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Studying and analyzing the impact of upgrading the Elekta Preces Linear accelerator on the percentage depth dose parameters.

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A B S T R A C T
The delivery of an accurate radiation dose to the tumor site, and thus the success of radiation treatment, depends on the accuracy of measurements of the radiation parameters. Therefore, this paper aimed to study and analyze the impact of upgrading the Electa Preces linear accelerator installed at the Radiotherapy department at Tripoli University Hospital, Tripoli, Libya, from a standard head collimator to a multileaf collimator on percentage depth dose (PDD) parameters for 6 MV and 15 MV photon beam energies at various field sizes and depths. The measurements in this study were carried out using a PTW MP3-M 3D water scanning system, and the acquired data were processed using MEPHYSTO mc^2 navigation software (PTW, Freiburg) version 1.6. The results of this paper showed considerable variations between the majority of parameters of PDD. The highest relative differences between the measured PDD pre- and post-upgrade were observed in the build-up region. The highest value recorded was 16.69% for 6 MV photon beam energy. Additionally, the relative deviation of surface dose reached 9.27% for photon beam energy. Therefore, recommissioning the collected data, which is used in the treatment planning system to evaluate dose distribution in patients, is needed and strongly recommended.

Keywords: PDD, MLC, SH collimator, surface dose, Elekta Preces Linac.

1. INTRODUCTION:

Radiation therapy is one of several methods used for treating different kinds of cancerous tumors by delivering a specific amount of radiation dose to the tumor site. According to the International Commission on Radiation Units and Measurements (ICRU) and other organizations, the percentage error in the prescribed radiation dose delivered to the tumor must not exceed 5% for radiotherapy to be effective (International Commission on Radiation Units and Measurements, 1999; Dutreix, 1984; Brahme, 1984). A linear accelerator (LINAC) is the most common and widely used machine to deliver a prescribed radiation dose to a tumor volume. Since 1953, medical linear accelerators have been used for treating cancer patients (Thwaites & Tuohy, 2006). Monitor unit calculations and treatment planning dose distribution depend on measurements of photon and electron beam characteristics produced by LINAC. Although for LINACs of different makes and models some parameters of beam characteristics are close for a given energy of primary electron beam, other parameters are influenced by treatment LINAC head components and head design (Podgorsak, 2005; Sheikh-Bagheri & Rogers, 2002; Mesbahi, et al., 2007). These differences are due to the different treatment LINACs head design and head components, such as the flattening filter, primary collimator, X-ray target material, and adjustable collimators (Sheikh-Bagheri & Rogers, 2002). Elekta Precise LINAC was the first linear accelerator installed in the radiotherapy department of the Tripoli

University Hospital (TUH), Libya, in 2004. The LINAC has multiple photon and electron beam energies and a standard radiation head with asymmetric jaws to define the regular radiation field geometry. In 2013, the Elekta Precise LINAC was partially upgraded. The upgrades involved only changing the standard head (SH) to a multileaf collimator head (MLC) to define the radiation field geometry. The newest head has two banks, which contain 40 leaves of 10 mm width in each bank (Elekta Oncology Systems Ltd. 2009).

The aim of this paper, therefore, is to analyze and study the impact of upgrading the Precise LINAC on PDD parameters of 6 MV and 15 MV photon beam energies.

2. MATERIALS AND METHODS:

The work described in this paper was conducted at the Department of Radiotherapy at the Tripoli University Hospital, Tripoli, Libya. PDD measurements were carried out for photon beams of energies 6 MV and 15 MV generated by the Elekta Precise linear accelerator (Elekta Oncology Systems, Crawley, UK). A PTW MP3-M 3D water scanning system (PTW, Freiburg, Germany) was used to carry out the measurements of the PDD. The system consists of a water tank of inner size 59.6×59.4×50.25 cm^3, a TANDEM electrometer, a TBA control unit, and two 0.125 cm^3 Semiflex chambers. The acquired data were processed using MEPHYSTO mc^2 navigation software (PTW, Freiburg) version 1.6.

