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Dosimetry acceptance test of linear accelerator Varian Clinac iX

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Performance of acceptance test after the installation of a linear accelerator (linac) is obligatory. The aim is to prove that the machine meets the specification requirements. In this work are presented some dosimetry acceptance test results of linac Varian Clinac iX, recently installed at the University Hospital St. Marina, Varna. They include depth of ionization as well field flatness and symmetry for the following electron beam energies: 6 MeV, 9 MeV, 12 MeV, 16 MeV and 20 MeV. The measurements are performed using a MP3-M water scanning system and two ionization chambers Semiflex 0.125 cm^3, (PTW -Freiburg, equipment). The measured values were found to be in the tolerance interval given by Varian which proved that the tested linac corresponds to the technical specification of the vendor.

Key words: linac, acceptance test, electron beam, depth of ionization, flatness, symmetry

INTRODUCTION

The electron beams are not in common clinical use in Bulgarian radiotherapy practice because of lack of experience due to limited number of linear accelerators. The Orthovoltage treatment machines are available at most of the Radiotherapy departments and they are used in cases suitable for electron treatment. Two linear accelerators Varian Clinac iX were recently installed at the University Hospital St. Marina - Varna. Both machines have two X energies - 6 and 18 MV and five electron energies - 6, 9, 12, 16, 20 MeV. Treatment planning is computerised and the electron beam application will be introduced soon.

When an installation of a linear accelerator is completed several tests are required. This procedure is the acceptance test aiming to check if the machine meets the specification requirements, functions properly and can be safely used in clinical practice. The acceptance test is done together with the vendor. Tasks that need to be performed during acceptance test include: safety checks, mechanical checks and dosimetry measurements. All measurements initially are performed at the vendor factory with strict limits. The acceptance test precedes the commissioning of the linac, which is obligatory before the clinical start. The commissioning includes: measuring output factors, acquiring beam quality data, performing absolute dosimetry calibration of the linac, etc.

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THEORY

Electron beams have been in clinical use since 1950s. Historically they were firstly generated by betatrons followed by microtrons and linacs. Electron beams are considered nearly monoenergetic. The electron interacts with matter by multiple scattering - inelastic and elastic collisions with the atomic electrons and nuclei. Because of specific depth dose distribution with maximum dose deposition close to the surface electron beams are used for treatment of superficial lesions. The underlying normal tissue could be maximally protected because the rapid doses fall-off with the depth. Multimodality linacs provide two or three photon energies and several electron energies in the range from 4 MeV to 22 MeV. Electron dosimetry measurements for linac during the acceptance test do typically involve depth of ionization and field flatness, and symmetry. As far as this is relative dosimetry, none correction factors are needed. During the commissioning – the absolute dosimetry measurements - dose values should be corrected for temperature and pressure, polarity effect, etc [1].

Electron depth of ionization is defined from the central axis depth dose curve. The typical curve starts with surface dose higher then surface dose of photon beams. Beyond the surface the dose builds up to a maximum at a particular depth – electron beam depth dose maximum $z_{\max}$. After $z_{\max}$ dose drops off rapidly and levels to a bremsstrahlung tail. Due to this dose distribution electron beams have clinical advantages over the orthovoltage machines in irradiating superficially located lesions. When entering the matter the electrons exhibit fall-off after only a few centimetres [2].

Percentage depth dose (PDD) is defined as the dose at certain point D_x of the central axis over the maximum dose D_{max} on the central axis multiplied by 100:

$$\mathrm{PDD} = \frac{D_x}{D_{max}}.100,\ \% \qquad (1)$$

PDD depends on the beam quality [3] that is defined mainly by energy, radiation field size and shape, source to surface distance (SSD), collimation of the beam, etc. Normally PDD is measured at the nominal treatment distance. In Varian protocol PDD of electron beams is defined with the use of a water phantom at SSD equal to 100 cm. The radiation field is 15 x 15 cm with applicator. The tolerance values are given for depth of ionization at 90%, 80%, 50% and 30% of the maximum beam intensity.

