Original Article

Implementation and Validation of Anisotropic Analytical Algorithm in Eclipse Treatment Planning System for Indigenous Telecobalt Machine (Bhabhatron II)

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Abstract

Background: The photon dose calculation model anisotropic analytical algorithm (AAA) available with eclipse integrated treatment planning system (TPS) (Varian) supports telecobalt dose calculation from Version 13.6 onward. Formerly, pencil beam convolution (PBC) was used for modeling telecobalt machines. Eclipse TPS no longer supports PBC dose calculation algorithm in v13.6 and above. The AAA dose calculation model is a three-dimensional PBC/superposition algorithm. Its configuration is based on Monte-Carlo-determined basic physical parameters that are tailored to measured clinical beam data. **Aim:** The study investigated the feasibility of clinical implementation of AAA in Eclipse TPS for Bhabhatron II. **Materials and Methods:** The indigenous telecobalt machine, Bhabhatron II, was configured as a generic machine because an inbuilt machine model for the same was not available in Varian Eclipse TPS algorithm library. In such a scenario, it was necessary to evaluate and validate dosimetric parameters of the TPS because improper tailoring would cause errors in dose calculations. Beam data measurements of the machine were carried out which were used for configuration of the algorithm. **Result:** After successful configuration, a variety of plans created in TPS were executed on the machine and subsequently evaluated. **Conclusion:** From this study, we concluded that AAA-based dose calculation in TPS is very well suited for accurate dose calculations for telecobalt machine and can be implemented for clinical use.

Keywords: Anisotropic analytical algorithm, Bhabhatron II, percentage depth dose, telecobalt, treatment planning system

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Introduction

Telecobalt units are still widely used in many developing countries for cancer treatment and are preferred over medical linear accelerators (linacs) because of its modest cost, reduced maintenance charges, lower power requirements, ease of operation, and usually lesser down time.[1] In most of these centers, patient treatment is done on the basis of manually calculated treatment time, depicting the dose to a point (usually the tumor center), primarily on the central axis. Visualizing the dose distribution on the patient computed tomography (CT) in a treatment planning system (TPS) can give much more information to help us make the correct choices regarding different aspects of a plan. It also helps us to predict the toxicities which the patient might encounter during or after the course of treatment.

The Bhabhatron II Tungsten, Asymmetric, motorized Wedge (TAW) is an indigenously produced, IEC (60601-2-11) compliant, affordable telecobalt machine which possesses advanced features such as asymmetric jaw, motorized wedge, and programmable control console as compared to its other conventional counterparts.[2-7] A separate vendor-specific TPS was not purchased with Bhabhatron by the institute.

Varian Eclipse anisotropic analytical dose calculation algorithm (AAA) (Version 15.6.06) is a Type B algorithm which supports the use of cobalt treatment units in external beam planning and IRREG two-dimensional (2D) planning.[8]

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It also allows the configuration of blocks and standard wedges for cobalt treatment units.

The AAA model for dose calculation comprises two key components, the configuration algorithm and the dose calculation algorithm.

The configuration algorithm determines the fundamental physical parameters such as photon energy spectrum, mean radial energy, and scatter kernels, which characterizes the photon and electron fluence and their energy spectra in the treatment beam.[9] Determining all these required parameters through measurements is not practically possible. Hence, AAA uses Monte Carlo precalculated parameters which are then modified according to measured data. These parameters are then stored after completion of configuration process, for retrieval during the dose calculation process.

The dose calculation algorithm uses a separate convolution model for primary photons, scattered extra-focal photons, and electrons scattered from the beam-limiting devices. To apply convolutions, the clinical broad beam is divided into small, finite-sized beamlets. The cross-section of the beamlet is the calculation voxel resolution. The final dose distribution is obtained by the superposition of the dose calculated with photon and electron convolutions for the individual beamlets.

All model parameters for AAA are computed in a water-equivalent medium.[10] While performing dose distribution calculation, to account for heterogeneity in media, density scaling according to patient tissue is done.

This study aimed to evaluate accuracy and clinical implementation of AAA in Eclipse TPS for the indigenous telecobalt machine.

Materials and Methods

The modeled telecobalt machine was a Bhabhatron II TAW (Panacea Medical technologies Pvt. Ltd.). It housed a cobalt-60 source of 2.3 cm diameter and 3.7 cm length with activity 9147.8 Ci as loaded on August 02, 2019, which had an output of 290.47 cGy/min on August 22, 2019. The output is the central axis dose, at the depth of dose maxima in a 10 cm × 10 cm square field at 80 cm source-to-axis distance (SAD). The specified maximum capacity of the machine was 250 roentgen per minute at 1 m. The Bhabhatron II had asymmetric Y jaws, symmetric X jaws, and a motorized wedge of 60°. The available field sizes were from 3 cm × 3 cm to 35 cm × 35 cm at the normal treatment distance of 80 cm. A set of manual/physical wedge filters of various wedge angles 15°, 30°, 45°, and 60° were also provided.

Beam data acquisition

Different beam data measurements, as detailed in Table 1, were performed as per requirement of Eclipse AAA algorithm.

Beam configuration

The measured depth dose curves, cross line profiles, diagonal profiles, and output factors (S_{cp}) for both open and wedged fields were imported into Eclipse to calculate beam data for the anisotropic analytical algorithm (AAA Version 15.6.06 Varian Medical Systems). The grid size used for the calculation of configured data was 2.5 mm. In Eclipse, the configuration of telecobalt was done as a generic machine. This enables the algorithm to draw generic parameters from a library built from Monte Carlo simulations of the treatment head for configuring the machine. These generic parameters are then used by configuration algorithm to build a phase space which is consistent with the measured data and that will be used for clinical calculations.

