100%	100%
Wedged field	100%	86.67%	59.60%

Table 3. Effective wedge angles' gamma index pass rates with 2%-2mm criteria for MC and TPS comparison (10×10 cm2 field size).

Wedge Angle (°)	2%-2mm
5	100%
10	100%
15	100%
20	100%
30	100%
45	88%

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Table 4. Calculated effective wedge angles obtained from experimental measurements, MC and TPS isodose curves.

Nominal Wedge Angle (°)	Dosimetry Wedge Angle (°)	MC Wedge Angle (°)	TPS Wedge Angle (°)
5	4	4	5
10	9	9	8
15	13	14	12
20	18	18	16
30	27	28	24
45	42	43	37

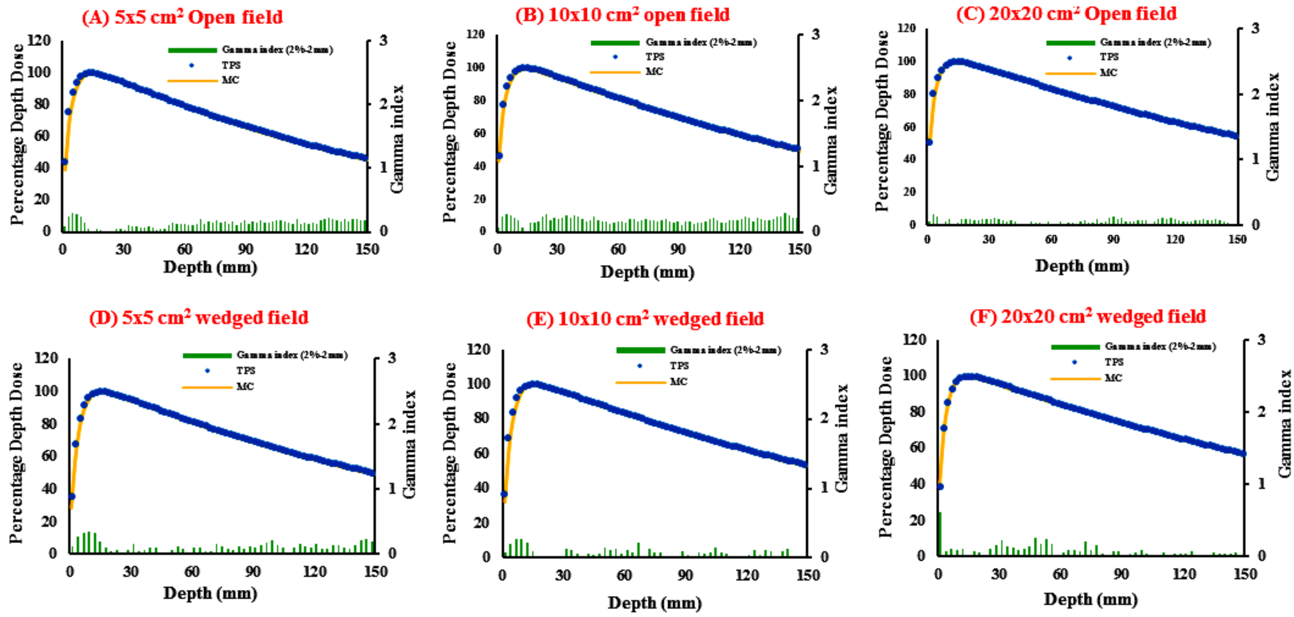

Figure 1. TPS and MC's PDDs comparison for open and wedged fields (60˚) at 10 cm depth beside the gamma index with 2%-2 mm criteria of 5×5, 10×10 and 20×20 cm^2 field sizes.

