Study of photon beam dosimetry quality for removing flattening filter linac configuration

Mohamed BENCHEIKH[1], Abdelmajid MAGHNOUJ[1], Jaouad TAJMOUATI[1], Abdessamad DIDI[1]

1: LISTA Laboratory, Physics department,
Faculty of Sciences Dhar El-Mahraz, University of Sidi Mohamed Ben Abdellah
Fez, Morocco
E-mail address: bc.mohamed@gmail.com

Abstract

Photon beam dosimetry quality concerns quality of photon beam variation, it is in terms of the quality index that is associated to percentage depth dose (PDD) and the symmetry and the homogeneity that are associated to off-axis ratios. The Monte Carlo model was carried for 6 MV photon beam that is produced by Varian Clinac 2100 linear accelerator. This study was done using the Monte Carlo calculation method that is considered to be the most accurate method for dose calculation in radiotherapy physics.

The objective of this study is to analyze the photon beam quality for removing flattening filter configuration of linac. After the Monte Carlo geometry of Varian Clinac 2100 validation, the flattening filter was removed from this geometry for photon beam dosimetry study. The Monte Carlo codes used in this work were BEAMnrc code for simulating linac head and photons beam transport and DOSXYZnrc code for calculating the absorbed dose in the simulated water phantom.

Removing flattening filter allows increasing the delivered dose to the patient but the photon beam quality was affected in the build-up dose and in beyond the depth of maximum dose in water phantom. The deterioration of photon beam quality is very great for the large field size than small field size.

Keywords*:* Monte Carlo simulation, Photon dosimetry quality, BEAMnrc code, Beam softening, Linac modeling.

I. INTRODUCTION

The photon beam quality as recommended by many AIEA protocols for good usage of the radiotherapy as an often used technique in the cancer treatment. The medical linear accelerators (linacs) are widely used in modern radiotherapy due to their flexibility and their high therapeutic reliability [1-3]. Photon beam is produced by energetic electrons striking a target generally constructed of tungsten to facilitate photon production by bremsstrahlung [4].

Monte Carlo modelling is a technique that provides both accurate and detailed calculation of dosimetry; the Monte Carlo methods have been used extensively in medical physics for radiation therapy study and dosimetry investigation. Monte Carlo methods are considered the most accurate method for predicting dose distributions for treatment-planning purposes [5-8].

Monte Carlo simulation in this work was performed by BEAMnrc code for modelling linac head and photons transport all head linac structures [9] and DOSXYZnrc code for modelling photons transport inside the phantom [10].

The purpose of this work is to build the Monte Carlo geometry of 6 MV photon beam Varian Clinac 2100 by BEAMnrc representing linac head model as realistically as possible, thereafter, the photon beam dosimetry quality for removing flattening filter configuration of linac for field size of 6×6 cm^2 and 10×10 cm^2 and the source surface distance (SSD) was 100 cm. The Modeling of physical process of the Monte Carlo simulation was based on the EGSnrc code [11].

The simulation validation was performed using gamma index as a technique for quantitative evaluation of dose distribution comparison [13, 14]. Gamma index criteria were chosen as recommended by SFPM [15] and they set to allow the dose difference (DD) and distance to agreement (DTA) of 3% and 3mm respectively. Gamma index acceptance rate was almost 99 % for PDDs, and almost 97 % for beam dose profiles, thus, Varian Clinac 2100 Monte Carlo geometry was validated according to tolerance limit recommended by AIEA in TRS430 [15] and in IAEA-TECDOC-1583 [16]. The statistical uncertainty of Monte Carlo simulation was 1% as determined by Aljamal M. et al [17].

Varian Clinac 2100 with removing flattening filter gives more benefits in increasing of delivered dose for field size of 6×6 cm^2 and 10×10 cm^2 but with the deterioration of photon beam quality for these field sizes. The main advantage of removing flattening filer was on increasing dose and the increasing of dose rate is approximately 80% for field size of 6×6 cm^2 and it is approximately 110% for field size of 10×10 cm^2.

II. MATERIAL AND METHOD

The Monte Carlo geometry of Varian Clinac 2100 was built based on manufacturer-provided information (Varian Medical Systems). Photon beam nominal energy is 6 MV. The figure 1 shows different linac head components that were simulated with BEAMnrc code and the position of scoring plane for scoring the phase space file for dosimetry analysis.