Electron field flatness and symmetry are given at z_{max} according to the International Electro-technical Commission (IEC). The profile requirement for the flatness is that the distance between 90% dose level and the geometrical beam edge does not exceed 1 cm along the major axes and 2 cm along the diagonals. Also, the maximum value of the absorbed dose in the 90% isodose region should not exceed 1.05 times the absorbed dose on the beam axis at the same depth [4].

A typical profile curve of the electron beam is shown in Fig. 1.

According to the Varian protocol, flatness and symmetry are calculated from profile curve measured at plane in a water phantom at certain depth. This depth is different from z_{max} (IEC) and specific for different electron energies. It is calculated as follows:

$$\mathrm{Depth} = \frac{85\%\ \text{beam intensity}}{2},\ \mathrm{cm} \qquad (2)$$

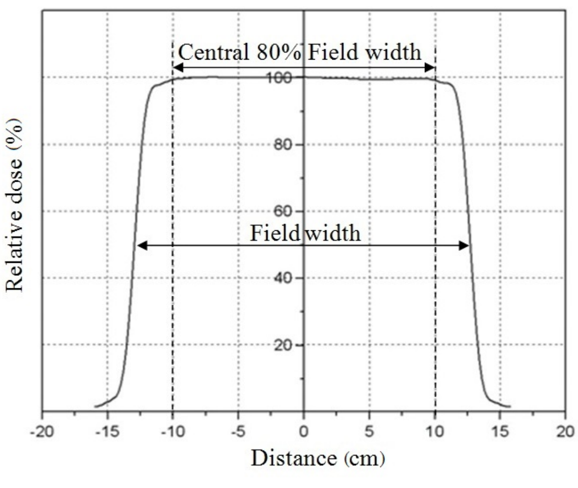

Fig. 1. Typical profile curve of megavoltage energy electron beam of linac.

The scanning depths for different electron energies of linac Varian Clinac iX are given in Table 1.

Table 1. Electron energies scanning depths.

Energy, MeV	**Depth, cm**
6	1.0
9	1.4
12	2.0
16	2.7
20	3.3

Flatness specification is the maximum variation of the integrated dose between the minimum and the maximum points within the central 80% field width of the radial (inplane) and transversal (crossplane) major axes at SSD 100 cm:

$$\mathrm{Flatness} = \frac{D_{max} - D_{min}}{2}.100,\ \% \qquad (3)$$

Symmetry specification is the maximum variation of the integrated dose between any two corresponding points equidistant from the beam centreline within the central 80% field width of the radial (inplane) and transversal (crossplane) major axes at SSD 100 cm.

$$\mathrm{Symmetry} = \frac{D_{(x)} - D_{(-x)}}{2}.100,\ \% \qquad (4)$$

MATERIALS AND METHODS

Dosimetry measurements for Varian Clinac iX linear accelerator are performed for the following electron energies: 6 MeV, 9 MeV, 12 MeV, 16 MeV and 20 MeV. Linac is equipped with five electron applicators defining radiation fields of 6×6 cm, 10×10 cm, 15×15 cm, 20×20 cm and 25×25 cm. The role of the applicator is to limit the radiation field, but more important to collimate the beam. The applicators are attached to the gantry head and provide homogeneity of the dose at irradiated area.

All measurements are performed with MP3-M Water Scanning System (PTW - Freiburg). This system includes water phantom made of Polymethyl methacrylate (PMMA). The water tank has outer dimensions of $636 \times 634 \times 522.5$ mm and inner dimensions of $596 \times 594 \times 502.5$ mm. The walls are 2 cm thick and the water capacity is 171 l. For all performed measurements the tank is filled with distilled water. Water phantom is connected to TBA control unit which provides remote positioning of the basic detector. Before each measurement the positions of the detector are defined, i.e. the detector is providing data at certain points inside the phantom while moving from point to point by the software and TBA system. A stand is attached to the water tank to place a referent detector which usually is set at the edge of radiation field in air. Its data are applied as correction coefficient of the data taken from the basic detector. Detectors are connected to TANDEM dual-channel electrometer. Mephysto 3.0 software is used. All dosimetry equipment is manufactured by PTW – Freiburg.

