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Electron Beam Measurements Employing Electron Montecarlo Algorithm on TrueBeam STx® and Clinac iX® Linear Accelerators

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Abstract

AIM: Electron beam measurement comparison between TrueBeam STx® and Clinac iX® was established.

METHODS: Data evaluation of electron Monte Carlo (eMC)-calculated and measured for TrueBeam STx® was performed. Dosimetric parameters were measured including depth dose curves for each applicator, percentage depth dose (PDD) curves without applicator, the profile in-air for a large field size 40 × 40 cm2, and the absolute dose (cGy/MU) for each applicator using a large water phantom (PTW, Freiburg, Germany), employing Roos and Markus plane-parallel ionization chambers. The data were examined for five electron beams of Varian's TrueBeam STx® and Clinac iX® machines. A comparison between measurement PDDs and calculated by the Eclipse eMC algorithm was performed to validate Truebeam STx® commissioning.

RESULTS: The measured data indicated that electron beam PDDs from the TrueBeam STx® machine are well matched to those from Clinac iX® machine. The quality index R50 for applicator 15 × 15 cm2 was in the tolerance intervals. However, surface dose (Ds) increases with increasing energy for both accelerators. Comparisons between the measured and eMC-calculated values revealed that the R100, R90, R80, and R50 values mostly agree within 5 mm. Measured and calculated bremsstrahlung tail Rp correlates well statistically. Ds agrees mostly within 2%.

CONCLUSION: Electron beams were successfully validated for TrueBeam STx®, a good agreement between modeled and measured data was observed.

Introduction

Radiotherapy using an electron beam is essential in superficial tumors treatment and often finds use in head and neck treatment, chest wall lesions for breast cancer, nodes boost, skin, and lip cancers [1]. Before starting treatment with the linear accelerator, the specialist from the vendor company works corporately with the local radiotherapy physics team during the acceptance procedure, to verify if the technical specification matched the clinical need. Then, the physicist performs the commissioning procedure once the acceptance controls are completed.

The previous algorithms for electron treatment planning were restricted in their calculation aptitude in several situations, such as small field depth dose, and the inaccuracy of the monitor units in the dose prediction in a variety of clinical cases as like backscattering of high-density materials (e.g., bone, air cavities, and other heterogeneities). Thus, Monte Carlo simulation is considered the main algorithm for precise dose calculation with electron beams [2]. It is deemed to be the primordial treatment planning calculation tool [3]. The electron Monte Carlo (eMC) dose calculation algorithm included in the Eclipse treatment-planning system (TPS) (Varian, Palo Alto, CA) is a fast implementation of the Monte Carlo method used for computation of absorbed dose to medium with a high-energy electron beam. The eMC algorithm consists of two models; the first is a transport model based on the Macro Monte Carlo method [4], which simulates the transfer of electrons by calculating the dose deposition on each point. The second one is an initial phase space model, describing the behavior of the electrons and photons that come from the treatment linear accelerator's head. [5].

This study consists of a systemic comparison and analysis between electron beam commissioning measurements parameters on TrueBeam STx® and Clinac iX® (Varian Medical System, USA) linear accelerators installed at the Sheikh Khalifa International University Hospital in Casablanca, Morocco. An evaluation of eMC calculations on Eclipse TPS and

extensive measurements on the TrueBeam STx® linear accelerator was performed [6], [7]. All measurements in this study were done following the recommendations of the AAPM TG-142 [8], TG-106 [9], TG-51 [10], TG-21 [11], TG-25 [12], IAEA TRS-398 protocols [13], and Varian protocols [14], [15] which provided us the guidelines to perform the commissioning operation. Markus and Roos waterproof parallels plates ion chambers (PTW, Freiburg, Germany) and Semiflex (31010) 0.125cm^3 ionization chamber (PTW, Freiburg, Germany) are used for the commissioning employing a three-dimensional scanning system MP3-M water phantom (PTW, Freiburg, Germany). Calculation and measurement agreement can be assigned by several parameters, such as calculation grids, accuracy, and smoothing methods employing measurement data from one or two machines. Previously, published studies stipulated fundamental data on factors related to eMC calculation settings [16], [17], [18], [19], [20], [21], [22], [23], However, the stochastic nature of the Monte Carlo calculation and the certain variations in measurements requires to make comparisons based on data from a group of machines to obtain more reliable results.

Material and Methods

Accelerators and detectors device

At Sheikh Khalifa International University Hospital in Casablanca, Morocco, a linear accelerator Clinac iX® (Varian Medical System, USA) was installed with two photons beams of six and 18 MV energies and five electrons beams of 6, 9, 12, 16, and 20 MeV. Recently, a TrueBeam STx® (Varian Medical System, USA) was installed. This machine consists of 6, 10, 15, and 18 MV photon beams, as well as eight electrons beams of 6, 9, 12, 15, 16, 18, 20, and 22 MeV. In this study, just five electrons beams (6, 9, 12,16, and 20 MeV) from the TrueBeam STx® will be compared to those from Clinac iX®.

All measurements of TrueBeam STx® and Clinac iX® linear accelerators were performed with the PTW MP3-M water phantom scanning dosimetry system (PTW, Freiburg, Germany) with MEPHYSTO (Medical Physics Tool) mc² software (PTW-Freiburg, Germany) [6], [7]. This system includes a phantom made of polymethyl methacrylate. For all performed measurements, the tank is filled with distilled water.

The detectors used for beam data collection and dosimetry measurements were Roos (34001) 0.35cm^3 and Markus (23343) 0.055 cm^3 plan parallel chambers (PTW, Freiburg, Germany) for the central axis depth dose measurement and Semiflex (31010) 0.125cm^3 for the profile measurements.