For cobalt source, effective spot size is larger than linear accelerator. The spot size effects the penumbral width. These parameters were adjusted and fine-tuned so as to match calculated and measured beam profiles.

The timer setting for cobalt fields was determined based on the reference dose and time required to deliver that reference dose at the calibration date, which was thereafter corrected for decay.

Couch modelling

A CT scan of the carbon fiber couch provided with Bhabhatron was taken and its Hounsfield Unit (HU) value at different parts was evaluated. The couch transmission factor was also measured at different parts of the treatment couch. After analyzing these data, a couch was modeled in the TPS as a support structure with a HU value of –780.

The modeled couch was inserted as a support structure in patient-specific plans and the resulting TPS dose was compared with manual calculation and measurement.

Beam data verification

To compare the measured data with configured data, in beam analysis window, beam data were calculated with 2.5 mm calculation grid size.

A variety of dose comparison tests, as detailed below,[11] were conducted to verify the treatment planning accuracy.

Point dose verification

A virtual phantom of 40 cm × 40 cm × 40 cm (1 g/cc density) was created in the TPS for validation. Different plans were created on virtual phantom to compare treatment time provided by TPS with manually calculated treatment time from measured data. This was done at multiple depths for a normalized dose of 100 cGy at the reference depths.

A CT of combination of slab phantom (HE Solid water; Gammex, USA) (30 cm × 30 cm × 20 cm) was taken with a 0.125cc (SNC 125c™; Sun Nuclear Corp, USA) chamber placed at 10 cm depth. Different plans of multiple field sizes, symmetric, asymmetric, wedged, open, and extended SSD (90 cm and 100 cm) were created in TPS on this CT. This ensured that the basic parameters of dose computation process were evaluated for different beam configurations.[12] All plans were calculated using AAA algorithm. All these plans were then irradiated on identical setup on the machine. The measured doses were then compared with the doses depicted in TPS.

Table 1: Details of beam data measurements performed for configuring anisotropic analytical algorithm

Measured parameter	Irradiation geometry used	Phantom/detector used
PDD	All measurements in SSD setup (SSD=80 cm) Open field sizes: 5 cm × 5 cm, 6 cm × 6 cm, 8 cm × 8 cm, 10 cm × 10 cm, 12 cm × 12 cm, 15 cm × 15 cm, 20 cm × 20 cm, 25 cm × 25 cm, 30 cm × 30 cm, and 35 cm × 35 cm Wedged field sizes: 5 cm × 5 cm, 6 cm × 6 cm, 8 cm × 8 cm, 10 cm × 10 cm, 12 cm × 12 cm, 15 cm × 15 cm, 20 cm × 15 cm for each available wedge angle i.e., 15°, 30°, 45° and 60°	RFA (Sun Nuclear Corporation, USA; 3D scanner) 0.125 cc cylindrical ion chamber (SNC 125c™; Sun Nuclear Corp, USA) both field chamber and reference chamber
Profiles	All measurements in SSD setup (SSD=80 cm) Crossline profiles: For each of the above-mentioned open field sizes at D_{max}, 5 cm, 10 cm, 20 cm, and 30 cm Diagonal profiles: For field size 35 cm × 35 cm at D_{max}, 5 cm, 10 cm, 20 cm, and 30 cm Crossline profiles: For each of the above-mentioned wedged field sizes, for each available wedge angle at D_{max}, 5 cm, 10 cm, 20 cm, and 30 cm Inline profiles: For maximum available square field (15 cm × 15 cm) at 5 cm depth (mandatory requirement for wedges to account for the hardening effect of wedges on profiles) for all available wedge angles	
Output factor (Scp) Ratio of the CAX dose for a given field size to that of the reference field size of 10 cm × 10 cm at a reference depth	All measurements in SSD setup (SSD=80 cm) and at 5 cm depth in central axis Open fields: For square and rectangular field sizes as per TPS requirements from 5 cm × 5 cm to 35 cm × 35 cm Wedged fields: For square and rectangular field sizes as per TPS requirement from 5 cm x5 cm up to maximum wedged field size i.e., 15W × 20	RFA (Sun Nuclear Corporation, USA; 3D scanner) 0.125 cc cylindrical ion chamber (SNC 125c™; Sun Nuclear Corp, USA)
Reference dose	Field size: 10 cm × 10 cm; 5 cm depth in central axis; SSD setup (SSD=80 cm); Irradiation time kept as 1.00 min	1D water phantom (SNC 1D scanner) Farmer-type chamber with 0.6 cc volume (SNC600c™)

AAA: Anisotropic analytical algorithm, PDD: Percentage depth dose, CAX: Central axis, SSD: Source-to-surface distance, RFA: Radiation field analyser, SNC: Sun nuclear corporation

A custom-made phantom [Figure 1] was used to perform measurements in inhomogeneous media. The nonwater equivalent inhomogeneous part was made using thermocol (mean HU value –930 HU), wax, and white cement (mean HU value of –80 HU and 1400 HU, respectively). Its dimension was about 29 cm × 24 cm × 7.8 cm. The chamber slab of SNC 125c was kept just below this unit. A backscatter of 9 cm was placed below the chamber slab. Above the thermocol unit, a build-up slab of 1 cm was kept. The physical depth of measurement was 9.8 cm and the corresponding water equivalent depth was 7.3 cm at central axis. This whole assembly was scanned in CT and different plans of multiple field sizes for both SSD (SSD = 80 cm) and SAD setup were made. Plans were irradiated on machine and the measured dose was compared to TPS predicted dose.

Wedge transmission and output factors

For output factor's comparison, we created plans of different field sizes on the above-mentioned slab phantom normalized to reference point at a depth of 10 cm. The factor was then calculated by dividing the treatment time of a given field with reference field size time. This was then compared with the measured values.