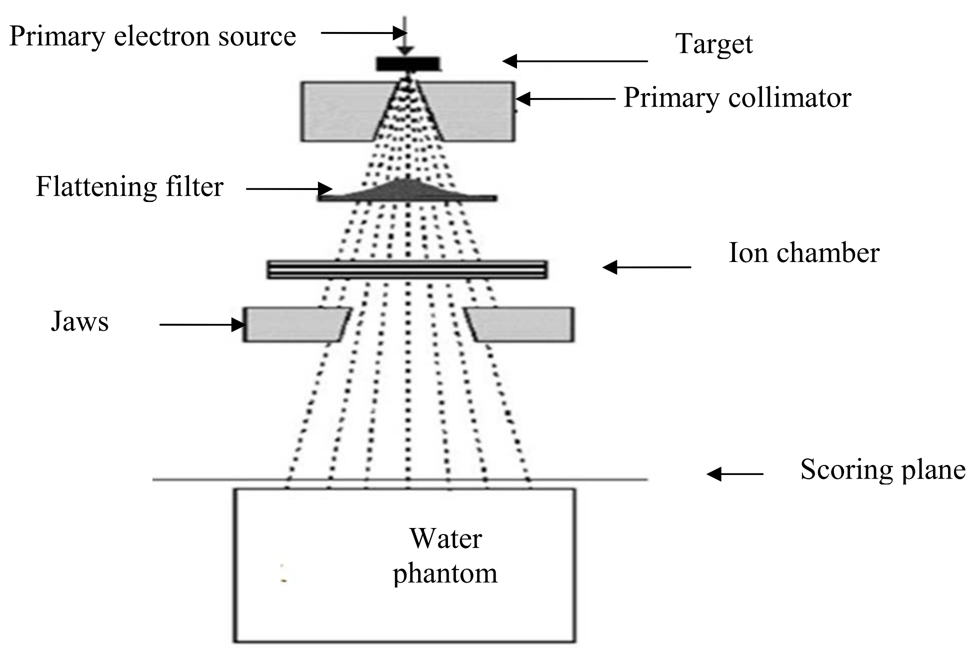

Figure 1: Monte Carlo geometry scheme including the linac head and the position of the scoring plane for the phase space file and water phantom.

EGSnrc-based physics modelling, the goal was also to simulate the radiation transport as realistically as possible, photon transport parameters was introduced as shown in table 1; they were selected with BEAMnrc code system version 2013.

EGSnrc MC transport parameter	Value
Global ECUT	0.700 MeV
Global PCUT	0.01 MeV
ESTEPE	0.25
XIMAX	0.5
Boundary crossing algorithm	EXACT
Skin depth for BCA	3
Electron-step algorithm	PRESTA-II
Spin effects	On
Brems angular sampling	KM
Brems cross-sections	NRC
Triplet production	On
Bound Compton scattering	On
Compton cross-sections	default
Pair angular sampling	KM
Pair cross-sections	NRC
Photoelectron angular sampling	On
Rayleigh scattering	On
Atomic relaxations	On
Electron impact ionization	On
Photon cross-sections	Xcom

Table 1: EGSnrc physics modelling parameters used in this study.

The initial electron energy is not clearly provided by the manufacturer and varies among linacs of the same model [18, 19]. Thus, electron beam energy was selected by comparing measured and calculated PDD distribution for 10×10 cm^2 field size using iterative Monte Carlo simulation by varying electron energy above the target. Source spot size and mean angular spread were determined by comparison of calculated and measured beam dose profiles at a depth of 10 cm on beam central axis. For this purpose, the dose distributions were normalized to maximum dose deposited on central beam axis for comparing calculated distribution to measured distribution.

Monte Carlo simulation validation was done by comparison of dose distributions to measurements using gamma index method [20]. Gamma index criteria used in this study were 3% for dose deviation (DD) and 3 mm for distance to agreement (DTA). Gamma index values which were ≤ 1 defined the agreement between the measured and the calculated dose distribution in the water phantom and gamma index acceptance rate was determined.

III. RESULTS AND DISCUSSION

A. *Monte Carlo simulation:*

The Monte Carlo geometry of Varian Clinac 2100 was modelled by BEAMnrc by the implementation of geometry data of linear accelerator that was supplied by the Varian manufacturer (Varian Medical Systems). The simulation of Varian Clinac 2100 was built and compiled and the Monte Carlo geometry of linac has been generated. The Monte Carlo simulation of Varian Clinac 2100 is a subject of our work [21].