Commissioning beam data of the TPS

According to the recommendation of the eMC algorithm using Eclipse algorithms reference guide [15], Eclipse TPS (version 13.5) requires four measured beam-specific inputs such as a depth-dose curve for the open field 40 × 40 cm^2 without applicator, a depth-dose curve for each applicator, an in-air profile at 95 cm source to surface distance (SSD) for the open field 40 × 40 cm^2, and the absolute dose in water cGy/MU.

Beam data measurements were performed for TrueBeam STx® linear accelerator and compared with Clinac iX® linear accelerator for electron beams energies E6, E9, E12, E16, and E20 MeV.

For measuring the percentage depth dose (PDD) curve, the field chamber is positioned along the central beam axis from 30 cm depth up to the water phantom surface with 3–5 mm intervals from bottom to top. All results were calculated using the Varian protocol [15]. Linac gantry and collimator are at position 0° during all measurements.

PDD and in-air Profile

PDD

Percentage depth ionization was measured at 100 cm SSD, then converted to PDD using MEPHYSTO (Medical Physics Tool) mc² software (PTW-Freiburg, Germany). PDDs curves were acquired for each applicator and without for the open field size 40 × 40 cm^2 at SSD = 100 cm (Figures 1 and 2).

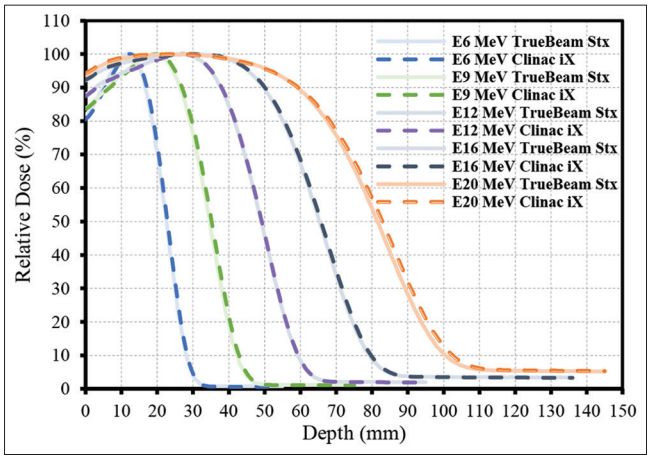

Figure 1: Percentage depth dose graph for applicator 15 × 15 cm^2 using different energies for TrueBeam STx® and Clinac iX®

The depth of maximum dose (R_{100}), therapeutic depth (R_{90}), depth of 80% isodose (R_{80}), and the half-value depth in water (R_{50}) used as the beam quality index for electron beams, the practical range (R_p), and the relative Surface dose (D_s), the dose at 0.5 mm depth. All these parameters were acquired and compared using the relative dose difference (RDD) method (Equation 1).

The RDD method was calculated with the equation 1, where D_m and D_r are, respectively, the measured doses in the Truebeam STx® and the Clinac iX®.

$$RDD(\%) = 100 \times \frac{D_m - D_r}{D_r} \quad (1)$$

The R_{50} is measured for reference field size 15 × 15 cm^2.

In-air profile

In-air dose profiles for open beams are required for beam configuration in the Eclipse eMC TPS.

The in-air profile provides direct electron fluence information and was measured without applicator at 95 cm SSD for the open field size 40 × 40 cm^2 for both Truebeam STx® and Clinac iX® machines.

Measured beam data acquired from MP3 water phantom were converted from MCC format to ASCII format then imported into Eclipse TPS.

Linear interpolation of the eMC dose distribution was used when necessary to match the measurement locations.

Absolute dose in water (cGy/MU)

Absolute dose in water expressed in (cGy/MU) was measured at the reference depth Z_{ref} then extrapolated to give 1 Gy/100 MU at D_{max} and SSD = 100 cm for the reference field size 15 × 15 cm^2 for both machines [13].

Zref, w = 0.6R50−0.1 g cm^{-2} (R_{50} in g cm^{-2}) (2)

Then, the absolute dose was measured and noted for each applicator as well as the large field size 40 × 40 cm^2 without applicator, under the same condition above.

Results

PDD

Figures 1 and 2 show the variation of the PDDs as a function of energy for the reference field 15 × 15 cm^2 and open field size 40 × 40 cm^2.

A typical electron PDD curve is shown in Figure 3.

Table 1 illustrates the measured PDD data comparison using the RDD method for different field sizes of TrueBeam STx® and Clinac iX® linear accelerators.

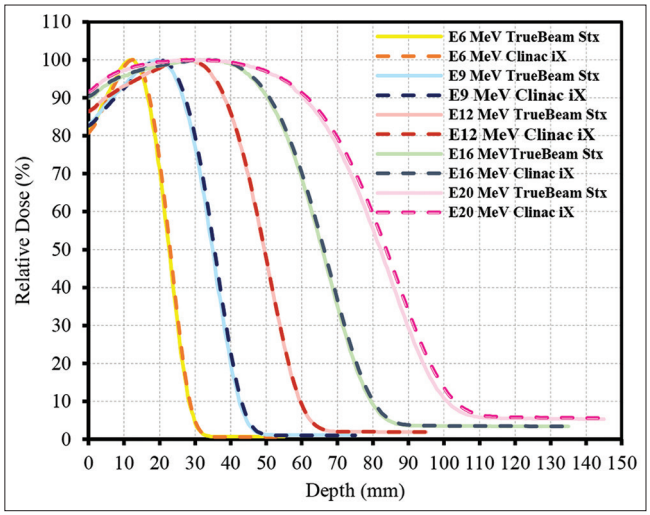

Figure 2: Percentage depth dose graph for field size 40 × 40 cm^2 without applicator using different energies for TrueBeam STx® and Clinac iX®

Maximum depth dose for the TrueBeam STx® and Clinac iX® for the following energies (6, 9, 12, 16, and 20 MeV) presented in Table 1.