To validate wedge transmission factors, plans were made on the slab phantom in TPS with and without wedges. The created TPS plans were then irradiated on the treatment machine. The measurements were compared with the factors obtained from the TPS.

Patient dose verification

Some patient-specific QA plans were made in TPS on the aforementioned slab phantom. These plans were then irradiated on the machine in the planned setup. The dose measured was then compared with the dose predicted by TPS.

Fluence verification

Verification of fluence was performed using the SNC 2D diode array MapCHECK®3. It consisted of 1527 diode detectors (solid state) with 7.07 mm spacing in an array size of 26 cm × 32 cm. Each detector had an active area of 0.48 mm × 0.48 mm. This array was used with an accessory (MapPHAN) which provided a build-up of 5cm to MapCHECK®3. It is modeled in TPS using a synthetic CT provided by the manufacturer.

Initially, array and dose calibration of MapCHECK®3 was performed, for cobalt energy. Array calibration determined relative sensitivity differences between detectors and stored it as individual correction factor for each detector, whereas absolute dose calibration correlated the counts to the known data establishing the absolute dose calibration factor.

Different open field sizes, various wedged fields, some extended SSD (90 cm and 100 cm) plans, and some half beam

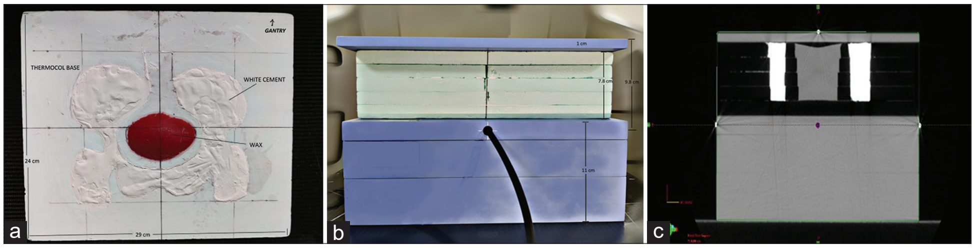

Figure 1: Custom-made inhomogeneous phantom. (a) Top view of inhomogeneous part in phantom. (b) Transverse view of the complete inhomogeneous phantom setup used for measurement. (c) Axial computed tomography image slice

block fields were irradiated on MapCHECK®3 assembly. Some fields with rotated collimator (collimator angle ≠ 0) were also irradiated. The measured dose distribution by the MapCHECK®3 device was compared with the dose distribution calculated by the TPS. The gamma analysis was done using SNC patient software (Sun Nuclear Corporation, USA). Dose distributions were analyzed using gamma criteria[13] of 3% dose difference and 3 mm distance to agreement (DTA) as well as 2% dose difference and 2 mm DTA.

Results

Percentage depth dose and profiles

Figure 2 shows the gamma error histogram for open fields, generated during the optimization process of AAA, for percentage depth dose (PDD) data after and before dmax and for profiles in three regions: inside field/flattened region, penumbra region, and outside field/umbra region. This compares the calculated data with the processed measured data. The γ index was computed with default setting of DTA = 3 mm and dose difference (d) = 1%. The figure shows a global agreement between measured and the optimized data.

There was also good agreement between TPS calculated and RFA measured PDDs. The mean of difference between TPS calculated and measured PDD at 10cm for different field sizes and their corresponding standard deviation were 0.92 ± 0.3 (Open) [Supplementary Table 1c], 0.45 ± 0.2 (W15), 0.4 ± 0.1 (W30), 0.24 ± 0.2 (W45), 0.63 ± 0.1 (W60).

PDD values of different fields from TPS plans were compared to BJR data (Supplement 17)[14] and were found to have a max difference of 0.8% [Supplementary Table 1a and 1b].

Figure 3 shows the configured energy spectrum. AAA configures cobalt machines with a continuous energy spectrum without its characteristic peaks at 1.17 and 1.33 MeV.

The electron contamination curve representing laterally integrated electron contamination doses at different depths was evaluated and was found to be acceptable. As shown in Figure 4, it peaked at surface with a fall-off tail at increasing depth. The smoothing factors for (Sigma values for Gaussian) electron contamination were Sigma 0 = 75.8 and Sigma 1 = 108.29.

Output factors

The Scp for field sizes of 5 cm × 5 cm to 35 cm × 35 cm varied from 0.903 to 1.126 [Supplementary Table 2a]. The Scp for wedged field sizes from 5 cm × 5 cm to 15W × 20 cm varied from 0.895–1.091 (W15) [Supplementary Table 2c], 0.892–1.1 (W30), 0.882–1.116 (W45), and 0.893–1.106 (W60) [Supplementary Table 2e].

The mean of the percentage difference between the RFA measurement and TPS calculated S_{cp} for square and rectangular fields in open and wedged fields were as shown in Table 2.

Couch factor

The difference in couch transmission factor between measurement and TPS model was 0.0098 (1.04%).

Point dose verification

The maximum difference between treatment time predicted by TPS and the manual calculated treatment time (from measured data) for a dose of 100 cGy at different prescribed depths was 1.2 s [Supplementary Table 3].

The mean ± standard deviation of the percentage difference between TPS calculated and measured point doses were 2.83 ± 0.5 [Supplementary Table 5] and 3.88 ± 0.5 for square and rectangular field sizes, respectively, in SSD (SSD = 80 cm) setup, for 10 cm depth. For square field sizes in isocentric setup, it was 3.70 ± 0.7 and for point doses at 10 cm depth in different wedged field sizes, it was 2.93 ± 1.

Measurements in inhomogeneous phantom gave a mean ± standard deviation of the percentage difference between TPS calculated and measured point doses of 2.54 ± 0.5 [Supplementary Table 4] and 2.74 ± 0.8 for SSD (SSD = 80 cm) and SAD setup, respectively.

