Original Article

Characteristics of mobile MOSFET dosimetry system for megavoltage photon beams

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ABSTRACT

The characteristics of a mobile metal oxide semiconductor field effect transistor (mobile MOSFET) detector for standard bias were investigated for megavoltage photon beams. This study was performed with a brass alloy build-up cap for three energies namely Co-60, 6 and 15 MV photon beams. The MOSFETs were calibrated and the performance characteristics were analyzed with respect to dose rate dependence, energy dependence, field size dependence, linearity, build-up factor, and angular dependence for all the three energies. A linear dose–response curve was noted for Co-60, 6 MV, and 15 MV photons. The calibration factors were found to be 1.03, 1, and 0.79 cGy/mV for Co-60, 6 MV, and 15 MV photon energies, respectively. The calibration graph has been obtained to the dose up to 600 cGy, and the dose-response curve was found to be linear. The MOSFETs were found to be energy independent both for measurements performed at depth as well as on the surface with build-up. However, field size dependence was also analyzed for variable field sizes and found to be field size independent. Angular dependence was analyzed by keeping the MOSFET dosimeter in parallel and perpendicular orientation to the angle of incidence of the radiation with and without build-up on the surface of the phantom. The maximum variation for the three energies was found to be within ± 2% for the gantry angles 90° and 270°, the deviations without the build-up for the same gantry angles were found to be 6%, 25%, and 60%, respectively. The MOSFET response was found to be independent of dose rate for all three energies. The dosimetric characteristics of the MOSFET detector make it a suitable *in vivo* dosimeter for megavoltage photon beams.

Key words: Angular dependence, build-up, dose rate, dosimetry, field size dependence, linearity, metal oxide semiconductor field effect transistor, threshold voltage

Introduction

In vivo dosimetry is routinely performed to estimate the radiation dose to validate the dose delivery to the patient organs such as the eye,[1,2] nasopharynx,[3] oropharynx,[3] breast,[4,5] and prostate.[4,6,7] Most of the *in vivo* dose measurements are either performed to measure the entrance and exit doses or the organs doses by intracavitary measurements. Dosimeters widely used for *in vivo* dose measurements include thermoluminescent dosimeter (TLDs), diodes, metal oxide semiconductor field effect transistor (MOSFET), and optically stimulated luminescence dosimeter (OSLD).

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Each of these dosimeters has certain advantages and disadvantages for *in vivo* dosimetry. TLDs[8-10] were most commonly used for *in vivo* dosimetry due to the small size of the dosimeter and that it could be easily placed on the patient surface for this purpose. However, the use of TLD is laborious and time-consuming. In addition, TLDs require repeat calibration due to variation in sensitivity due to progressive use. Semiconductor diodes[11] have some advantages over TLD for *in vivo* dosimetry, namely, immediate readout and reproducibility. However, diodes[11,12] have certain disadvantages such as energy, dose rate, and angular dependent response. In addition, diodes need to be connected to the reader system during measurement by running a long cable from the treatment room to the measurement station.

The mobile MOSFET dose verification system[13-18] was introduced by Best Medical, Canada that makes the dosimetric measurements faster and easier. The use of a MOSFET dosimeter has several advantages, such as small detector size that allows pinpoint measurements, lightweight that does not cause any harm to the patient, minimal power requirement, ease of use, and online readout. The MOSFET dosimeter is sensitive to radiation and its electrical property, i.e. the "threshold voltage", is permanently altered by the absorption of radiation.[9,13-24]

The desirable properties of dosimeters are characterized by precision, linearity, dose rate dependence, energy response, and directional dependence. However, the response of dosimeters depends upon their construction, physical dimension, and angle of incidence of the radiation. It is imperative to quantify their desirable characteristics before the actual use and apply the necessary corrections.

Soubra *et al*., (1994)[13] investigated the use of the first dual bias MOSFET dosimeter (TN502RD), introduced commercially by Thomson and Nielson (Canada) as a tool for patient dose verification. Butson *et al*., (1996)[14] investigated the use of the MOSFET dosimeter in radiotherapy for *in vivo* dosimetry. Ramani *et al*., (1997)[15] studied dosimetric characteristics such as energy response, angular dependence, and change in sensitivity due to accumulated dose for the commercially available MOSFET dosimeters.