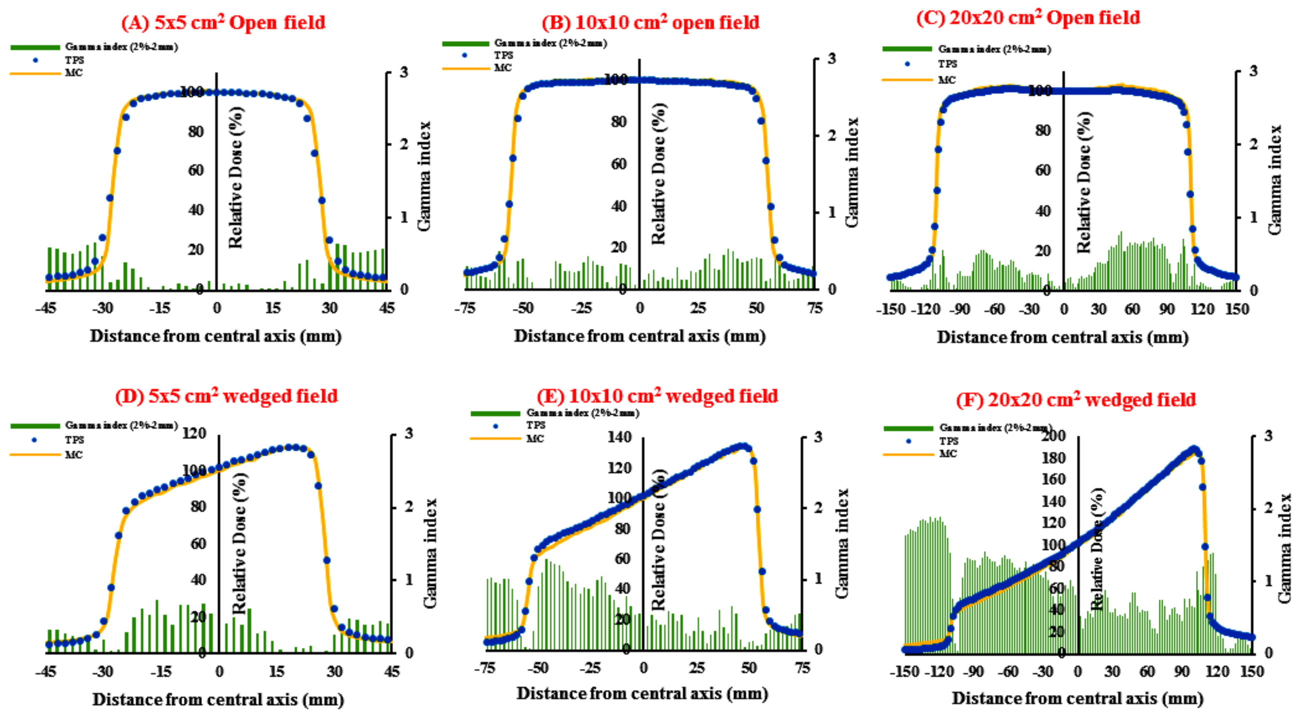

Figure 2. TPS and MC's dose profile comparison beside the gamma index results with 2%-2mm criteria for three (5×5, 10×10, 20×20 cm^2) open and wedged fields (60˚) at 10 cm depth.

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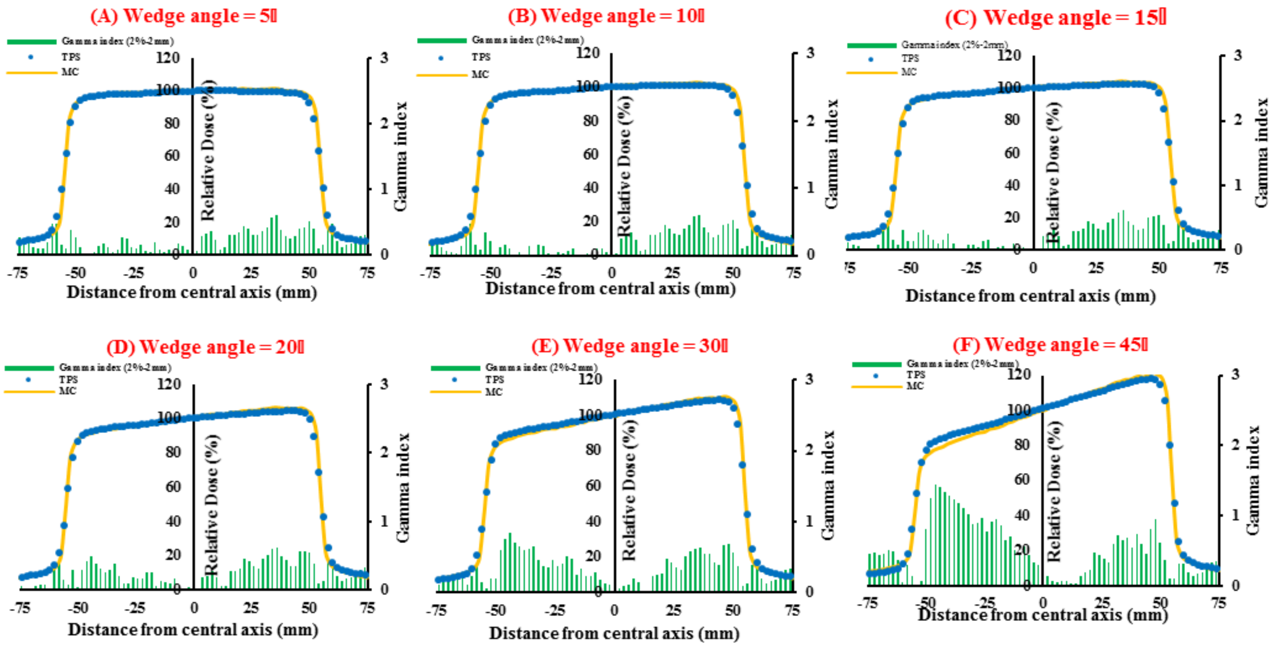