Two Semiflex 0.125 cm^3 ionization chambers are used as detectors (PTW – Freiburg). Nominal voltage of both detectors is + 400 V. One of them is used as basic and the other one - as referent. For measuring PDD the basic chamber is positioned along the central beam axis from 15 cm depth up to the water phantom surface with several mm intervals. When studying the electron field flatness and symmetry, the basic chamber moves in horizontal planes at different depth level according to the measured electron energy – Table 1. The movement is both inplane (radial) and crossplane (transversal) in lines longer than the dimensions of the radiation field. The beam data are taken through several mm by the moving detector. For all presented measurements a referent detector is placed in the air at the edge of the radiation field.

RESULTS AND DISCUSSION

All results are calculated using the Varian protocol. Linac gantry and collimator are at position zero degrees during all measurements.

Electron depth of ionization

For PDD measurements 15×15 cm electron applicator is mounted on the linac head. SSD is 100 cm and this specifies radiation field 15×15 cm on the water phantom surface. The depth at 90%, 80%, 50% and 30% of the maximum dose intensity is defined in cm.

The tolerance intervals and measured values are presented in Table 2.

The protocol with measurement results from Mephysto 3.0 is given in Fig. 2.

The PDD curves of all electron energies are presented. As it is visible maximum dose for highest energy (20 MeV) is achieved in 1.59 cm (R100) [5]. Bremsstrahlung tail per energy levels as follows: 6 MeV – 3 cm, 9 MeV – 4.5 cm, 12 MeV – 6.2 cm, 16 MeV – 8.1 cm and 20 MeV – 10.2 cm.

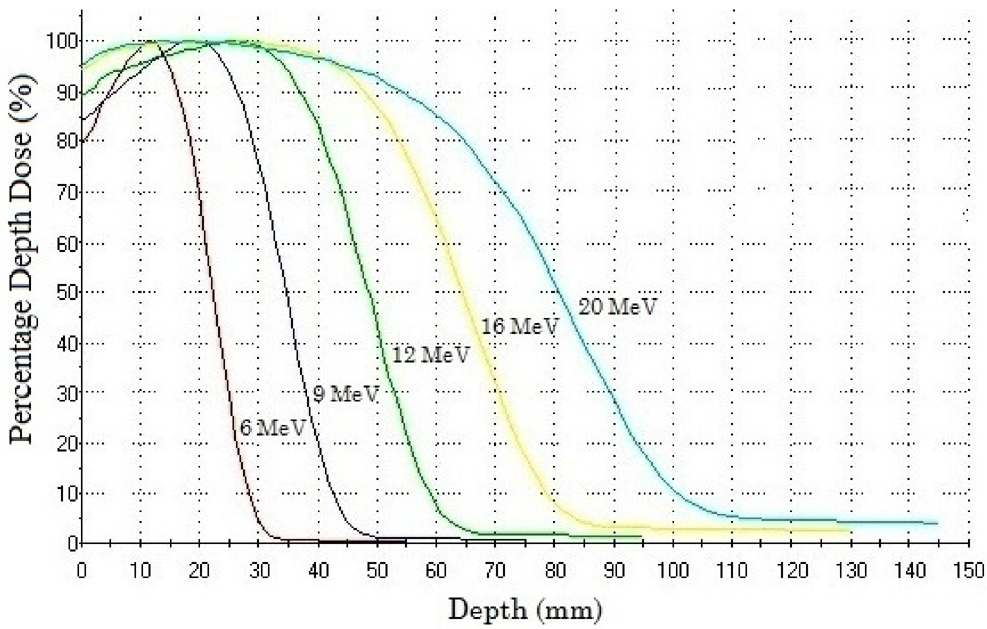

Fig. 2. PDD curves for all electron energies.