The Figure 1 shows the Monte Carlo geometry of Varian Clinac 2100 in X-ray mode.

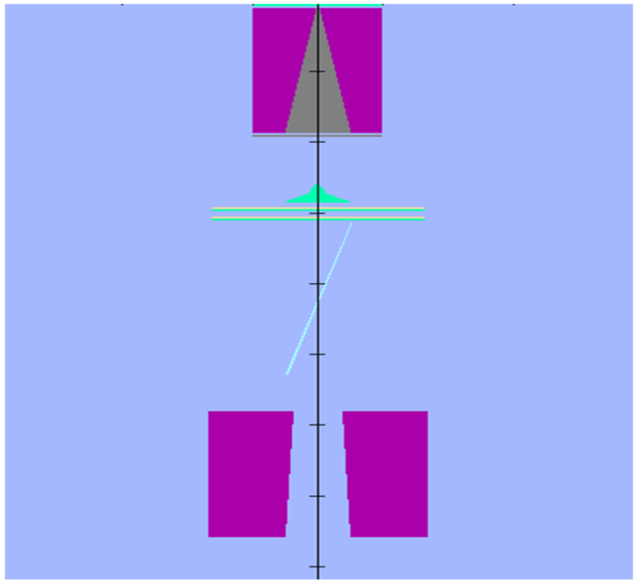

Figure 2: Monte Carlo geometry of Varian Clinac 2100 in XZ plan generated by BEAMnrc (the scheme is not scaled).

In the Monte Carlo simulation of Varian Clinac 2100, the primary electron source above the target was elliptical geometry and it had the Gaussian spread of electrons and the X and Y coordinates equal to 1.4 mm, the mean angle spread was 1° and the electron source energy above the target was 6.52 MeV.

Figures 3 and 4 present calculated PDDs, measured PDD, and gamma index curves for field sizes of 6×6 cm² and 10×10 cm² respectively.

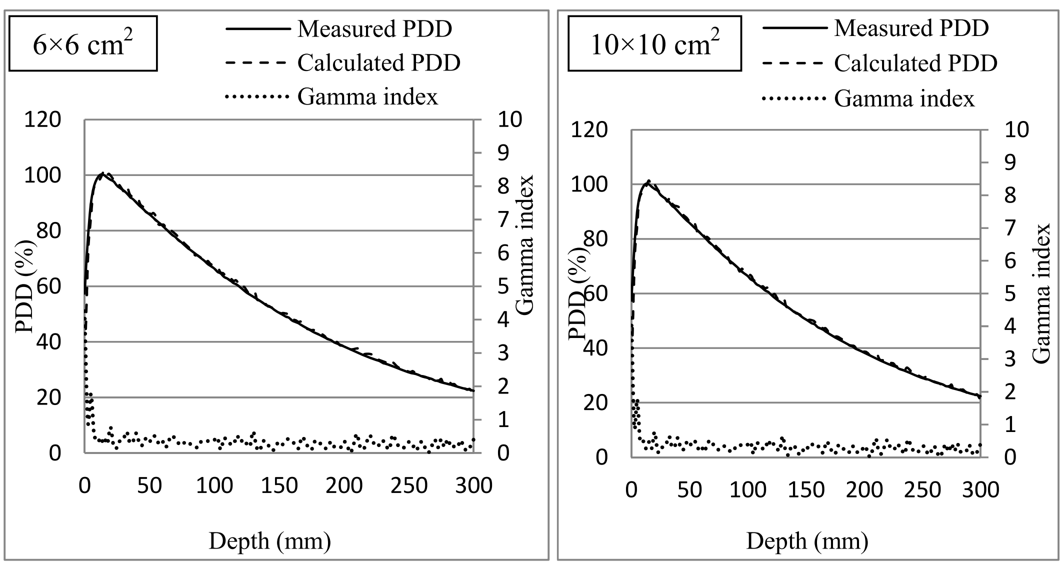

Figure 3: Calculated PDD, measured PDD and gamma index as a function of depth for field size of 6×6 cm^2 and 10×10 cm^2.