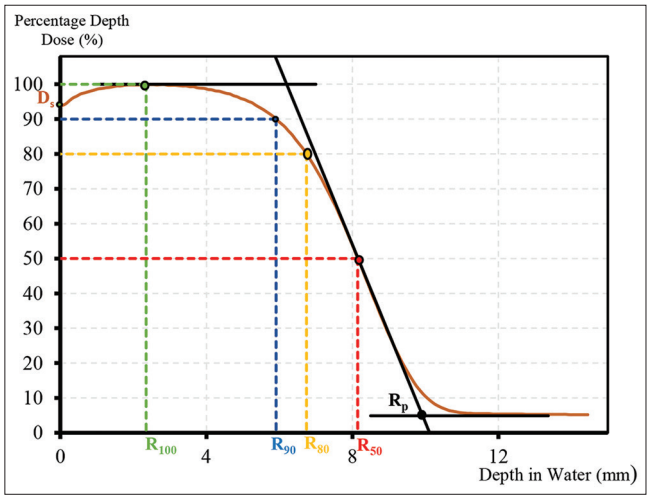

Figure 3: Typical electron percentage depth dose curve

The R_{50} and R_p values for the TrueBeam STx® and the Clinac iX® are almost the same Table 1.

According to the Varian specification, the R_{50} is within the tolerance intervals (R_{50} < 4 g.cm^{-2} for E_0 < 10 MeV and R_{50} > 4 g.cm^{-2} for E_0 >10 MeV).

D_s increases as a function of electron beam energy for both machines TrueBeam STx® and Clinac iX®, (Table 1, Figures 1 and 2).

Figure 4 represents the fitted PDD curves for the reference field 15 × 15 cm^2, using different energies at 100 cm SSD for TrueBeam STx®. The fitted PDD curve corresponds to the PDD measured using PTW water phantom and the eMC generated PDD curve from eclipse TPS.

The mean and the standard deviation RDD of the PDD parameters for the measured and eMC calculated handed out in Table 2.

Table 1: Depth dose parameter for E6, E9, E12, E16, and E20 MeV for TrueBeam STx® and Clinac iX® electron energies for different field sizes applicators measured

Applicator (cm^2)	Depth (mm)	E6			E9			E12			E16			E20		
		TB_{STx}®	CL_{iX}®	RDD (%)	TB_{STx}®	CL_{iX}®	RDD (%)	TB_{STx}®	CL_{iX}®	RDD (%)	TB_{STx}®	CL_{iX}®	RDD (%)	TB_{STx}®	CL_{iX}®	RDD (%)
6×6	R_{100}	12.48	12.01	3.91	18.02	18.99	5.11	25.00	24.47	2.17	24.02	25.50	5.80	18.98	18.00	5.44
	R_{90}	16.85	16.79	0.36	26.41	26.53	0.45	37.01	36.72	0.79	46.39	46.03	0.78	52.25	52.03	0.42
	R_{80}	18.81	18.71	0.53	29.16	29.27	0.38	41.07	40.75	0.79	52.55	52.30	0.48	61.43	61.56	0.21
	R_{50}	22.78	22.59	0.84	34.78	34.88	0.29	49.02	48.60	0.86	64.30	64.03	0.42	78.36	78.93	0.72
	R_p	28.61	28.27	1.20	43.05	42.86	0.44	59.85	59.44	0.69	79.53	79.41	0.15	99.18	100.5	1.31
	D_s	81.32	81.01	0.38	84.12	84.31	0.23	88.97	89.22	0.28	93.28	93.72	0.47	94.97	95.50	0.55
10×10	R_{100}	12.00	12.49	3.92	19.01	19.50	2.51	27.01	27.01	0.00	29.01	29.50	1.66	21.97	19.96	10.07
	R_{90}	16.69	17.05	2.11	26.48	26.86	1.41	37.80	37.86	0.16	49.61	49.82	0.42	57.85	58.03	0.31
	R_{80}	18.58	18.91	1.75	29.14	29.58	1.49	41.61	41.59	0.05	55.03	55.31	0.51	66.72	67.31	0.88
	R_{50}	22.58	22.80	0.96	34.62	35.14	1.48	49.06	49.09	0.06	65.25	65.60	0.53	81.15	82.49	1.62
	R_p	28.45	28.56	0.39	42.47	43.16	1.60	59.51	59.53	0.03	78.89	79.31	0.53	98.57	100.6	1.99
	D_s	81.83	80.73	1.36	83.90	83.65	0.30	87.84	87.87	0.03	92.70	93.06	0.39	94.74	95.15	0.43
15×15	R_{100}	11.53	12.49	7.69	18.98	19.52	2.77	26.00	27.01	3.74	31.00	29.99	3.37	23.52	23.99	1.96
	R_{90}	16.67	17.11	2.57	26.34	26.93	2.19	37.72	37.99	0.71	49.75	50.08	0.66	59.08	59.44	0.61
	R_{80}	18.58	18.94	1.90	29.09	29.67	1.95	41.54	41.74	0.48	55.14	55.53	0.70	67.41	68.27	1.26
	R_{50}	22.69	22.85	0.70	34.64	35.20	1.59	49.10	49.21	0.22	65.31	65.74	0.65	81.47	82.91	1.74
	R_p	28.53	28.63	0.35	42.84	43.25	0.95	59.71	59.66	0.08	78.88	79.34	0.58	98.60	100.9	2.16
	D_s	82.35	81.03	1.63	84.06	83.91	0.18	88.20	87.84	0.41	92.38	92.58	0.22	93.87	94.59	0.76
20×20	R_{100}	12.00	12.03	0.25	19.00	19.97	4.86	26.48	27.00	1.93	30.05	28.51	5.40	22.50	23.51	4.30
	R_{90}	16.64	17.07	2.52	26.50	26.98	1.78	37.80	37.86	0.16	49.67	49.89	0.44	59.06	59.31	0.42
	R_{80}	18.66	18.97	1.63	29.19	29.68	1.65	41.65	41.68	0.07	55.22	55.44	0.40	67.45	68.23	1.14
	R_{50}	22.67	22.86	0.83	34.84	35.26	1.19	49.18	49.21	0.06	65.53	65.77	0.36	81.66	83.00	1.61
	R_p	28.49	28.63	0.49	42.64	43.33	1.59	59.75	59.79	0.07	79.10	79.42	0.40	99.04	100.8	1.71
	D_s	82.66	81.64	1.25	84.68	84.54	0.17	89.26	89.44	0.20	92.82	93.22	0.43	93.90	94.99	1.15
25×25	R_{100}	11.54	12.49	7.61	19.47	19.51	0.21	26.51	26.98	1.74	29.01	31.00	6.42	23.50	21.99	6.87
	R_{90}	16.66	17.11	2.63	26.42	27.01	2.18	37.85	38.03	0.47	49.81	50.13	0.64	59.22	59.69	0.79
	R_{80}	18.63	18.96	1.74	29.17	29.74	1.92	41.67	41.83	0.38	55.34	55.65	0.56	67.68	68.53	1.24
	R_{50}	22.66	22.90	1.05	34.80	35.32	1.47	49.23	49.32	0.18	65.53	65.93	0.61	81.77	83.19	1.71
	R_p	28.67	28.74	0.24	43.03	43.40	0.85	59.75	59.84	0.15	79.18	79.48	0.38	99.05	100.9	1.81
	D_s	83.45	82.03	1.73	85.18	84.58	0.71	89.36	89.39	0.03	92.85	93.37	0.56	94.01	94.38	0.39
40×40*	R_{100}	12.00	12.49	3.92	19.48	20.00	2.60	27.01	27.52	1.85	32.50	33.48	2.93	33.99	29.99	13.34
	R_{90}	16.69	17.15	2.68	26.60	27.22	2.28	38.19	38.38	0.50	50.34	50.93	1.16	60.57	61.59	1.66
	R_{80}	18.67	19.03	1.89	29.30	29.93	2.10	41.91	42.11	0.47	55.73	56.22	0.87	68.36	69.72	1.95
	R_{50}	22.69	22.97	1.22	34.92	35.43	1.44	49.46	49.49	0.06	65.78	66.26	0.72	82.17	83.76	1.90
	R_p	28.69	28.82	0.45	42.61	43.33	1.66	59.76	59.88	0.20	79.28	79.72	0.55	99.18	101.0	1.81
	D_s	82.25	81.31	1.16	83.37	82.94	0.52	86.47	86.68	0.24	90.04	90.53	0.54	91.66	91.91	0.27