Wedge transmission and output factors

The mean of percentage differences between TPS calculated and measured wedge transmission factors for different field sizes were 0.46 ± 0.6 [Supplementary Table 5], 0.11 ± 0.7, 0.64 ± 0.6 and 0.49 ± 1.1 for W15°, W30°, W45°, and W60°, respectively. For open field, output factor at 10 cm depth, it was 0.46 ± 0.57 for SSD (SSD = 80cm) setup and 0.51 ± 0.75 for SAD setup.

Patient dose verification

A maximum difference of 1.2 s was found between manually calculated and TPS calculated treatment times for a dose of 100 cGy irrespective of setup. The statistical mode of the differences was 0.6 s.

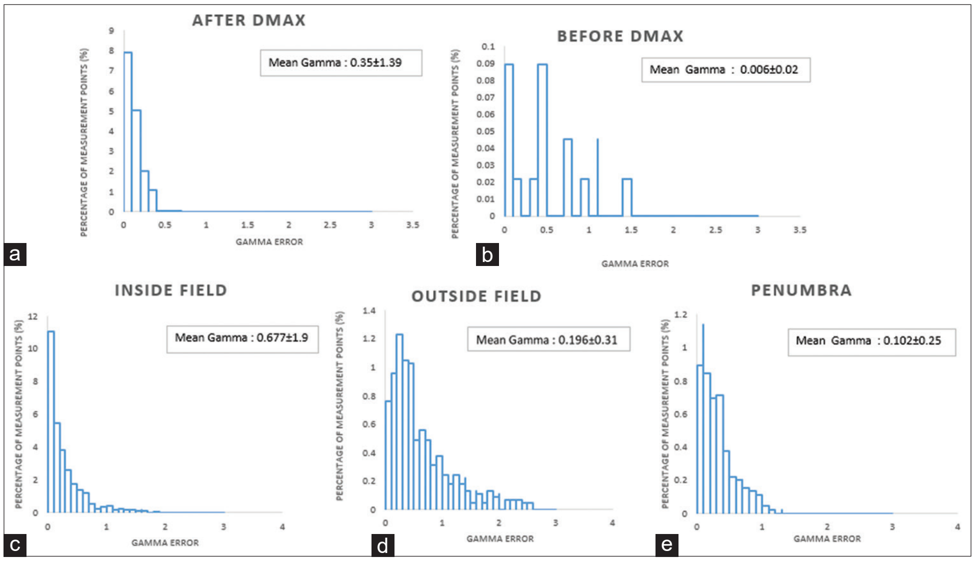

Figure 2: Gamma error histogram for open fields (a) PDD after Dmax; (b) PDD before Dmax; (c) Profiles inside field; (d) Profiles outside field; (e) Profiles in penumbra

Table 2: The mean±standard deviation of percentage difference between RFA measured and calculated output factors for different field sizes of open and wedged fields

	Open (%)	W15 (%)	W30 (%)	W45 (%)	W60 (%)
Square fields	0.02±0.09	0.12±0.2	0.24±0.2	0.05±0.1	0.21±0.2
Rectangular fields	0.008±0.09	0.03±0.7	0.04±0.9	0.02±0.6	0.13±0.6

RFA: Radiation field analyser

Table 3: Mean gamma pass rate, standard deviation, maximum gamma pass rate, and minimum gamma pass rate of different field sizes for open and wedged fields

Test	Mean gamma pass rate (%)±SD	Maximum gamma pass rate (%)	Minimum gamma pass rate (%)
Open beam	98.02±1.4	99.5	94.6
W15	99.08±0.4	99.5	98.6
W30	99.15±0.3	99.5	98.8
W45	99.00±0.5	99.5	98.4
W60	99.20±0.2	99.5	99.1

SD: Standard deviation

Fluence verification

Table 3 shows the results from MapCHECK®3 irradiation measurements. The table includes the mean of gamma pass rate for measurement of various field sizes, its standard deviation, maximum and minimum gamma pass rates. The mean gamma percentage was calculated as the averages of per-field gamma pass percentage. The tolerance for gamma evaluation was kept as dose difference of 3% and a DTA of 3 mm.

Discussion

The machine was configured as a generic machine because an inbuilt machine model for Bhabhatron II was not available in Varian Eclipse TPS algorithm library. The Monte-Carlo precalculated fundamental parameters are not now specific to any machine model. Thus, an inherent possibility of discrepancy exists between the measured data and calculated output values. These differences may be either due to intrinsic approximations or limitations of the model or due to insufficient optimization/tailoring of the fundamental physical parameters in the configuration phase.[9]

From data summarized in this paper, there is a good agreement between measured and computed data. The deviations observed are within acceptable range. During configuration, the algorithm calculates the gamma index with an inbuilt setting (1%, 3 mm) and the mean gamma was found to be within 1. The PDD value at 10 cm depth and S_{cp} for open and wedged fields is within 1%. The point dose differences for open and wedged field widths are within 4%. A systematic under estimation of absolute point dose prediction is observed in the TPS. Although the AAPM Task group 53[15] in its report recommends a tolerance criterion of 1.5% for central axis doses in rectangular fields, a higher difference was accepted keeping in view the simple planning conditions prevalent for cobalt machine in the institute. It was observed that if no heterogeneity correction was applied, the dose difference between measured and TPS calculated value systematically reduces, thus implying that there is an under estimation of scatter contribution (about 2% on an average) by the algorithm for any kind of heterogeneous media. The mean gamma passing rate with 3% dose difference and 3 mm DTA is more than 95% for the most of the cases.