Ramaseshan *et al*., (2004)[19] investigated the dosimetric characteristics of the micro MOSFET dosimeter for the use in radiotherapy. In his study, the angular dependence of the mobile micro MOSFET dosimeter was determined in a cylindrical solid water phantom of 20-cm diameter and has reported that the micro MOSFETs are independent of the angle of incidence of the beam in phantom. Halvorsen (2005)[20] investigated on the accuracy, interbatch uniformity, and dose linearity for the OneDose MOSFET dosimeter used for *in vivo* patient dosimetry, which is a pre-calibrated dosimeter designed for one-time use.

Varadhan Raj *et al*., (2006)[7] had studied the dosimetric characteristics like linearity, energy dependence, and angular dependence for 6 and 10 MV photon beams. Chung *et al*.,[21] (2009) investigated the dosimetric characteristics of the MOSFET dosimeter for clinical electron beams and performed a comparative study between standard and micro MOSFET in a slab-shaped PMMA phantom and verified the angular dependence using cylindrically shaped PMMA phantom.

Cheng *et al*., (2010)[22] performed dose measurements using OneDose single use MOSFET detector system for proton therapy and studied dosimetric characteristics such as the reproducibility (consistency) of the dosimeter, linearity with dose and dose rate, energy dependence, directional dependence, LET dependence, and fading (delay readout with time) for proton beams.

The purpose of this study is to investigate the characteristics such as linearity, energy, dose rate, field size, and angular dependence for the MOSFET (TN502RD) dose verification system (Best Medical, Canada) for the photon beams, namely Co-60, 6 MV and 15 MV x-rays. This study is performed as a pre-investigation on the characteristics and could be used as *in vivo* dosimeter routinely in our clinic.

Materials and Methods

Mobile MOSFET dose verification system

The MOSFET dosimeter is an electronic device that measures integrated radiation dose. It is a silicon chip of 1 mm^2 with an active area of 0.2 × 0.2 mm located under a black epoxy bulb. This study was carried out using TN502RD mobile MOSFETs (Best Medical, Canada) of standard sensitivity along with the reader module TN RD 70W dose verification system [Figure 1]. The dose verification system consists of remote monitoring dose verification software and wall-mounted Bluetooth wireless transceiver. The reader module has a dual bias setting (standard bias and high bias); in this study, the standard bias setting was kept constant. The variation due to the change in the voltage caused by irradiation is proportional to the absorbed radiation.[23] The wireless transceiver acts as a channel between the reader module and the remote verification software. The MOSFET dosimeters are provided with an inherent build-up of about 0.8 mm due to its construction, however, for measurement of surface dose and the dose at the depth of dose maximum (d_m), custom-shaped build-up caps (TN-RD-56-0.63, Best Medical, Canada) made of brass (density 8.5 g/cm^3, Z ~ 30) with a groove at the center for secure placement of the MOSFET dosimeters [Figure 1] supplied by the manufacturer were utilized.

Therapy units and phantom

The characteristics of the MOSFET dosimeters were determined for Co-60 gamma rays (1.25 MeV) of Theratron 780C (MDS Nordian, Canada) and for 6 and 15 MV x-rays beams of Clinac 2100 C/D (Varian Medical Systems, USA). During the experimental measurements, the MOSFET

Figure 1: Photograph of Mobile MOSFET dose verification system with brass build-up cap

dosimeters were placed on the top of acrylic slab (each of thickness 10 mm) phantom [Figure 1] of density 1.18 g/cm^3. The total thickness of this slab phantom was about 10 cm, which was sufficient to provide adequate backscattering[22,25] for the photon beams in this study.

Calibration of the MOSFET dosimeters

The MOSFET dosimeters can be used for *in vivo* online dosimetry either by placing them at the beam entry surface of the patient (e.g. total body irradiation) or by inserting them into the natural body cavities of the patients (e.g. esophagus, rectum, and cervix). Accordingly, the dose-response calibration of the MOSFETs was carried out by simulating the two different practical conditions of their use.