The measurements of PDD were performed for various field sizes from $3 \times 3\ cm^2$ to $35 \times 35\ cm^2$ in a range of depths starting from $0\ cm$ to $35\ cm$ at a fixed source-to-surface distance of 100 cm before and after the upgrade. The collimator and gantry angles were both at 0^o. During the PDD measurements, the dosimetry protocol recommendations of the International Atomic Energy Agency (IAEA) in the Technical Report Series 277 and 398 were strictly followed (International Atomic Energy Agency, 1987; International Atomic Energy Agency, 2000).

3. RESULTS AND DISCUSSION:

PDD, which is the percentage ratio of the radiation dose at any depth to the radiation dose at a depth of the maximum radiation dose (d_{max}) on the central axis (Dutreix et al., 1997), for the photon beam energies of 6 MV and 15 MV for SH collimator and MLC collimator are presented in Figures 1 and 2, respectively.

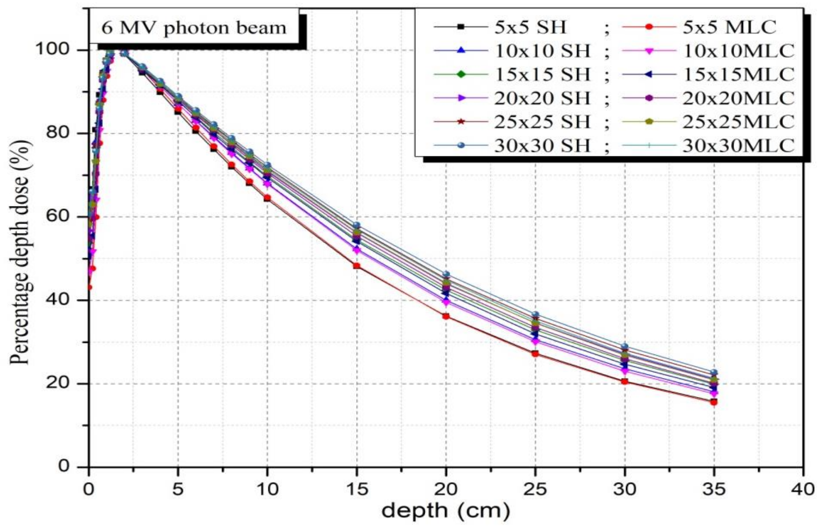

Figure (1): PDD of 6 MV photon beam of the SH collimator and the MLC collimator.

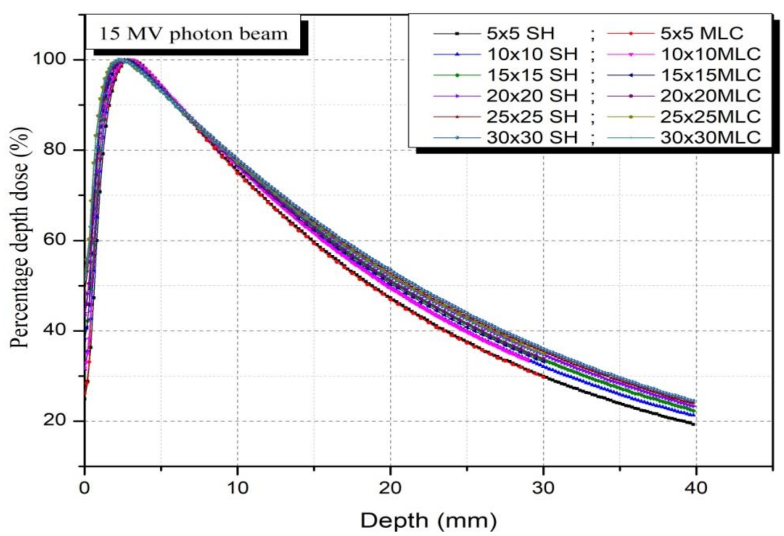

Figure (2): PDD of 15 MV photon beam of SH collimator and MLC collimator.

Figures 1 and 2 show the radiation doses along the beam central axis are well-distributed. The radiation dose increases until reaching a maximum of 100% at d_{max}, then decreases as depth increases. Moreover, the figures showed that the radiation doses are directly proportional to field size.