The gamma index acceptance rate was more than 98.35 % for 6×6 cm^2 but gamma index acceptance rate was found at 98.35 % for 10×10 cm^2. For good validation, beam dose profiles were calculated and compared to measurements for a depth of dose maximum (D_{max}) and a depth of 10 cm on the beam central axis. Figures 4 and 5 give, for both depths of 1.5 cm (depth of D_{max}) and of 10 cm, calculated dose profiles were compared to measured dose profiles for field sizes of 6×6 cm² and 10×10 cm² respectively.

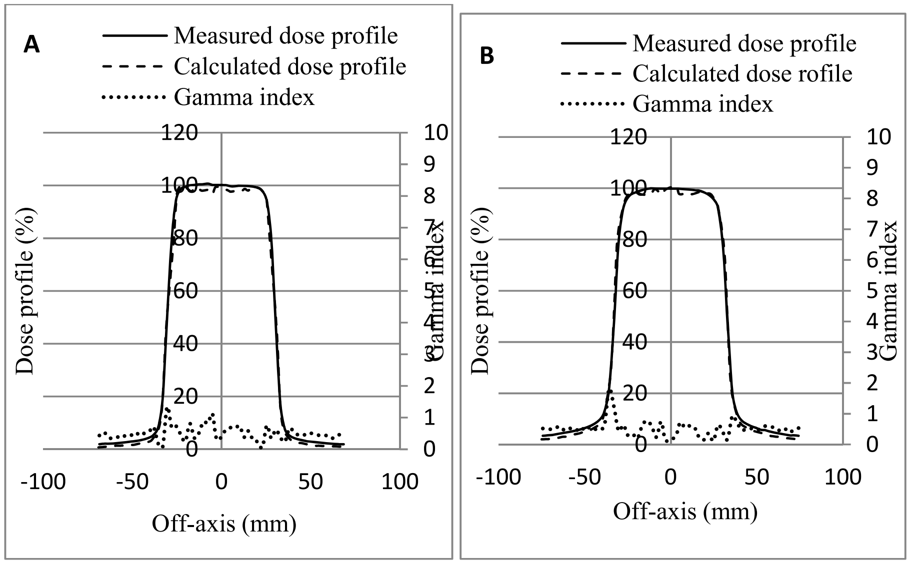

Figure 4: Calculated dose profile and measured dose profile and gamma index as a function of off axis distance at a depth of D_{max} (A) and 10 cm (B) for field size of 6×6 cm^2.

The gamma index passing rate was found at 96.3 % for both beam dose profiles at a depth of D_{max} and at a depth of 10 cm, the field was 6×6 cm^2.

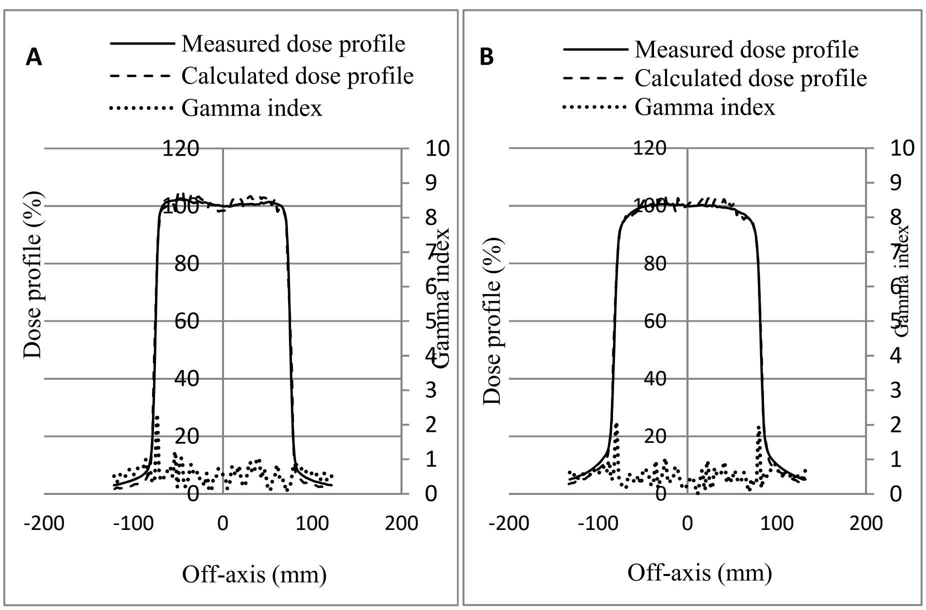

Figure 5: Calculated dose profile and measured dose profile and gamma index as a function of off axis distance at a depth of D_{max} (A) and 10 cm (B) for field size of 10×10 cm^2.