Table 2. PDD for all electron energies

Energy MeV	**Interval**	**Depth of respective percentage depth dose**, cm 90%	80%	50%	30%
6	Specification	1.71 ± 0.10	1.90 ± 0.07	2.30 ± 0.10	≤ 2.60
	Measured	1.63	1.83	2.23	2.49
9	Specification	2.68 ± 0.10	2.95 ± 0.07	3.50 ± 0.10	≤ 3.90
	Measured	2.64	2.90	3.47	3.78
12	Specification	3.77 ± 0.10	4.15 ± 0.07	4.89 ± 0.10	≤ 5.40
	Measured	3.71	4.08	4.86	5.29
16	Specification	4.87 ± 0.10	5.45 ± 0.07	6.49 ± 0.10	≤ 7.30
	Measured	4.80	5.38	6.44	7.10
20	Specification	5.52 ± 0.10	6.55 ± 0.07	8.13 ± 0.10	≤ 9.30
	Measured	5.43	6.49	8.08	8.94

Field flatness and symmetry

For electron field flatness and symmetry both inplane and crossplane profiles are taken. The setup is the same as for PDD but radiation fields are 10×10 cm and 25×25 cm on the water phantom surface (respectively 10×10 cm and 25×25 cm applicators are mounted to the gantry). Profiles of the different electron energies are taken in planes located at certain depth defined in Table 1. Table 3 presents the specification intervals and calculated values of inplane line.

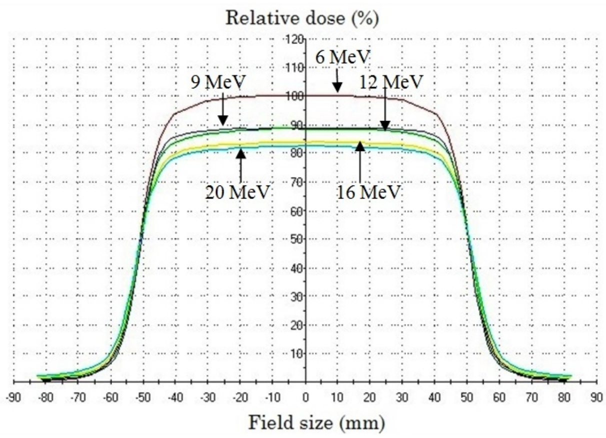

Fig. 3. Inplane profile curves for all energies – radiation field 10×10 cm. (Mephysto 3.0).

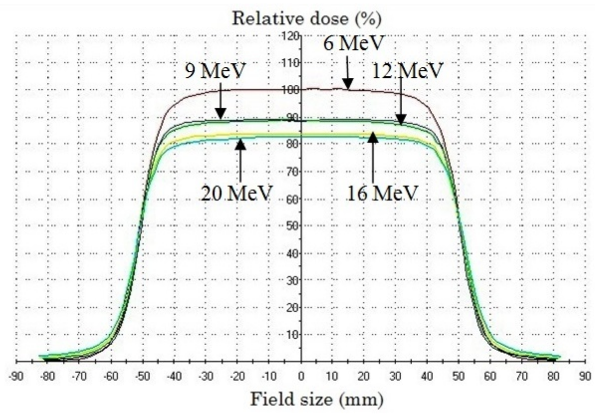

Fig. 4. Crossplane profile curves for all energies – radiation field 10×10 cm. (Mephysto 3.0).