In the first case, the MOSFETs with brass build-up cap were placed on the surface of the perspex slab phantom of thickness 10 cm and were irradiated in the dose range of 10–400 cGy in steps of 50 cGy. The calibration factor (cGy/mV) was obtained by taking the ratio of the MOSFET response, i.e. the change in the threshold voltage V_{TH} (mv) to the dose at d_m for all the three photon beams. The output, i.e. the dose at d_m of the three photon beams used in this study was measured using a 0.6 cc Farmer type ionization chamber (Capintec, USA) and its electrometer (Model 192, Capintec, USA) following the methodologies of IAEA TRS 398.[26-29]

In the second case, for the calibration at depth the dose was measured for the pre-calculated time (or MU) for 100 cGy at 5 cm depth using ion chamber in solid phantom and the MOSFETs response, i.e. change in the threshold voltage V_{TH} were recorded at the same depth. With these measurements, the calibration factor (cGy/mV) was obtained at 5 cm depth.

Energy dependence

Energy response is an important characteristic of a dosimetry system. Dosimeters may exhibit energy dependence particularly for low energy beams due to their higher atomic number. It is difficult to find a dosimeter that is tissue equivalent and energy-independent over the entire energy range used in radiotherapy. Hence, a study of energy dependence is necessary for a dosimeter.[10,22,30-32] In this study, we investigated the energy dependence of the MOSFET dosimeters for Co-60 gamma rays and 6 and 15 MV x-rays. The MOSFET dosimeters were placed at a depth of 5 cm in a perspex phantom and exposed to 100 cGy with 10 × 10 cm^2 field size at 100 cm SSD for all three energies.

Dose rate dependence

In an integrated system, the dosimeter response should be independent of the rate at which the radiation dose is delivered. The dose rate dependence of a dosimeter should be checked and appropriate corrections applied.[4,7,22,30,33] In order to investigate the dose rate dependence, the response of the MOSFETs dosimeters were obtained by irradiating them to 100 cGy for dose rates (pulse rate) ranging from 100 to 600 MU/min in steps of 100 MU/min for 6 and 15 MV photon beams. For the Co 60 beam, the dose rates from 90 to 180 cGy/min were achieved by varying the SSD from 100–60 cm.

Field size dependence

The response of the dosimeter should be independent of the field size when irradiated using different field. However, it is recommended that the dependence on the field size is checked before using it for dosimetry.[25] The field size dependence was studied by irradiating them to 50 cGy for various field size from 4 × 4 cm^2 to 40 × 40 cm^2 for 6 MV and 15 MV photon beams and the response of the MOSFETs dosimeters were recorded.

Angular dependence

The response of the dosimeters varies with direction and angle of incidence of the radiation beam depending on their construction, physical size, shape, and the energy of the incident radiation.[6,10,19,30,32,34] The design of the MOSFET dosimeters was found to be isotropic, which may exhibit certain correction factors due to the angle of incidence of radiation. In this study, the variation in the MOSFET response was studied. The measurements were performed with the MOSFET dosimeters placed both parallel (i.e. MOSFETs perpendicular to the axis of gantry rotation) and perpendicular (i.e. MOSFETs along the axis of rotation of the gantry) to the axis of gantry rotation with and without build-up [Figure 2] on the surface of the perspex slab phantom.

The response of the MOSFET dosimeters were obtained by irradiating the MOSFETs at various gantry angles from 90° to 270° at an interval of 10°, with 10 × 10 cm^2 field size for all three energies. The schematic diagram showing the MOSFET orientation and the direction of gantry rotation is given in Figure 2.

MOSFET response for various threshold voltages

The threshold voltage is the gate voltage that is necessary to allow conduction through the MOSFET. The threshold voltage of the MOSFET dosimeter is increased every time it is irradiated and hence the response of the MOSFET

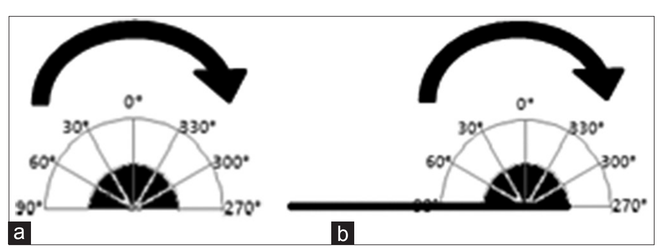

Figure 2: Schematic diagram showing the orientation of the MOSFET dosimeters to study their directional and angular dependence (a) parallel and (b) perpendicular to the axis of gantry rotation

could be different with the accumulation of dose.[15] The effect of the increase in the threshold voltage was studied by exposing the MOSFETs with different threshold voltages namely 5000, 5500, 6500, 8000, 12000, and 15000 mV to a dose of 100 cGy for 6 MV photon beam under electronic equilibrium condition.