*Open field without applicator. RDD: Relative dose difference

Table 3 compares the depth R_{100}, R_{90}, R_{80}, R_{50}, R_p, and D_s of measured and eMC values employing the RDD method.

Table 2: The mean and SD of the RDD for the reference field size applicator 15×15 cm^2 measured and eMC calculated PDD parameters for TrueBeam STx® using different energies

Electron energies (MeV)	E6	E9	E12	E16	E20
RDD Mean (%)	1.21	0.45	−0.91	2.43	−2.47
SD	3.08	0.57	3.31	3.92	8.33

RDD: Relative dose difference, PDD: Percentage depth dose, eMC: Electron Monte Carlo, SD: Standard deviation

In-air profile

Figure 5 performs measured open beam dose in-air profile for beam energies from 6 to 20 MeV for TrueBeam STx® and Clinac iX®.

In-air profile comparison was done employing (RDD) method for Truebeam STx® and Clinac iX®, respectively, (Figure 5 and Table 4).

The results show that the sharpness of these profiles depends on beam energy.

Absolute dose

The absolute dose is ranged from (0.937 to 1.067 Gy) and (0.892 to 1.034 Gy) for the Truebeam STx® and Clinac iX®, respectively, as shown in Tables 5 and 6.

Jaw opening with the applicator for TrueBeam STx® and Clinac iX®

Table 7 tabulated the corresponding jaw opening for clinical electron beam using specific applicators for TrueBeam STx® and Clinac iX® linear accelerators [24].

For each applicator, there is an associated jaw setting that is larger than the field size defined by the applicator. The corresponding jaw opening for TrueBeam STx® and Clinac iX® is not the same for all energies and specific applicators.

Discussion

The PDD is measured for the nominal treatment distance and depends on field size and electron beam energy.

Evaluation of electron beams for TrueBeam STx® and Clinac iX®

Based on results in Table 1 for the reference field size 15 × 15 cm^2, the maximum RDD for R_{100}, R_{90}, R_{80}, R_{50}, R_p, and D_s were, respectively, 7.6, 2.57, 1.95, 1.74, 2.16, and 1.63%.