The minimum modeled (and clinically used) field size in TPS was restricted to 5 cm × 5 cm, as smaller field sizes, although physically possible in machine, introduce more measurement errors and modeling them using generic machine parameter would have increased the deviations to unacceptable values.

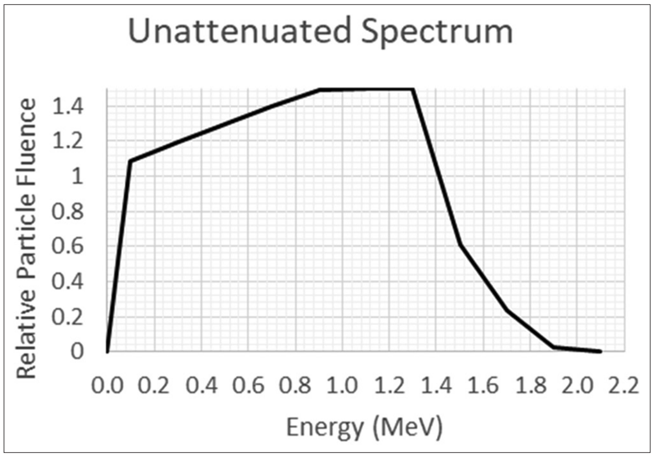

Figure 3: The configured energy spectrum of the source

The maximum modeled field size was 35 cm × 35 cm, which was the largest possible physical field size.

For each wedge angle, other than 15°, the machine has two wedges: one for smaller field sizes (5 cm × 5 cm–16 cm × 10 cm) and another for larger field sizes (used for field sizes between 16 cm × 10 cm and 20 cm × 15 cm). For such wedge angles, only the wedge pertaining to the largest field size was modeled in TPS as for a given wedge angle, multiple wedges cannot be modeled in Eclipse planning system in a single beam model.

The beam data for cobalt can also be used for IRREG planning workspace in which planning can be done on 2D images or without using any images. The algorithm calculates treatment time according to the dose per field, field size, and depth information provided. The manually calculated treatment time matched with the TPS provided in the limited trials conducted by us.

The implementation of AAA-based dose calculation in TPS for Bhabhatron was done in our institute. It has helped in visualizing and ensuring sufficient dose coverage for many palliative spine treatments. Decisions about appropriate wedge angle to be used in anterolateral head-and-neck treatments have been made easy. A case of glioblastoma with vertex (noncoplanar) beam was treated, in which the couch rotation and gantry angle were decided based on the optimum dose distribution in the TPS. Chest wall treatments are done using bitangential fields with gantry angle, field sizes, and depths decided based on dose coverage seen in TPS.

Conclusion

The Bhabhatron II TAW was successfully modeled in the Varian Eclipse TPS using AAA dose calculation algorithm. Multiple complementary as well as redundant verifications of beam data were carried out and were found satisfactory.

Our study suggests that the Varian AAA for Bhabhatron II TAW is suitable for clinical use. This will help to visualize the dose distribution and plan the treatment more efficiently which is the need of the hour of modern era. The implementation of AAA-based dose calculation in TPS is very well suited for accurate radiation therapy treatment planning and its clinical usage will minimize the uncertainties in delivery.

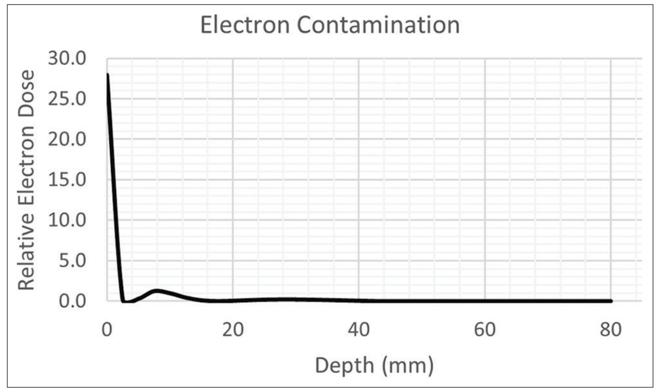

Figure 4: The electron contamination curve

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Conflicts of interest

There are no conflicts of interest.

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Supplementary: Data

Supplementary Table 1a: Percentage depth dose data: Symmetric field sizes

Energy	Field size (cm × cm)	Depth, d (cm)	TPS CALCULATED	BJR data (SUPP 17)	Var (%) (TPS vs. BJR)	Measured data (RFA)	Var (%) (TPS vs. RFA)
1.25X	5×5	5	74.90	75.2	−0.30	75.30	−0.40
		10	50.80	51.2	−0.40	51.22	−0.42
		15	34.07	34.5	−0.43	34.30	−0.23
		20	22.90	23.2	−0.30	23.03	−0.13
	10×10	5	78.07	78.8	−0.73	78.40	−0.33
		10	55.86	56.4	−0.54	56.30	−0.44
		15	39.15	39.4	−0.25	39.20	−0.05
		20	27.30	27.4	−0.10	27.20	0.10
	30×30	5	81.65	82.1	−0.45	81.50	0.15
		10	62.20	62.6	−0.40	62.02	0.18
		15	46.10	46.9	−0.80	46.20	−0.10
		20	33.90	34.7	−0.80	34.03	−0.13

max variation. TPS: Treatment planning system, BJR:British journal of radiology, RFA: Radiation field analyser