Figure 3. TPS and MC's effective wedge dose profiles comparison beside the gamma index results with 2%-2mm criteria for 10×10 cm^2 at 10 cm depth, 5˚(A), 10˚ (B), 15˚(C), 20˚(D), 30˚(E), 45˚(F).

DISCUSSION

The study simulated and validated the Elekta Compact linac head using Monte Carlo GATE code for open and wedged fields. It compared PDDs and dose profiles with ISOgray TPS calculations. Regarding to the gamma index results for comparing the experimental measurement and MC simulation in open and wedged fields (table 1), more than 98% of points could pass the 2%-2mm criteria. Therefore, the MC simulation codes have reliable accuracy and can be considered the gold standard for the rest of the study. The difference which reported in MC and TPS dose profile comparison for three open field sizes (table 2), may relate to TPS dose calculation algorithms. Furthermore, the gamma index passing rate decreases with decreasing field size and Maqbool *et al.* in 2009 [35] and Dawod *et al. in* 2015 [16] studies confirm the obtained results. The reason may be the increase of penumbra area in small fields and electron disequilibrium in the penumbra area. Based on the results of this study, particularly in figure 2, TPSs dose calculation does not have enough accuracy in out-of-treatment plan fields (penumbra area) and the results of Berris *et al.* [36], Howell *et al.* [37], Venselaar *et al.* [38], and Wang *et al.* [39] confirm this instance.

In wedged fields with increasing the field size, more wedge surface is placed in the field, and the non-uniformity increase; therefore, mismatching will also increase. The results in Table 3 indicate that TPS cannot calculate this non-uniformity in the direction of wedge slope, which is reported in Fraass *et al.* study in 1998 [40]. The incoherence between TPS and MC simulations increased with increasing the wedge angle for investigated effective wedge angles (tables 3 and 4). It is due to the increase in scattered photons and delivered monitor units to the wedged field that affect beam quality. This difference between MC and TPS dose profiles demonstrated in figure 3. Nath *et al.* in 1994 [41], Pasquino *et al.* in 2009 [42], Momennezhad *et al.* in 2010 [30], and Dawod *et al.* in 2015 [16] studies confirm the presented results. The results indicate that effective wedge angles are usually less effective than nominal wedge angles (table 4), and the difference increases by increasing the wedge angle. It is owing to more contribution of the scattered rays from the presence of the wedge at large effective wedge angles. The most significant difference is related to the nominal and TPS effective wedge angle at 45º, which is less than the difference reported by Behjati *et al.* in 2018 [15] and Gamit *et al.* in 2020 [17]. However, it's more than the acceptable rate suggested by ICRU24 [43].

CONCLUSION

The results of the present study indicate significant discrepancies for small open and large wedged fields between the MC and TPS dose profile. The practical wedge angle was smaller than the nominal angle, especially for larger wedges. Using a TPS with a Monte Carlo dose calculation algorithm can help reduce the TPS dose calculation error or at least medical physicist consider this issue in their treatment plans and think about the solutions.