The gamma index passing rate was found at 95.84 % for the dose profile distribution at a depth of D_{max} and 98.62 % for dose profile at a depth of 10 cm, the field was 10×10 cm^2.

B. *Dose evaluation for removing flattening filter*

The dose was evaluated for linac configuration with flattening filter and for removing flattening filter from linac head. The figure 6 gives the variation of increasing dose due to removing flattening filter from linac head. We have evaluated the increasing rate of dose due to removing flattening filter from linac head as studied before in our work [22].

The figure 6 gives the increasing dose as a function of depth for tow field sizes 6×6 cm^2 and 10×10 cm^2.

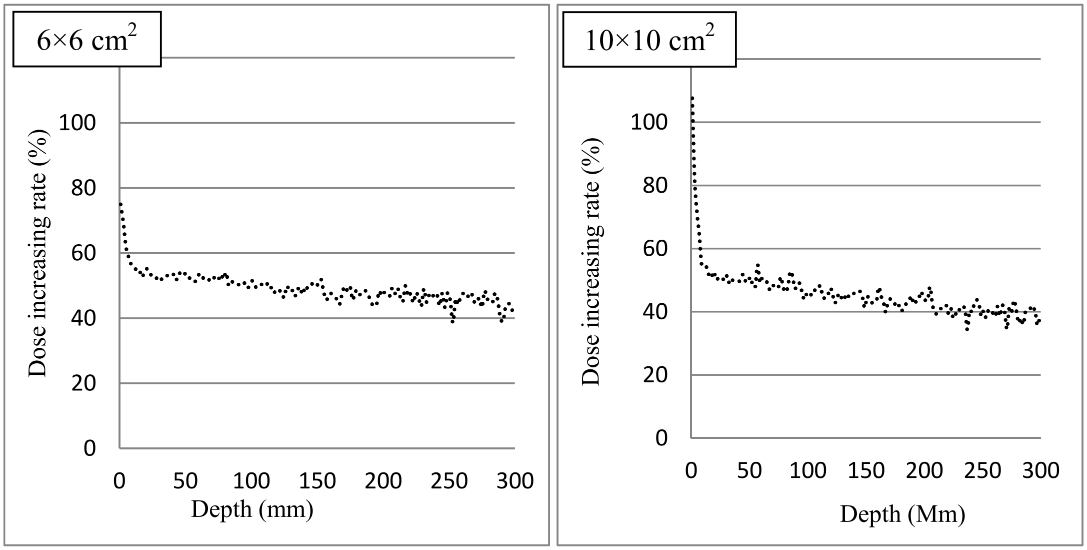

Figure 6: Increasing dose rate due to removing flattening filter as a function of depth for filed size of 6×6 cm^2 and 10×10 cm^2.

From figure 6, the increasing dose rate of removing flattening filter decreased with depth and it was high in the build-up region and it was approximately 80% for 6×6 cm^2 field size and it was approximately 110% for 10×10 cm^2 of the dose delivered by the linac configuration with flattening filter. The removing flattening filter configuration of linac head allow to increase dose and the delivered dose increased more than 40% for all depth in water phantom.

C. *Photon beam dosimetry quality study of removing flatening filter*

To increase radiotherapy efficiency, the dosimetry should be high and equitably distributed inside the tumor volume and thereafter the healthy cells must earned while treatment of cancer, subsequently, the patient life will be improved and time treatment will be reduced. The photon beam quality should be conserved when removing flattening filter from the linac head for this purposes, the photon beam dosimetry quality was investigated and studied with and without flattening filter (FF) for Varian Clinac 2100 configuration and compared to measurements. The photon beam quality was studied in terms of beam quality index as defined by AIEA protocols as the following formulas:

$$QI = \frac{PDD_{20}}{PDD_{10}} \quad (1)$$

Where,

PDD_{20} is the percentage depth dose at a depth of 20 cm

PDD_{10} is the percentage depth dose at a depth of 10 cm

We have introduced a parameter to analyze the effects of removing flattening filter on delivered dose. The local difference between linac configuration with flattening filter (with FF) and linac configuration without flattening filter (without FF) was evaluated for of 6×6 cm^{2}and 10×10 cm^2. The local difference (LD) is defined as following:

$$LD = 100 \times \frac{PDD_{without-FF} - PDD_{with-FF}}{PDD_{with-FF}} \quad (2)$$

Figure 7 and 8 present PDDs with and without flattening filter and *LD* associated for field size of 6×6 cm^2 and 10×10 cm^2 respectively.