Supplementary Table 1b: Percentage depth dose data: Asymmetric field sizes

Energy	Field size (cm×cm)	Depth, d (cm)	TPS calculated	BJR (REF) (equivalent field size)	Var (%) (TPS vs. BJR)	Measured data (RFA)	Var (%) (TPS vs. RFA)
1.25X	5×10	5	76.79	76.83	−0.04	76.50	0.29
		7	66.49	66.70	−0.21	66.30	0.19
		10	53.14	53.41	−0.27	53.13	0.01
		15	36.26	36.40	−0.14	36.21	0.05
	5×25	5	78.23	77.95	0.28	77.40	0.83
		7	68.19	68.11	0.08	67.50	0.69
		10	55.03	55.07	−0.04	54.50	0.53
		15	38.06	37.87	0.19	37.80	0.26
	10×15	5	80.24	79.50	0.74	79.10	1.14
		7	70.88	70.30	0.58	69.85	1.03
		10	58.24	57.70	0.54	57.32	0.92
		15	41.23	40.80	0.43	40.60	0.63
	10×20	5	80.53	79.86	0.67	79.60	0.93
		7	71.31	70.82	0.49	70.30	1.01
		10	58.86	58.35	0.51	57.90	0.96
		15	41.95	41.55	0.40	41.30	0.65
	15×10	5	80.19	79.50	0.69	78.99	1.20
		7	70.80	70.30	0.50	69.90	0.90
		10	58.19	57.70	0.49	57.40	0.79
		15	41.27	40.80	0.47	40.60	0.67
	15×20	5	81.79	80.72	1.07	80.90	0.89
		7	72.93	71.96	0.97	71.60	1.33
		10	60.40	59.87	0.53	59.50	0.90
		15	43.99	43.34	0.65	43.20	0.79
	25×5	5	77.80	77.95	−0.15	77.10	0.70
		7	67.80	68.11	−0.31	67.30	0.50
		10	54.73	55.07	−0.34	54.30	0.43
		15	37.89	37.87	0.02	37.60	0.29

TPS: Treatment planning system, BJR: British journal of radiology, RFA: Radiation field analyser

Supplementary Table 1c: Percentage depth dose data: Depth wise percentage depth dose for open fields

FIELD SIZE (cm)→		5	6	8	10	12	15	20	25	30	35		
DEPTH (cm)↓													
Configured	1	99.70	99.77	99.91	99.93	99.96	99.99	100.01	100.01	100.01	100.01		
Measured		97.50	97.60	97.50	97.80	97.80	98.00	97.90	98.20	98.00	98.00		
Difference		**2.20**	**2.17**	**2.41**	**2.13**	**2.16**	**1.99**	**2.11**	**1.81**	**2.01**	**2.01**		
Configured	2	94.37	94.61	95.05	95.26	95.41	95.57	95.68	95.58	95.37	95.16		
Measured		92.05	92.52	92.75	93.22	93.45	93.75	93.89	94.08	94.08	94.18		
Difference		**2.32**	**2.09**	**2.30**	**2.04**	**1.96**	**1.82**	**1.79**	**1.50**	**1.29**	**0.98**		
Configured	3	88.38	88.88	89.73	90.22	90.57	90.99	91.45	91.64	91.64	91.54		
Measured		86.35	86.95	87.52	88.08	88.68	89.08	89.45	89.82	89.85	90.03		
Difference		**2.03**	**1.94**	**2.21**	**2.13**	**1.89**	**1.91**	**2.00**	**1.82**	**1.78**	**1.51**		
Configured	4	82.51	83.27	84.44	85.17	85.70	86.28	86.93	87.25	87.34			
Measured		80.64	81.44	82.36	83.35	84.03	84.60	85.10	85.62	85.65			
Difference		**1.88**	**1.83**	**2.07**	**1.81**	**1.67**	**1.68**	**1.83**	**1.63**	**1.70**			
Configured	5	76.77	77.73	79.20	80.18	80.89	81.66	82.47	82.89	83.06			
Measured		74.98	75.95	77.29	78.81	79.68	80.31	81.10	81.39	81.59			
Difference		**1.79**	**1.78**	**1.91**	**1.37**	**1.21**	**1.35**	**1.37**	**1.50**	**1.47**			
Configured	10	52.01	53.38	55.68	57.42	58.78	60.35	61.98	62.87	63.32		Mean	0.92
Measured		50.95	52.15	54.39	56.78	58.31	59.77	61.09	61.77	62.31		STDV	0.2943
Difference		**1.05**	**1.23**	**1.29**	**0.64**	**0.47**	**0.58**	**0.89**	**1.10**	**1.01**			
Configured	15	34.88	36.22	38.51	40.32	41.76	43.45	45.30	46.38	47.00	47.34		
Measured		34.19	35.33	37.39	39.15	40.59	42.29	44.13	45.43	46.29	46.73		
Difference		**0.68**	**0.89**	**1.12**	**1.17**	**1.17**	**1.16**	**1.18**	**0.96**	**0.71**	**0.61**		
Configured	20	23.41	24.53	26.45	28.01	29.29	30.81	32.58	33.68	34.36	34.77		
Measured		22.94	23.81	25.57	27.14	28.37	29.94	31.94	33.21	34.11	34.67		
Difference		**0.47**	**0.72**	**0.88**	**0.87**	**0.92**	**0.87**	**0.64**	**0.47**	**0.25**	**0.10**		
Configured	25	15.79	16.66	18.20	19.46	20.51	21.80	23.36	24.37	25.03	25.45		
Measured		15.50	16.07	17.50	18.67	19.80	21.14	22.87	24.18	24.94	25.44		
Difference		**0.29**	**0.59**	**0.70**	**0.79**	**0.71**	**0.66**	**0.49**	**0.19**	**0.09**	**0.01**		
Configured	30	10.67	11.34	12.52	13.52	14.36	15.41	16.70	17.58	18.16			
Measured		10.40	11.01	11.97	12.90	13.77	14.90	16.34	17.30	18.10			
Difference		**0.27**	**0.33**	**0.55**	**0.62**	**0.59**	**0.51**	**0.36**	**0.28**	**0.06**			

Supplementary Table 2a: Output and wedge factor: Output factor (open square field)