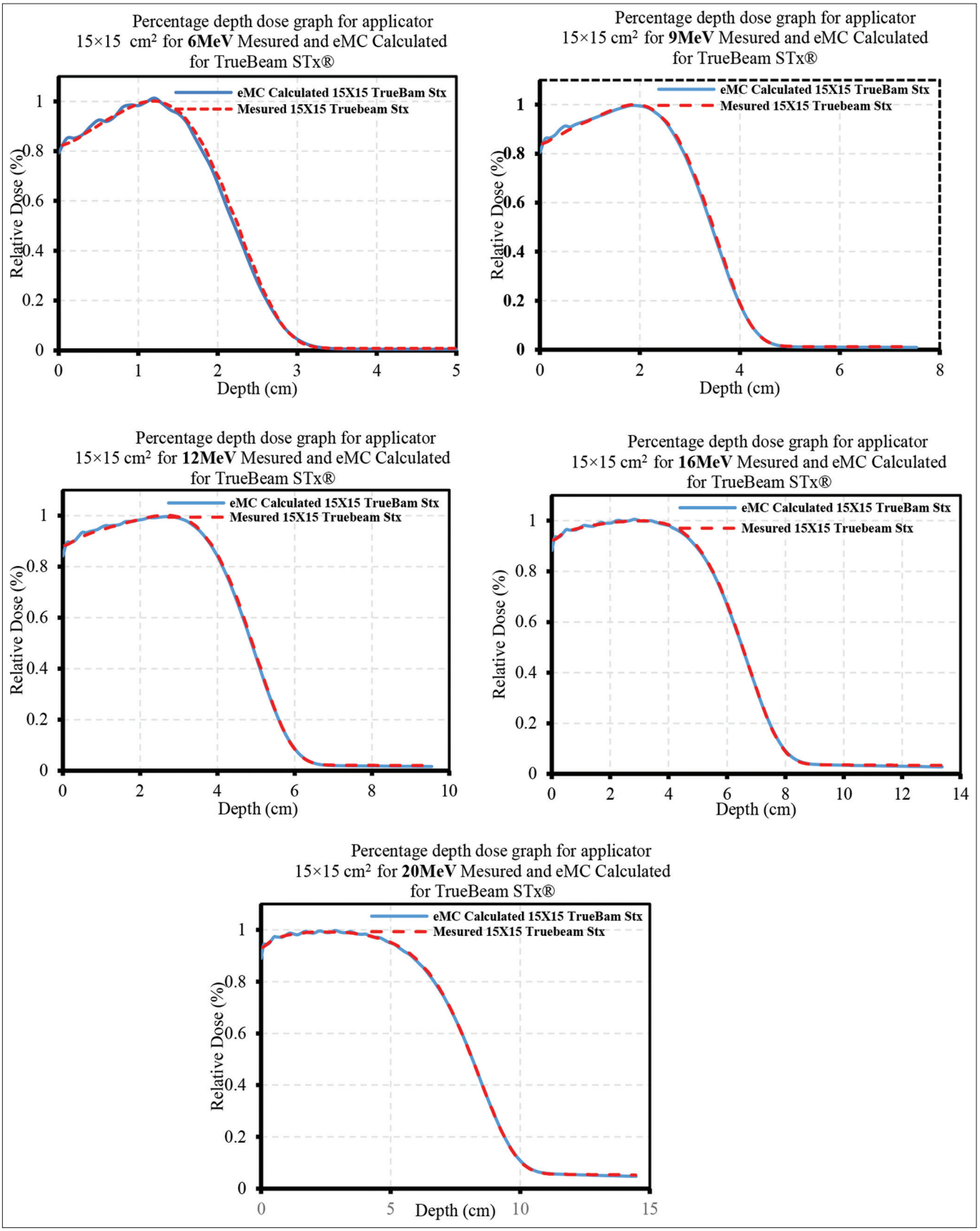

Figure 4: Fitted percentage depth dose graph for applicator 15 × 15cm² measured and eMC calculated for TrueBeam STx® using different energies

For electron beam energies from E9 to E20 MeV, a slight difference between TrueBeam STx® and Clinac iX® was found in in-air profiles for the open field output, can be due to the differences in the electron source, and scattering foil design as well as the change in the bending magnet impacting the incident electron source width.

Table 3: Depth dose parameter for E6. E9. E12. E16, and E20 MeV for TrueBeam STx® for different field sizes applicators measured and eMC calculated