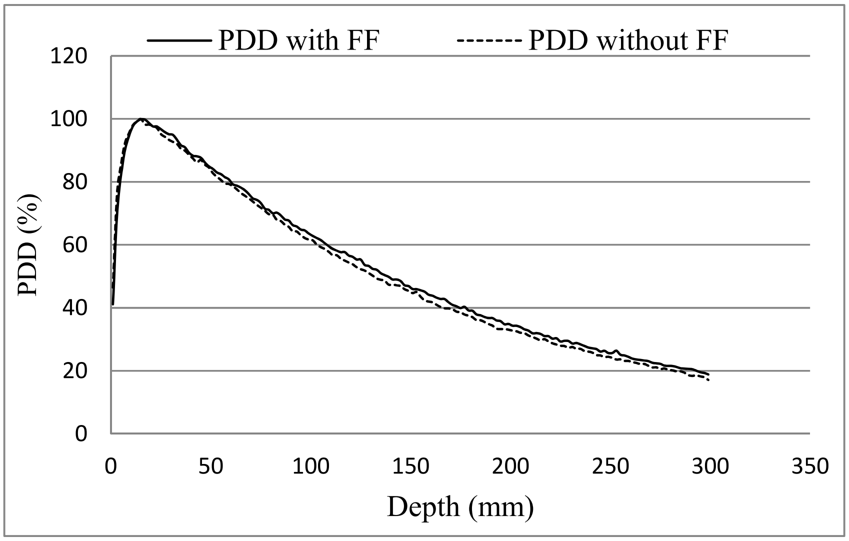

Figure 6: PDD distributions for linac configuration with FF and without FF as a function of depth for filed size of 6×6 cm^2.

The PDDs decreased with depth in water phantom for both linac configurations and the PDD curve of linac configuration without FF was under the PDD curve of linac configuration with FF for depths beyond depth of maximum dose, but in the build-up region, the PDD curve of linac configuration with FF was under the PDD curve of linac configuration without FF. The photon beam quality was affected by removing flattening filter from linac head for field size of 6×6 cm^2.

The figure 7 shows the PDDs variation with depth in water phantom.

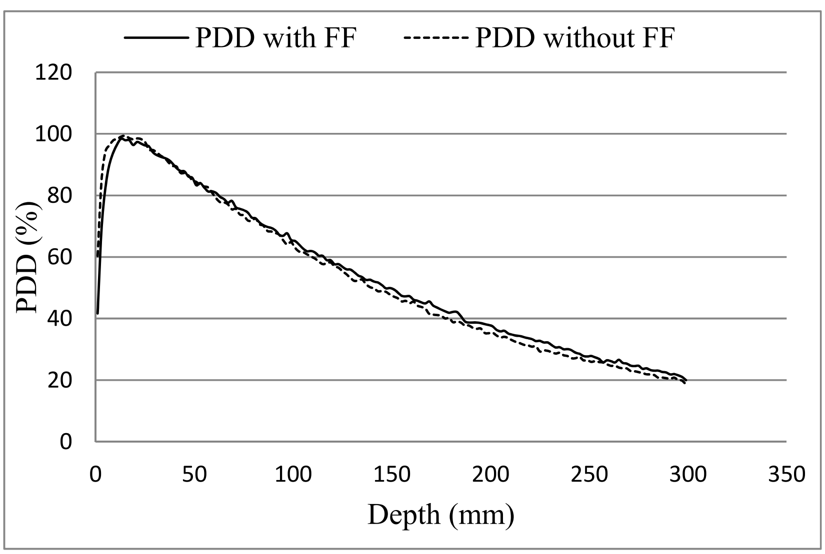

Figure 7: PDD distributions for linac configuration with FF and without FF as a function of depth for filed size of 10×10 cm^2.