RFA measurements done with SNC 125c chamber

Depth of measurement: 5 cm

TPS calculation done in virtual phantom

Field size (cm × cm)	TPS calculated treatment time for 100 cGy	TPS calculated output factor	Measured (RFA)	Variation (%)
5×5	1.167	0.904	0.903	0.1138
6×6	1.133	0.931	0.930	0.1243
8×8	1.088	0.970	0.971	−0.1371
10×10	1.055	1.000	1.000	0.0000
12×12	1.03	1.024	1.024	0.0265
15×15	1.003	1.052	1.051	0.0803
20×20	0.972	1.085	1.085	0.0360
25×25	0.954	1.106	1.107	−0.1021
30×30	0.942	1.120	1.119	0.0856
35×35	0.937	1.126	1.126	−0.0059
			Average	0.02
			SD	0.09

Value quoted in manuscript text. SD: Standard deviation, TPS: Treatment planning system, RFA: RAdiation field analyser

Supplementary Table 2b: Output and wedge factor: Output factor (open rectangular field)

Field size (cm × cm)	TPS calculated treatment time for 100 cGy	TPS calculated output factor	Measured (RFA)	Variation (%)
10×15	1.032	1.022	1.022	0.0281
5×25	1.087	0.971	0.972	−0.1480
15×10	1.03	1.024	1.024	0.0265
10×10	1.055	1.000	1.000	0.0000
20×15	0.989	1.067	1.066	0.0689
5×15	1.098	0.961	0.96	0.0873
30×5	1.083	0.974	0.974	0.0150
5×20	1.092	0.966	0.965	0.1158
10×12	1.043	1.012	1.011	0.0500
8×12	1.061	0.994	0.996	−0.1662
			Average	0.008
			SD	0.09

value quoted in manuscript text. SD: Standard deviation, TPS: Treatment planning system, RFA: RAdiation FIeld Analyser

Supplementary Table 2c: Output and wedge factor: Wedge factor (square field), 15 degree

Field size (cm × cm)	TPS calculated treatment time for 100 cGy	TPS calculated wedge factor	Measured (RFA)	Variation (%)
5×5	1.76	0.898	0.895	0.3047
6×6	1.71	0.924	0.924	−0.0025
8×8	1.63	0.969	0.968	0.1369
10×10	1.58	1.000	1.000	0.0000
12×12	1.54	1.026	1.027	−0.0999
15×15	1.48	1.068	1.068	−0.0405
20×15	1.44	1.097	1.091	0.5703
			Average	0.12
			SD	0.2

Value quoted in manuscript text. SD: Standard deviation, TPS: Treatment planning system, RFA: Radiation fIeld analyser

Supplementary Table 2d: Output and wedge factor: Wedge factor (rectangular field), 15 degree

Field size (cm × cm)	TPS calculated treatment time for 100 cGy	TPS calculated wedge factor	Measured (RFA)	Variation (%)
10×15	1.54	1.026	1.031	−0.4875
15×10	1.52	1.039	1.030	0.9198
10×10	1.58	1.000	1.000	0.0000
5×15	1.66	0.952	0.957	−0.5426
10×12	1.56	1.013	1.020	−0.7039
8×12	1.59	0.994	0.995	−0.1296
20×5	1.61	0.981	0.970	1.1718
			Average	0.03
			SD	0.7

Value quoted in manuscript text. SD: Standard deviation, TPS: Treatment planning system, RFA: Radiation field analyser

Supplementary Table 2e: Output and wedge factor: Wedge factor (square field), 60 degree

Field size (cm × cm)	TPS calculated treatment time for 100 cGy	TPS calculated wedge factor	Measured (RFA)	Variation (%)
5×5	3.22	0.894	0.893	0.1579
6×6	3.13	0.920	0.919	0.1227
8×8	2.99	0.963	0.962	0.1259
10×10	2.88	1.000	1.000	0.0000
12×12	2.78	1.036	1.034	0.1906
15×15	2.66	1.083	1.079	0.3435
20×15	2.59	1.112	1.106	0.5397
			Average	0.21
			SD	0.2

Value quoted in manuscript text. SD: Standard deviation, TPS: Treatment planning system, RFA: Radiation field analyser

Supplementary Table 2f: Output and wedge factor: Wedge factor (rectangular field), 60 degree

Field size (cm × cm)	TPS calculated treatment time for 100 CGY	TPS calculated wedge factor	Measured (RFA)	Variation (%)
10×15	2.80	1.029	1.034	−0.5250
15×10	2.76	1.043	1.037	0.6247
10×10	2.88	1.000	1.000	0.0000
5×15	3.03	0.950	0.954	−0.3674
10×12	2.83	1.018	1.017	0.0657
8×12	2.90	0.993	0.995	−0.1906
20×5	2.94	0.980	0.967	1.3022
			Average	0.13
			SD	0.6

Value quoted in manuscript text. SD: Standard deviation, TPS: Treatment planning system, RFA: Radiation field analyser