Energy (MeV)	Applicator (cm^2)	R_{100}			R_{90}			R_{80}			R_{50}			Rp			Ds		
		Measured (mm)	eMC (mm)	RDD (%)	Measured (mm)	eMC (mm)	RDD (%)	Measured (mm)	eMC (mm)	RDD (%)	Measured (mm)	eMC (mm)	RDD (%)	Measured (mm)	eMC (mm)	RDD (%)	Measured (mm)	eMC (mm)	RDD (%)
E6	6×6	12.48	12.06	3.48	16.85	16.27	3.56	18.81	18.02	4.38	22.78	22.12	2.98	28.61	28.57	0.14	81.32	80.08	1.55
	10×10	12.00	12.16	−1.32	16.69	16.17	3.22	18.58	17.90	3.80	22.58	22.05	2.40	28.45	28.54	−0.32	81.83	80.74	1.35
	15×15	**11.53**	**12.06**	**−4.39**	**16.67**	**16.15**	**3.22**	**18.58**	**17.88**	**3.91**	**22.69**	**22.03**	**3.00**	**28.53**	**28.52**	**0.04**	**82.35**	**81.13**	**1.50**
	20×20	12.00	12.06	−0.50	16.64	16.21	2.65	18.66	17.97	3.84	22.67	22.11	2.53	28.49	28.59	−0.35	82.66	81.35	1.61
	25×25	11.54	12.06	−4.31	16.66	16.18	2.97	18.63	17.93	3.90	22.66	22.08	2.63	28.67	28.57	0.35	83.45	81.70	2.14
	40×40*	12.00	12.06	−0.50	16.69	16.26	2.64	18.67	18.00	3.72	22.69	22.12	2.58	28.69	28.56	0.46	82.25	80.06	2.74
E9	6×6	18.02	19.10	−5.65	26.41	26.22	0.72	29.16	28.93	0.80	34.78	34.45	0.96	43.05	42.41	1.51	84.12	83.22	1.08
	10×10	19.01	19.10	−0.47	26.48	26.28	0.76	29.14	28.95	0.66	34.62	34.43	0.55	42.47	42.37	0.24	83.90	83.17	0.88
	15×15	**18.98**	**19.10**	**−0.63**	**26.34**	**26.23**	**0.42**	**29.09**	**28.92**	**0.59**	**34.64**	**34.43**	**0.61**	**42.84**	**42.38**	**1.09**	**84.06**	**83.53**	**0.63**
	20×20	19.00	18.09	5.03	26.50	26.21	1.11	29.19	28.11	3.84	34.84	34.43	1.19	42.64	42.38	0.61	84.68	83.63	1.26
	25×25	19.47	18.09	7.63	26.42	26.13	1.11	29.17	28.85	1.11	34.80	34.41	1.13	43.03	42.39	1.51	85.18	83.68	1.79
	40×40*	19.48	20.10	−3.08	26.60	26.66	−0.23	29.30	29.25	0.17	34.92	34.58	0.98	42.61	42.39	0.52	83.37	82.24	1.37
E12	6×6	25.00	22.11	13.07	37.01	37.01	0.00	41.07	41.00	0.17	49.02	48.79	0.47	59.85	59.85	0.00	88.97	87.85	1.27
	10×10	27.01	28.14	−4.02	37.80	37.83	−0.08	41.61	41.51	0.24	49.06	48.95	0.22	59.51	59.64	−0.22	87.84	86.83	1.16
	15×15	**26.00**	**28.14**	**−7.60**	**37.72**	**37.74**	**−0.05**	**41.54**	**41.42**	**0.29**	**49.10**	**48.88**	**0.45**	**59.71**	**59.62**	**0.15**	**88.20**	**87.07**	**1.30**
	20×20	26.48	27.14	−2.43	37.80	37.65	0.40	41.65	41.40	0.60	49.18	48.93	0.51	59.75	59.66	0.15	89.26	87.75	1.72
	25×25	26.51	27.14	−2.32	37.85	37.72	0.34	41.67	41.52	0.36	49.23	49.02	0.43	59.75	59.67	0.13	89.36	87.84	1.73
	40×40*	27.01	28.14	−4.02	38.19	38.62	−1.11	41.91	42.16	−0.59	49.46	49.28	0.37	59.76	59.29	0.79	86.47	84.93	1.81
E16	6×6	24.02	28.14	−14.64	46.39	45.69	1.53	52.55	52.26	0.55	64.30	64.32	−0.03	79.53	80.47	−1.17	93.28	91.23	2.25
	10×10	29.01	28.14	3.09	49.61	48.81	1.64	55.03	54.68	0.64	65.25	65.12	0.20	78.89	79.22	−0.42	92.70	90.64	2.27
	15×15	**31.00**	**28.14**	**10.16**	**49.75**	**48.88**	**1.78**	**55.14**	**54.76**	**0.69**	**65.31**	**65.19**	**0.18**	**78.88**	**79.28**	**−0.50**	**92.38**	**90.34**	**2.26**
	20×20	30.05	28.14	6.79	49.67	48.99	1.39	55.22	54.84	0.69	65.53	65.26	0.41	79.10	79.34	−0.30	92.82	90.65	2.39
	25×25	29.01	28.14	3.09	49.81	49.06	1.53	55.34	54.94	0.73	65.53	65.39	0.21	79.18	78.74	0.56	92.85	90.76	2.30
	40×40*	32.50	28.14	15.49	50.34	49.96	0.76	55.73	55.67	0.11	65.78	65.75	0.05	79.28	78.74	0.69	90.04	88.02	2.29
E20	6×6	18.98	17.09	11.06	52.25	51.63	1.20	61.43	60.82	1.00	78.36	78.27	0.11	99.18	99.09	0.09	94.97	92.62	2.54
	10×10	21.97	17.09	28.55	57.85	57.08	1.35	66.72	66.10	0.94	81.15	81.18	−0.04	98.57	98.49	0.08	94.74	92.49	2.43
	15×15	**23.52**	**29.15**	**−19.31**	**59.08**	**57.97**	**1.91**	**67.41**	**66.76**	**0.97**	**81.47**	**81.49**	**−0.02**	**98.60**	**99.24**	**−0.64**	**93.87**	**91.78**	**2.28**
	20×20	22.50	28.14	−20.04	59.06	58.20	1.48	67.45	66.95	0.75	81.66	81.63	0.04	99.04	99.38	−0.34	93.90	91.93	2.14
	25×25	23.50	28.14	−16.49	59.22	58.43	1.35	67.68	67.14	0.80	81.77	81.82	−0.06	99.05	99.57	−0.52	94.01	92.00	2.18
	40×40*	33.99	29.15	16.60	60.57	59.05	2.57	68.36	67.78	0.86	82.17	82.22	−0.06	99.18	99.67	−0.49	91.66	88.95	3.05

RDD: Relative dose difference, eMC: Electron Monte Carlo

Evaluation of electron beams measured and eMC Calculation for TrueBeam STx®

For the reference field size 15 × 15 cm^2 based on results in Table 3, the maximum shift in R_{100}, R_{90}, R_{80}, R_{50}, and R_p were 5.63, 1.11, 0.7, 0.66, and 0.64 mm, respectively. The variation in the relative surface dose (D_s) was about 2.09%.