The relative deviation (RD) between the measured PDD values of the SH collimator and the MLC collimator for the photon beam of energies 6 MV and 15 MV are presented in figures 3 and 4, respectively. The values of RD were calculated using the following formula:

$$RD = \frac{PDD-\overline{PDD}}{\overline{PDD}} \times 100$$

Where the $\overline{PDD}$ is the average percentage depth dose.

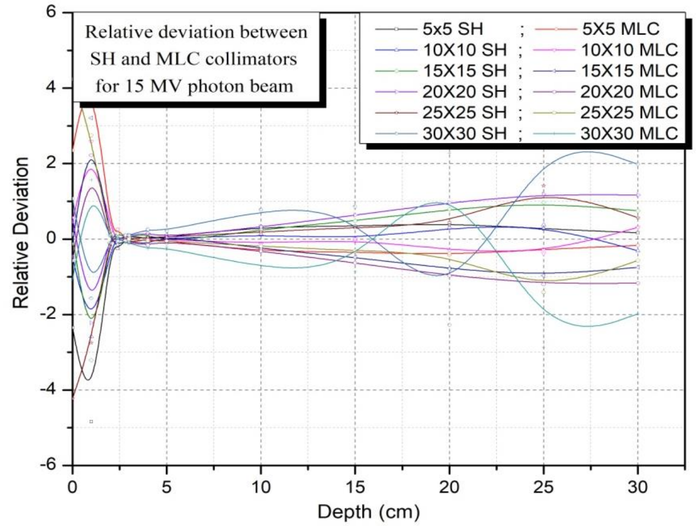

Figure (3): RD of PDD between the SH collimator and MLC collimator for a 6 MV photon beam.

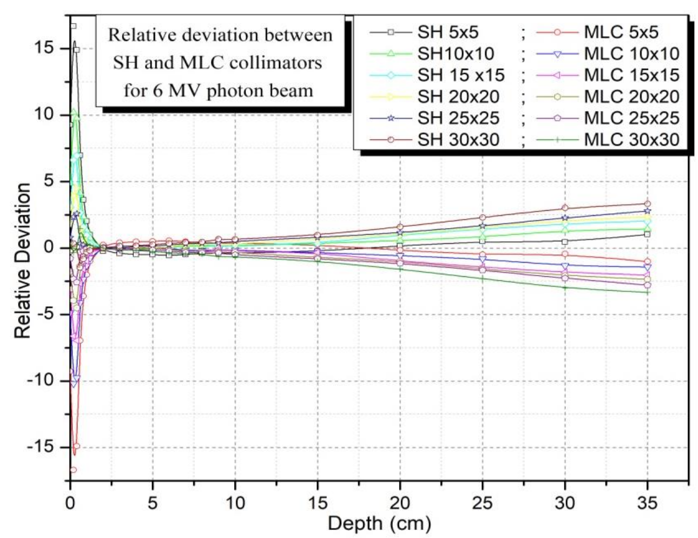

Figure (4): RD of PDD between the SH collimator and MLC collimator for a 15 MV photon beam.

The RD between PDD values of 6 MV and 15 MV photon beam energies for both the SH and the MLC collimators are shown in Figures 3 and 4, respectively. For both photon beam energies, the maximum RD values in PDD observed were in the build-up region at a field size of $5 \times 5\ cm^2$. At the depth of d_{max}, the RD is close to zero. However, as depth increases, the RD increases for all field sizes and for both photon beam energies. In the build-up region, which is very sensitive to the movement of water near the surface, the highest value of RD recorded for 6 MV photon beam energy was 16.69%, while for 15 MV photon beam energy, it was 4.84%.

The results shown in Table 1 represent the measured percentage surface doses $D_s(\%)$ for field sizes ranging from $3 \times 3\ cm^2$ to $35 \times 35\ cm^2$ for photon beam energies of 6 MV and 15 MV for both the SH collimator and the MLC collimator.

Table 1: Percentage Surface doses $D_s(\%)$ for photon beam of energies 6 MV and 15 MV for the SH and the MLC collimators for various field sizes.