Table 3. Electron field flatness and symmetry – Inplane

Energy, MeV	**Field**, cm	**Flatness**, % Specification	Actual	**Symmetry**, % Specification	Actual
6	25×25	± 4.5	± 1.13	2%	0.32
9	25×25	± 4.5	± 1.04	2%	0.44
12	25×25	± 4.5	± 0.77	2%	0.38
16	25×25	± 4.5	± 0.65	2%	0.46
20	25×25	± 4.5	± 1.50	2%	0.64
6	10×10	± 5.0	± 3.66	2%	0.62
9	10×10	± 4.5	± 2.04	2%	0.70
12	10×10	± 4.5	± 3.17	2%	1.05
16	10×10	± 4.5	± 3.12	2%	0.89
20	10×10	± 4.5	± 3.44	2%	0.75

Table 4. Electron field flatness and symmetry – Crossplane

Energy, MeV	**Field**, cm	**Flatness**, % Specification	Actual	**Symmetry**, % Specification	Actual
6	25 × 25	± 4.5	± 1.10	2%	0.62
9	25 × 25	± 4.5	± 0.96	2%	0.89
12	25 × 25	± 4.5	± 0.48	2%	0.65
16	25 × 25	± 4.5	± 1.25	2%	0.75
20	25 × 25	± 4.5	± 1.27	2%	0.98
6	10 × 10	± 5.0	± 3.61	2%	0.66
9	10 × 10	± 4.5	± 2.21	2%	0.78
12	10 × 10	± 4.5	± 2.87	2%	0.64
16	10 × 10	± 4.5	± 2.57	2%	0.71
20	10 × 10	± 4.5	± 2.84	2%	0.77

Fig. 3 presents a protocol from Mephysto 3.0. Inplane profiles for different electron energies per field 10 × 10 cm are shown.

Table 4 presents crossplane line specification intervals and calculated values.

Fig. 4 shows a protocol from Mephysto 3.0. Crossplane profiles for different electron energies and field 10 × 10 cm are given.

Results for the observed fields (10 × 10 cm and 25 × 25 cm) both inplane and crossplane are in the tolerance intervals. Calculated flatness and symmetry are quite lower than the specification. This means that the dose all over the radiation field is highly homogeneous with no dependence of radiation field size.

CONCLUSIONS

The presented measurements for percentage depth dose and field flatness and symmetry are in tolerance intervals given by Varian. This proves that the studied linac meets the specification and can be used in clinical practice with all available electron energies. After the complete acceptance test is finished, machine commissioning including the absolute dosimetry calibration should be performed. After acquisition of all beam quality data they need to be transferred to the treatment planning system. Then commissioning of the treatment planning system itself and a number of verification tests with the linac before clinical start are required.

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ДОЗИМЕТРИЧНИ ПРЕДВАРИТЕЛНИ ПРИЕМНИ ИЗПИТВАНИЯ НА ЛИНЕЕН УСКОРИТЕЛ Clinac iX, Varian

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(Резюме)

При приемане на линеен ускорител за медицински цели се провеждат цялостни тестове с оглед правилното сработване на всички системи и тяхната калибровка. Важна част от това са и дозиметричните приемателни тестове, включващи процентното разпределение на дозата в дълбочина по протежение на централната ос на лъчевия сноп и изследване на изравнеността и симетрията за различни лъчеви полета. Представените данни са за линеен ускорител Varian Clinac iX с енергии съответно: а) фотони – 6 MV, 18 MV; б) електрони – 6 MeV, 9 MeV, 12 MeV, 16 MeV, 20 MeV. Измерванията са направени във воден фантом MP3-M посредством йонизационни камери Semiflex 0,125 cm^3 и софтуерна система Mephysto 3.0 (производител PTW). Получените резултати са сравнени със заложените толерансни стойности от фирмата производител на линейния ускорител. За референтен документ служи също и Suplemant 25. Едва след като апаратът е калибриран, за да влезе в толеранс, могат да започнат пусковите изпитвания на линейния ускорител, включващи снемането на корекционни фактори и абсолютни дозиметрични измервания.