Table 4: Average RDD between measured in-air profile for open field size 40×40 cm^2 without applicator for TrueBeam STx® and Clinac iX® accelerators using different energies

Electron energies (MeV)	E6	E9	E12	E16	E20
RDD (%)	−1.75	5.55	2.86	2.44	3.16

RDD: Relative dose difference

The plot of PDD from measured overlaid with those of the eMC calculated plans shows good agreements except for the first 1–3 mm of the surface (Tables 2 and 3).

Bremsstrahlung tail Rp

R_p is the key beam parameter for acceptance and R_{50} is recommended as the beam quality specifier. Close agreement of measured Rp and R50 is not unexpected either between the TrueBeam STx® and Clinac iX®.

The Rp is independent of beam field size, and depends only on electron beam energy. Figure 6 clearly illustrates when the field size is larger than the R_p is about 10 cm for E20 MeV, the PDD curve remains essentially unchanged.

D_s

As the energy increases, D_s increases while R_{100} is rising from lower energy to 16 MeV. Tables 1 and 3 show that D_s slightly increases when the beam energy gets much higher, from E12 to E20 MeV for both machines. However, the lower D_s for the open field was caused by the lack of scattering from the applicator.

Absolute dose

The difference between open and applicator fields is negligible for electron beam energies <12 MeV. However, significant differences exist between absolute dose at 100 cm SSD for open and applicator fields (5.82% for Clinac iX® and 12% for TrueBeam STx®).

In air profile

At 6 MeV, the in-air profile is nearly identical between the machines, otherwise, a difference was found in energies of 9, 12, 16, and 20 MeV, with a maximum of 5.5% in the E9 shoulder region profile (Table 4 and Figure 5).

Lloyd *et al*. [23] and Yang, *et al*. [25] showed the same relationship for electrons. Therefore, the variation can be attributed to a difference in the electron source and the change in the material and design of the flattening filter and other head components that contribute to scattering, as well as the change in the bending magnet impacting the incident electron source width.

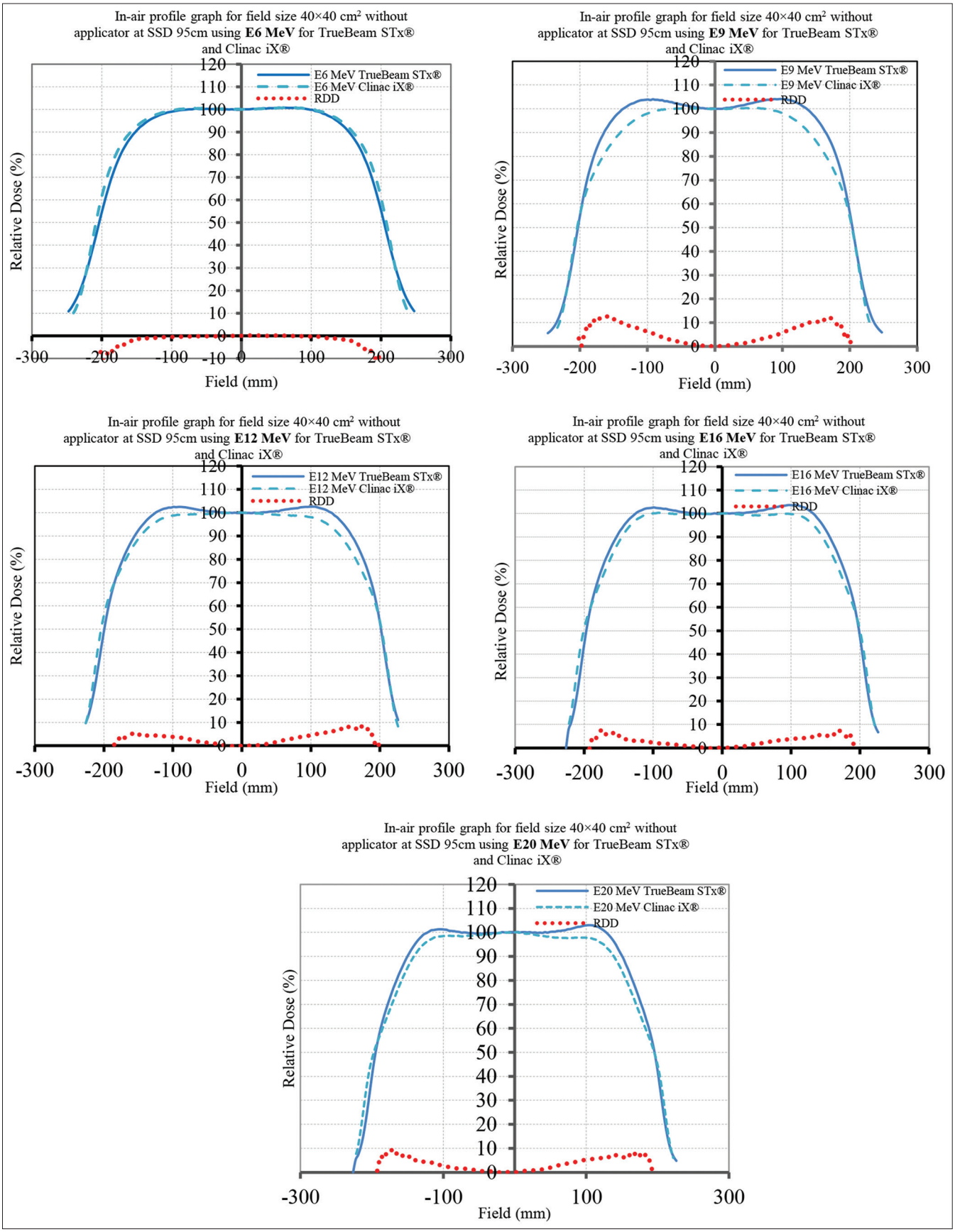

Figure 5: Profile in-air graph comparison for field size 40 × 40 cm² without applicator using different energies for TrueBeam STx® and Clinac iX®