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REFERENCES

1. Hansen CR, Crijns W, Hussein M, *et al.* (2020) Radiotherapy treatment planning study guidelines (rating): A framework for setting up and reporting on scientific treatment planning studies. *Radiother Oncol, **153**: 67-78*.
2. Mesbahi A, Thwaites D, Reilly A (2006) Experimental and Monte Carlo evaluation of Eclipse treatment planning system for lung dose calculations. *Rep Pract Oncol Radiother, **11**: 123-33*.
3. Wieslander E and Knöös T (2003) Dose perturbation in the presence of metallic implants: treatment planning system versus Monte Carlo simulations. *Phys Med Biol, **48**(20): 3295-305*.
4. Ahnesjö A (1989) Collapsed cone convolution of radiant energy for photon dose calculation in heterogeneous media. *Med Phys, **16**(4): 577-92*.
5. Ardu V, Broggi S, Cattaneo GM, *et al.* (2011) Dosimetric accuracy of tomotherapy dose calculation in thorax lesions. *J Radiat Oncol, **6** (1): 14*.
6. Ahnesjö A and Aspradakis M (1999) Dose calculations for external photon beams in radiotherapy. *Phys Med Biol, **44**: R99-155*.
7. Ding GX and Yu CW (2001) A study on beams passing through hip prosthesis for pelvic radiation treatment. *Int J Radiat Oncol Biol Phys, **51**(4): 1167-75*.
8. Fippel M (1999) Fast Monte Carlo dose calculation for photon beams based on the VMC electron algorithm. *Med Phys, **26**(8): 1466-75*.
9. Ma CM, Pawlicki T, Jiang SB, *et al.* (2000) Monte Carlo verification of IMRT dose distributions from a commercial treatment planning optimization system. *Phys Med Biol, **45**(9): 2483-95*.
10. Miften M, Wiesmeyer M, Monthofer S, Krippner K (2000) Implementation of FFT convolution and multigrid superposition models in the focus RTP system. *Phys Med Biol, **45**(4): 817-33*.
11. Chen W-Z, Xiao Y, Li J (2014) Impact of dose calculation algorithm on radiation therapy. *World J Radiol, **6**(11): 874-80*.
12. Van Esch A, Tillikainen L, Pyykkonen J, *et al.* (2006) Testing of the analytical anisotropic algorithm for photon dose calculation. *Med Phys, **33**(11): 4130-48*.
13. Hajizadeh Saffar M, Ghavamnasiri MR, Gholamhosseinian H (2004) Assessment of variation of wedge factor with depth, field size and SSD for Neptun 10PC Linac in Mashhad Imam Reza Hospital. *Int J Radiat Res, **2**(2): 53-8*.
14. Geraily G, Mirzapour M, Mahdavi SR, *et al.* (2014) Monte Carlo study on beam hardening effect of physical wedges. *Int J Radiat Res, **12**(3): 249-56*.
15. Behjati M, Sohrabpour M, Shirmardi SP, *et al.* (2018) Dosimetric verification of the Elekta motorized wedge. *Arch Adv Biosci, **9**(3): 32-41*.
16. Dawod T (2015) Treatment planning validation for symmetric and asymmetric motorized wedged fields. *Cancer Ther Oncol Int J, **3**: 030118*.
17. Gamit J, Nair S, Charan S, *et al.* (2020) Validation of motorized wedge effective isodose angle with a 2D array detector. *Iran J Med Phys, **17**(6): 380-5*.
18. Petti PL and Siddon RL (1985) Effective wedge angles with a universal wedge. *Phys Med Biol, **30**(9): 985-91*.
19. Tatcher M (1970) A method for varying the effective angle of wedge filters. *Radiology, **97**(1): 132*.
20. Van der Laarse R, van Overbeek P, Strackee J (1984) Wedge filters for megavoltage roentgen ray beams. *Acta Radiologica: Oncology, **23**(6): 477-84*.
21. Almberg SS, Frengen J, Kylling A, Lindmo T (2012) Monte Carlo linear accelerator simulation of megavoltage photon beams: independent determination of initial beam parameters. *Med Phys, **39** (1): 40-7*.
22. Grevillot L, Frisson T, Maneval D, *et al.* (2011) Simulation of a 6 MV Elekta Precise Linac photon beam using GATE/GEANT4. *Phys Med Biol, **56**: 903-18*.
23. Sadoughi HR, Nasseri S, Momennezhad M, *et al.* (2014) A comparison between GATE and MCNPX Monte Carlo codes in simulation of medical linear accelerator. *J Med Signals Sens, **4**(1): 10-7*.