It can be seen from figure 7, the same conclusion that is observed above for the field size of 6×6 cm^2 but the deterioration of beam quality for field size of 10×10 cm^2 was higher than the deterioration of beam quality for field size of 6×6 cm^2. For this reason, we have evaluated the beam quality index (QI) for both linac head configurations. The table 2 shows the photon beam quality index (QI) for both linac configurations with FF and without FF and the measured of beam quality index for filed size of 6×6 cm^2 and 10×10 cm^2

Field size	$PDD_{20/10}$		
	Mesured quality index (linac configuration with FF)	Linac configuration with FF	Linac configuration without FF
6×6 cm^2	$5.58\ 10^{-01}$	$5.46\ 10^{-01}$	$5.33\ 10^{-01}$
10×10 cm^2	$5.76\ 10^{-01}$	$5.75\ 10^{-01}$	$5.62\ 10^{-01}$

Table 2: Quality index for both linac configurations with FF and without FF.

The beam quality index (QI) for linac configuration of removing flattening filter is low than the beam quality index for linac configuration with flattening filter. It is now clear the removing flattening filter from linac head lead to decrease the beam photon quality index and subsequently the deterioration of photon beam quality.

To evaluate the difference between linac configuration with FF and linac configuration without FF, the local difference was evaluated for field sizes of 6×6 cm^2 and 10×10 cm^2. Figure 8 gives the variation of local difference (LD) as a function of depth.

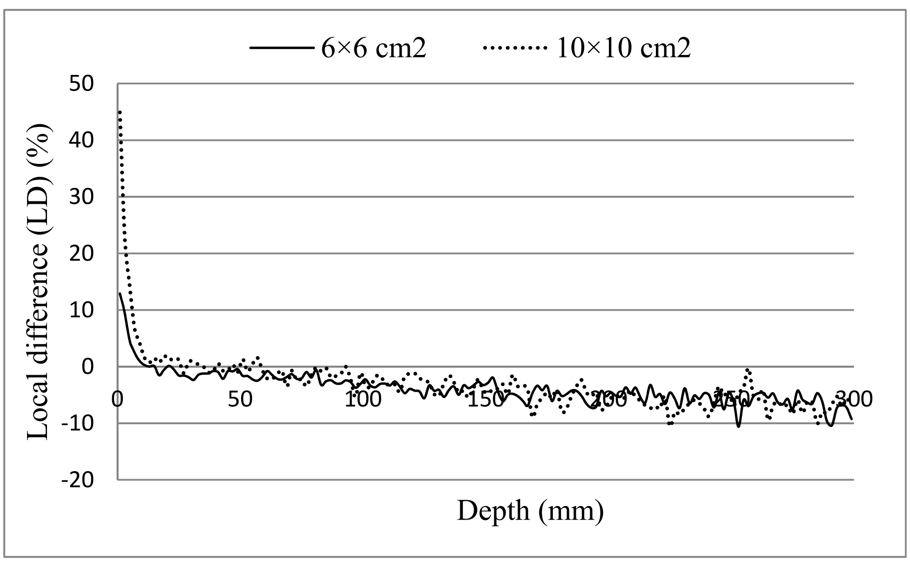

Figure 8: Local difference (LD) variation as a function of depth

It can be seen from figure 8, the more pounced difference on PDDs between linac configuration with FF and linac configuration without FF is in build-up region. That explains the effects of particles of low energy (photons) and electron contaminations for removing flattening filter linac configuration [4].

IV. CONCLUSION

The Varian Clinac 2100 was modeled by the BEAMnrc code. The simulation was validated by the comparison of calculated PDD and calculated beam dose profiles to measurement dose distributions; thus, the Monte Carlo simulation of Varian Clinac 2100 was performed with accuracy.

The removing flattening filter from linac head allows increasing the delivered dose to the patient, but the dose distributions lose its quality for the studied field sizes. The main benefit of removing flattening filer from linac head was on increasing delivered dose and the increasing dose rate was approximately 80% for field size of 6×6 cm^2 and it was approximately 110% for field size 10×10 cm^2. We have done many studies on the experiments data for studying and analyzing the quality of photon beam dosimetry [23-26]

Removing flattening filter from linac head configuration allows increasing the delivered dose to the patient while the beam quality deteriorated in the build-up dose region and in the beam quality index (beyond maximum dose). For adopting the removing flattening filter linac configuration, the photon beam quality must be conserved with depth in water phantom. The removing linac configuration from linac head gives way naturally to photons of low energy and electrons contamination for reaching the patient while radiotherapy treatment [4]

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