Field size cm^2	Photon beam of energy 6 MV		Photon beam of energy 15 MV	
	D_S (%)		D_S (%)	
	MLC	SH	MLC	SH
3x3	41.63	49.8	24.69	23.4
4x4	42.52	48.2	25.33	24.1
5x5	43.09	51.9	26.08	24.9
6x6	43.65	51.5	28.33	26.1
7x7	44.58	51.3	28.39	27.4
10x10	46.82	51.6	31.79	31.5
12x12	48.49	53.3	34.17	34.2
15x15	50.6	53.8	38.06	38.2
20x20	54.74	56.7	43.51	44.0
25x25	58.17	59.1	53.04	48.7
30x30	60.91	60.6	50.76	51.9

For a photon beam of energy 6 MV, the differences in measured surface dose $D_s(\%)$ between the SH collimator and MLC collimator are significant for most of the field sizes; however, the $D_s(\%)$ for the photon beam of energy 15 MV is very close, and the differences are insignificant except for the field size of $25 \times 25\ cm^2$. For 6 MV photon energy, the maximum RD between $D_s(\%)$for the SH and MLC collimators is 9.27%, which occurred at the field size of $5 \times 5\ cm^2$, while for 15 MV photon energy, the maximum relative deviation is 4.27%, which appeared at the field size of $25 \times 25\ cm^2$. The results confirm the existing controversy over the accuracy of measurements of surface dose values.

Table 2 presents the depth of 50% dose $(d_{50\%})$ and the d_{max} in cm for 6 MV and 15 MV photon beam energies and for both the SH and the MLC collimators. The calculated average decrease of dose from (d_{max}) to $(d_{50\%})$ per cm as a function of field size for both energies and collimators is presented in Table 3.

Table (2): $(d_{50\%})$ in cm and the depth of maximum dose for both photon energies and collimators for various field sizes.

Field size	Photon beam of energy 6 MV		Photon beam of energy 15 MV		Photon beam of energy 6 MV		Photon beam of energy 15 MV	
	$d_{50\%}\ (cm)$		$d_{50\%}\ (cm)$		$d_{max}\ (cm)$		$d_{max}\ (cm)$	
	MLC	SH	MLC	SH	MLC	SH	MLC	SH
3x3	13.66	13.72	18.03	18.00	1.6	1.6	3.00	2.95
4x4	14.05	14.04	18.33	18.30	1.6	1.6	2.85	2.85
5x5	14.38	14.36	18.62	18.79	1.6	1.6	2.85	2.90
6x6	14.7	14.71	18.89	18.96	1.6	1.6	2.85	2.85
7x7	15.11	15.06	19.12	19.23	1.6	1.6	2.85	2.85
10x10	15.69	15.86	19.75	19.89	1.6	1.6	2.70	3.00

12x12	16.16	16.23	20.27	20.20	1.6	1.6	2.85	2.85
15x15	16.49	16.73	20.21	20.50	1.6	1.6	2.55	2.60
20x20	17.1	17.4	20.51	20.95	1.6	1.6	2.40	2.45
25x25	17.47	17.93	21.15	21.31	1.6	1.6	2.40	2.40
30x30	17.7	18.32	20.98	21.68	1.6	1.6	2.40	2.40

Table (3): Average decrease of dose in the depth between (d_{max}) and ($d_{50\%}$).

Field size	Photon beam of energy 6 MV		Photon beam of energy 15 MV	
	Average decrease values (%cm^{-1})		Average decrease values (%cm^{-1})	
	MLC	SH	MLC	SH
3x3	4.15	4.13	3.33	3.32
4x4	4.02	4.02	3.23	3.24
5x5	3.91	3.92	3.17	3.15
6x6	3.82	3.81	3.12	3.10
7x7	3.7	3.71	3.07	3.05
10x10	3.55	3.51	2.93	2.96
12x12	3.43	3.42	2.87	2.88
15x15	3.36	3.3	2.83	2.79
20x20	3.23	3.16	2.76	2.70
25x25	3.15	3.06	2.67	2.64
30x30	3.11	2.99	2.69	2.59