Supplementary Table 3: Treatment planning system validation

Setup details

Date: 02.09.2020
Phantom: Virtual phantom
Set up: SSD
Dose: 100 cGy
Depth: 10 cm

Field size (cm × cm)	Virtual phantom (min)	Manual calculated for 100 cGy (ref) (min)	Difference (min)	Difference (s)
5×5	0.81	0.83	0.020	1.2
7×7	0.75	0.76	0.010	0.6
9×9	0.71	0.71	0.000	0
10×10	0.69	0.70	0.010	0.6
10×10 (colli45)	0.69	0.70	0.010	0.6
10×10 (colli315)	0.69	0.70	0.010	0.6
10×10 (colli90)	0.69	0.70	0.010	0.6
12×12	0.67	0.67	0.000	0
14×14	0.65	0.65	0.000	0
15×15	0.64	0.64	0.000	0
15×15 (colli45)	0.64	0.64	0.000	0
15×15 (colli315)	0.64	0.64	0.000	0
15×15 (colli90)	0.64	0.64	0.000	0
17×17	0.63	0.63	0.000	0
18×18	0.62	0.62	0.000	0
20×20	0.61	0.61	0.000	0
20×20 (colli45)	0.61	0.61	0.000	0
20×20 (colli315)	0.61	0.61	0.000	0
20×20 (colli90)	0.61	0.61	0.000	0
25×25	0.59	0.59	0.000	0
25×25 (colli45)	0.59	0.59	0.000	0
25×25 (colli315)	0.59	0.59	0.000	0
25×25 (colli90)	0.59	0.59	0.000	0
30×30	0.58	0.58	0.000	0
		Average	0.00292	0.175
		SD	0.00538452	

Value quoted in manuscript text. SD: Standard deviation, SSD: Source-to-surface distance

Supplementary Table 4: Inhomogenous phantom measurements

Setup details	
Date: 27.05.2021	TEMP: 22°C
Phantom: Inhomogenous Phantom	P (mbar): 995
Set up: SSD (80 cm)	KTP: 1.018291
Depth: 10 cm	Nd, w: 28.14 cGy/nc
Chamber used: SNC 125C	
PHANTOM : SLAB PHANTOM (10 CM BACKSCATTER + 10CM BUILDUP (7.5 CM CUSTOMISED INHOMOGENEITY)	

Field size (cm × cm)	TPS time (beam on time) (min)	MR1 (nC)	MR2 (nC)	Average MR (nC)	Measured dose (cGy)	TPS dose (cGy)	Variation (%)
5×5	0.79	3.429	3.434	3.4315	98.3287	100	−1.67
7×7	0.74	3.41	3.415	3.4125	97.7842	100	−2.22
8×8	0.72	3.401	3.401	3.4010	97.4547	100	−2.55
9×9	0.7	3.378	3.384	3.3810	96.8816	100	−3.12
10×10	0.69	3.409	3.412	3.4105	97.7269	100	−2.27
12×12	0.66	3.381	3.385	3.3830	96.9389	100	−3.06
14×14	0.65	3.415	3.416	3.4155	97.8702	100	−2.13
15×15	0.64	3.392	3.392	3.3920	97.1968	100	−2.80
17×17	0.63	3.398	3.390	3.3940	97.2541	100	−2.75
20×20	0.62	3.388	3.392	3.3900	97.1395	100	−2.86
						Average	−2.54
						SD	0.5

Value quoted in manuscript text. SD: Standard deviation, SNC: Sun nuclear corporation, SSD: Source-to-surface distance, KTP:Temperature and pressure corrections, TPS: Treatment planning system, MR: Electrometer reading

Supplementary Table 5: Point dose verification (TPS vs. measured)

Setup details		
Date: 12.12.2020	TEMP: 21°C	Chamber used: SNC 125C
Phantom: Slab phantom	P (mbar): 1012	Nd, w: 28.14 cGy/nC
Set up: SSD	KTP 0.997794	
Depth: 10 cm		

Field size (cm × cm)	TPS time (beam on time)	MR1 (nC)	MR2 (nC)	Average MR (nC)	Measured dose (cGy)	TPS dose (cGy)	Variation (%)	Measured factor	TPS dose factor	Variation (%)
5×5	0.99	4.173	4.171	4.172	117.141	113.1	3.45	0.9181	0.9165	−0.17
7×7	0.96	4.377	4.375	4.376	122.869	118.4	3.64	0.9630	0.9595	−0.37
8×8	0.95	4.468	4.465	4.4665	125.410	120.4	3.99	0.9829	0.9757	−0.74
9×9	0.93	4.473	4.471	4.472	125.565	122.2	2.68	0.9842	0.9903	0.62
10×10	0.92	4.545	4.543	4.544	127.586	123.4	3.28	1.0000	1.0000	0.00
12×12	0.9	4.599	4.598	4.5985	129.116	125.3	2.96	1.0120	1.0154	0.34
14×14	0.88	4.625	4.623	4.624	129.832	126.4	2.64	1.0176	1.0243	0.66
15×15	0.87	4.63	4.628	4.629	129.973	126.6	2.59	1.0187	1.0259	0.71
17×17	0.85	4.615	4.613	4.614	129.552	126.7	2.20	1.0154	1.0267	1.12
19×19	0.83	4.588	4.589	4.5885	128.836	126.3	1.97	1.0098	1.0235	1.36
20×20	0.83	4.623	4.621	4.622	129.776	126.0	2.91	1.0172	1.0211	0.38
22×22	0.81	4.575	4.574	4.5745	128.442	125.2	2.52	1.0067	1.0146	0.78
24×24	0.8	4.558	4.557	4.5575	127.965	124.4	2.79	1.0030	1.0081	0.51
25×25	0.79	4.549	4.547	4.548	127.698	123.9	2.97	1.0009	1.0041	0.32
27×27	0.78	4.511	4.51	4.5105	126.646	122.9	2.96	0.9926	0.9959	0.33
29×29	0.77	4.459	4.456	4.4575	125.157	121.8	2.68	0.9810	0.9870	0.62
30×30	0.76	4.403	4.401	4.402	123.599	121.2	1.94	0.9688	0.9822	1.39
						Average	2.83		Average	0.46
						SD	0.5		SD	0.57

Value quoted in manuscript text. SD: Standard deviation, SNC: Sun nuclear corporation, SSD: Source-to-surface distance, KTP:Temperature and pressure corrections, TPS: Treatment planning system, MR: Electrometer reading