24. Sarrut D, Bardiès M, Boussion N, *et al.* (2014) A review of the use and potential of the GATE Monte Carlo simulation code for radiation therapy and dosimetry applications. *J Med Phys, **41**(6Part1): 064301*.
25. Verhaegen F and Seuntjens J (2003) Monte Carlo modelling of external radiotherapy photon beams. *Phys Med Biol, **48**(21): R107-64*.
26. Bahreyni Toossi MT, Behmadi M, Ghorbani M, Gholamhosseinian H (2013) A Monte Carlo study on electron and neutron contamination caused by the presence of hip prosthesis in photon mode of a 15 MV Siemens PRIMUS linac. *J Appl Clin Med Phys, **14**: 4253*.
27. Bahreyni-Toosi MT, Nasseri S, Momennezhad M, Hasanabadi F, Gholamhosseinian H (2014) Monte Carlo Simulation of a 6 MV X-Ray Beam for Open and Wedge Radiation Fields, Using GATE Code. *J Med Signals Sens, **4**(4): 267-73*.
28. Elhassan SE (2008) Evaluation of motorized wedge for a new generation telecobalt machine.
29. Kinhikar RA, Sharma S, Upreti R, *et al.* (2007) Characterizing and configuring motorized wedge for a new generation telecobalt machine in a treatment planning system. *J Med Phys, **32**(1): 29-33*.
30. Momennezhad M, Bahreyni Toosi MT, Sadeghi R, *et al.* (2010) A Monte Carlo simulation and dosimetric verification of physical wedges used in radiation therapy. *Int J Radiat Res, **7**(4): 223-7*.
31. Acar H, Yavas G, Yavas C (2016) The impact of dose calculation algorıthms for perıpheral dose dıstrıbutıons of enhanced dynamıc and physıcal wedges. *Int J Radiat Res, **14**(1): 17-24*.
32. Kumar R, Kar DC, Sharma SD, Mayya YS (2012) Design, implementation and validation of a motorized wedge filter for a telecobalt machine (Bhabhatron-II). *Phys Med, **28**(1): 54-60*.
33. Das IJ, Ding GX, Ahnesjö A (2008) Small fields: nonequilibrium radiation dosimetry. *Med Phys, **35**(1): 206-15*.
34. Shalek RJ (1977) Determination of Absorbed Dose in a Patient Irradiated by Beams of X or Gamma Rays in Radiotherapy Procedures. *Med Phys, **4**: 461*.
35. Maqbool M and Ahmad I (2007) Spectroscopy of gadolinium ion and disadvantages of gadolinium impurity in tissue compensators and collimators, used in radiation treatment planning. *Spectrosc, **21**: 581949*.
36. Berris T, Mazonakis M, Stratakis J, *et al.* (2013) Calculation of organ doses from breast cancer radiotherapy: a Monte Carlo study. *J Appl Clin Med Phys, **14**(1): 4029*.
37. Howell RM, Scarboro SB, Taddei PJ, *et al.* (2010) Methodology for determining doses to in-field, out-of-field and partially in-field organs for late effects studies in photon radiotherapy. *Phys Med Biol, **55**(23): 7009-23*.
38. Venselaar J, Welleweerd H, Mijnheer B (2001) Tolerances for the accuracy of photon beam dose calculations of treatment planning systems. *Radiother Oncol, **60**(2): 191-201*.
39. Wang L and Ding GX (2018) Estimating the uncertainty of calculated out-of-field organ dose from a commercial treatment planning system. *J Appl Clin Med Phys, **19**(4): 319-24*.
40. Fraass B, Doppke K, Hunt M, *et al.* (1998) American Association of Physicists in Medicine Radiation Therapy Committee Task Group 53: quality assurance for clinical radiotherapy treatment planning. *Med Phys, **25**(10): 1773-829*.
41. Nath R, Biggs PJ, Bova FJ, *et al.* (1994) AAPM code of practice for radiotherapy accelerators: report of AAPM Radiation Therapy Task Group No. 45. *Med Phys, **21**(7): 1093-121*.
42. Pasquino M, Borca VC, Tofani S, Ozzello F (2009) Verification of varian enhanced dynamic wedge implementation in MasterPlan treatment planning system. *J Appl Clin Med Phys, **10**(2): 11-20*.
43. Anon (1987) Determination of absorbed dose in a patient irradiated by beams of X or gamma rays in radiotherapy procedures ICRU report 24. United States: ICRU; 1987.

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