It is clear from Table 2 that $d_{50\%}$ is proportional to both field size and photon beam energy. The d_{max} for 6 MV was 1.6 cm for both the SH and the MLC collimators, while for the photon beam of energy 15 MV, the d_{max} was between 2.40 cm and 3.00 cm. According to the IEC 60731 Scale (International Electrotechnical Commission, Medical Electrical Equipment, 1997), the tolerance values of d_{max} for 6 MV and 15 MV photon energies are 1.5±0.2 cm and 3±0.2 cm, respectively. The results of 6 MV are within the tolerance limit of the IEC 60731 Scale. However, the results of 15 MV are out of the tolerance limit of ±0.2. In comparison, the results of the depth of a maximum dose of a 15 MV photon beam are very close to the results published by Mai et al. (Mai, et al., 2019).

As seen from Table 3, the average decrease in dose in the depth between d_{max} and $d_{50\%}$ is inversely proportional to field size and beam energy. For the 6 MV photon beam energy for both the SH collimator and the MLC collimator and 10×10 cm^2 field size, the decrease of dose in depth between d_{max} and $d_{50\%}$ were 3.51% and 3.55%, respectively, whereas for the 15 MV photon beam energy were 2.96% and 2.93%. It is obvious that the 6 MV photon beam is attenuated more rapidly than the 15 MV photon beam due to the mechanism through which high-energy photon beams interact with matter differing from that of low-energy photons (Buzdar, et al., 2009). The results in Table 5 also show that the RD of the decrease in dose in depth between d_{max} and $d_{50\%}$ for both collimators and both energies does not exceed 1% for field sizes from $3 \times 3\ cm^2$ to $15 \times 15\ cm^2$, while for field sizes greater than $15 \times 15\ cm^2$ the maximum recorded value was 1.96% for field size $30 \times 30\ cm^2$ at

6 MV photon beam energy. The PDDs for the SH and MLC collimators, together with the photon beam energies of 6 MV and 15 MV at a depth of 10 cm, are presented in Table 4.

Table (4): The percentage depth dose values of $10 \times 10\ cm^2$ at a depth of 10 cm for photon beam energies of 6 and 15 MV for both SH and MLC collimator.

Field size	Photon beam of energy 6 MV		Photon beam of energy 15 MV	
	MLC	SH	MLC	SH
10x10	67.87%	68.10%	76.51	76.7

The results presented in Table 6 are the PDD at $10 \times 10\ cm^2$ field size and $10\ cm$ depth for both 6 MV and 15 MV photon beam energies and the SH and MLC collimators. This value is used as an indicator of beam quality (Pichandi, et at., 2014; Almond, et al., 1999). For the 6 MV photon beam, the PDDs for the SH and MLC collimators were 67.87% and 68.10%, respectively, while those for the 15 MV photon beam were 76.51% and 76.7%. According to the Elekta customer acceptance tests document (Elekta Oncology Systems Ltd. 2007), the tolerances for 6 MV and 15 MV photon beam energies are 67.5±1% and 76.5±1%, respectively. For comparison, the RD for 6 MV photon energy between measured PDD of 10×10 cm^2 field size at 10 cm depth for the SH collimator and MLC collimator was 0.17%, while for the photon beam of 15 MV, it was 0.14%.

4. CONCLUSIONS:

This paper studied the impact of upgrading the Elekta Precise Linac on the parameters of PDD for photon beams of energies 6 MV and 15 MV. The results showed significant differences in the RD between the PDD measurement values before and after the Linac upgrade in both energies. The highest differences observed were in the build-up region, which reached 16.69% for a photon beam of energy 6 MV. The measured surface dose showed that both photon beam energies pre- and post-upgrading differ significantly; the highest reported variances were 9.27% for the 6 MV photon beam and 4.27% for the 15 MV photon beam. However, the differences in PDD measurements of 10×10 cm^2 field size at 10 cm depth between the SH and MLC collimator for both photon beam energies did not exceed 0.17%.

To sum up, the measurements of PDD parameters, which affects the radiation dose delivery to radiotherapy patients, showed a significant difference between pre- and post-upgrading. Therefore, recommissioning the collected data, which is used in the treatment planning system to evaluate dose distribution in patients, is needed and strongly recommended.

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