Table 5: Output Factors at 100 cm wSSD for 6, 9, 12, 16, and 20 electron beams at depth of maximum (R_{100}) for Clinac iX®

Absolute dose at 100 cm SSD for 6, 9, 12, 16, and 20 MeV electron beams at depth of maximum (R_{100})							
Energie (MeV)	Applicator (cm×cm)	6×6	10×10	15×15	20×20	25×25	40×40
E6	R_{100} (cm)	1.20	1.25	1.25	1.20	1.25	1.25
	Absolute Dose (cGy/MU)	0.967	1.005	**1.000**	1.018	1.012	0.992
E9	R_{100} (cm)	1.90	1.95	1.95	2.00	1.95	2.00
	Absolute Dose (cGy/MU)	0.981	1.004	**1.000**	0.989	0.967	0.929
E12	R_{100} (cm)	2.45	2.70	2.70	2.70	2.70	2.75
	Absolute Dose (cGy/MU)	0.980	1.009	**1.000**	0.985	0.957	0.915
E16	R_{100} (cm)	2.55	2.95	3.00	2.85	3.10	3.34
	Absolute Dose (cGy/MU)	1.004	1.016	**1.000**	0.983	0.949	0.901
E20	R_{100} (cm)	1.80	2.00	2.40	2.35	2.20	2.99
	Absolute Dose (cGy/MU)	1.034	1.029	**1.000**	0.980	0.948	0.892

Table 6: Output factors at 100 cm SSD for 6, 9, 12, 16, and 20 electron beams at depth of maximum (R_{100}) for TrueBeam STx®

Absolute dose at 100 cm SSD for 6, 9, 12, 16, and 20MeV electron beams at depth of maximum (R_{100})							
Energie (MeV)	Applicator (cm×cm)	6×6	10×10	15×15	20×20	25×25	40×40
E6	R_{100} (cm)	1.25	1.20	1.15	1.20	1.15	1.20
	Absolute Dose (cGy/MU)	0.937	0.988	**1.000**	1.045	1.067	1.051
E9	R_{100} (cm)	1.80	1.90	1.90	1.90	1.95	1.95
	Absolute Dose (cGy/MU)	0.981	1.001	**1.000**	1.019	1.022	1.001
E12	R_{100} (cm)	2.50	2.70	2.60	2.65	2.65	2.70
	Absolute Dose (cGy/MU)	0.938	0.996	**1.000**	1.002	0.990	0.966
E16	R_{100} (cm)	2.40	2.90	3.10	3.05	2.90	3.25
	Absolute Dose (cGy/MU)	0.977	1.008	**1.000**	0.998	0.985	0.958
E20	R_{100} (cm)	1.90	2.20	2.35	2.25	2.35	3.40
	Absolute Dose (cGy/MU)	1.016	1.019	**1.000**	0.993	0.977	0.945

SSD: Source to surface distance

Table 7: Corresponding jaw opening for clinical electron beam using specific applicators for TrueBeam STx® and Clinac iX® accelerator all measurements are in centimeters, If the jaw settings are the same for both TrueBeam and Clinac, only one value is shown; if they are different, the value for Clinac iX® is shown in parentheses

Applicator	Energie (MeV)				
(cm × cm)	E6	E9	E12	E16	E20
6 × 6	20 × 20	20 × 20	11 × 11	11 × 11	11 × 11
10 × 10	22 × 22 (20 × 20)	20 × 20	15 × 15 (14 × 14)	15 × 15 (14 × 14)	14 × 14
15 × 15	22 × 22 (20 × 20)	20 × 20	19 × 19 (17 × 17)	18 × 18 (17 × 17)	17 × 17
20 × 20	27 × 27 (25 × 25)	25 × 25	25 × 25	23 × 23	22 × 22
25 × 25	32 × 32 (30 × 30)	30 × 30	30 × 30	28 × 28	27 × 27

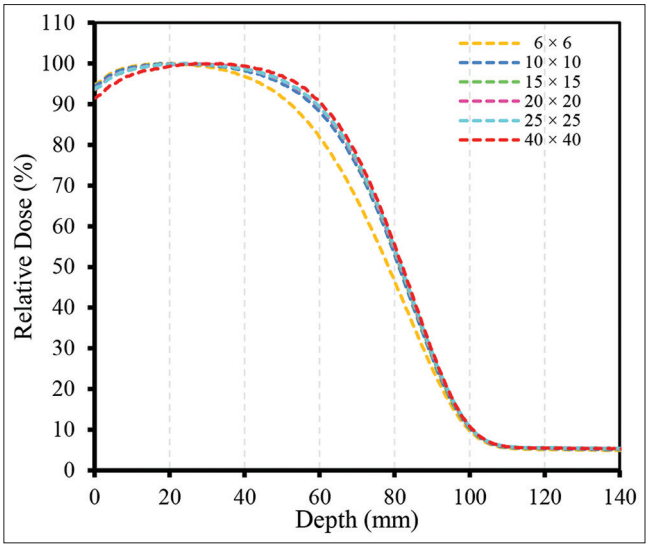

Figure 6: Percent depth dose curves for different field sizes for E20 MeV electron beam from TrueBeam STx® linear accelerator

Conclusion

Electron beams were successfully commissioned and validated for TrueBeam STx®, a good agreement between modeled and measured data was observed. The solution of Monte Carlo implemented in the TPS has been well verified and approved for clinical use for both machines.

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