Measurement of PDD and dose build-up

While performing surface dose measurements, build-up caps are used to achieve electronic equilibrium conditions. Insufficient build-up may lead to large involvement of correction factors, and it may also affect the accuracy of the dosimeter readings.[7] However, in order to verify the actual build-up thickness required for these MOSFETs, since the MOSFET dosimeters are provided with an intrinsic build-up of about 0.8 mm, the percentage depth dose from the surface to 20 cm depth was measured. These measurements were performed both by MOSFET and parallel plate chamber for 6 and 15 MV photon beam by increasing the build-up thickness using perspex sheets of 1 mm in the steep dose gradient region, i.e. up to their maximum dose and 5-mm sheets were used beyond dose maximum and up to 20 cm depth. The SSD was maintained at 100 cm throughout the measurements.

Results

Calibration factor

The dose–response curve of the MOSFET dosimeters corresponding to their use for surface dose measurements with brass build-up for Co-60 gamma rays and 6 and 15 MV x-rays are shown in Figure 3. As seen from this figure, the dose–response curve is linear for Co-60 gamma rays and 6 MV and 15 MV x-rays. The calibration factors of MOSFET dosimeters derived from the dose–response curve using the build-up are given in Table 1. The average calibration factor for the MOSFET dosimeters at 5 cm depth corresponding to their use as *in vivo* dosimeter in body cavities was found to be 1.1 cGy/mV for Co-60 gamma rays and 6 MV and 15 MV x-rays. The calibration factor remains same for variable doses.

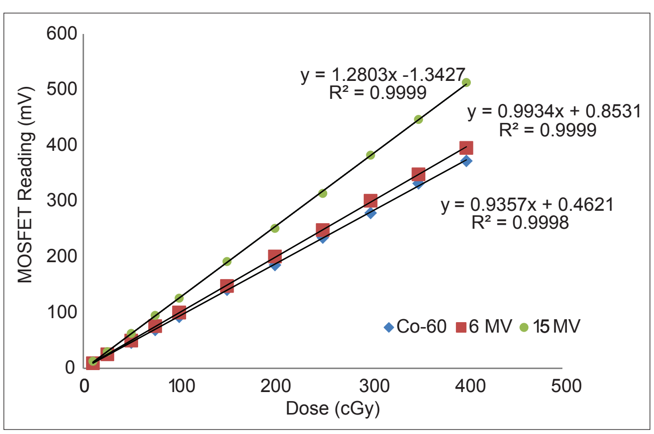

Figure 3: Dose-response curve of the mobile MOSFET dosimeter at different photon beam energies

Energy and dose rate dependence

Figure 4 presents the response of the MOSFET dosimeters for Co-60 gamma rays and 6 MV and 15 MV x-rays at a given dose value. It is observed from this figure that the response of the MOSFET dosimeter is nearly energy independent of about ± 1% for the photon energy range used in this study. The response of the MOSFET dosimeter at varying dose rates (pulse rate) from 100 to 600 MU/min for 6 and 15 MV x-rays and from 90 to 180 cGy/min for Co-60 gamma rays is shown in Figure 5. This study shows that the variation in the response of the MOSFET dosimeter was found to be ± 2% for dose rates from 100 to 600 MU/min for 6 and 15 MV and from 90 to 180 cGy/min for Co-60.

Field size dependence

Figure 6 presents the response of the MOSFET dosimeters for various field sizes for a constant dose of 50 cGy. It is observed that the response of the MOSFET dosimeters is nearly independent of field size (±1%) for both 6 MV and 15 MV photon beams.

Angular dependence

The angular response of the MOSFET dosimeter was investigated for Co-60 gamma rays and 6 and 15 MV x-rays for gantry angles starting from 270° to 90° and the measurement results are shown in Figure 7, respectively, for Co-60, 6 MV, and 15 MV. From these graphs, it can be observed that the MOSFET responses are independent to the angle of incidence of the beam when the brass build-up is used for both the orientations with a variation of about ± 2%.

Table 1: Calibration factor of the mobile MOSFET dosimeter for the three different photon beam energies under full electronic equilibrium

Photon beam	*Calibration factor (cGy/mV)*
Co-60	1.03
6 MV	1.00
15 MV	0.79

MOSFET: Metal oxide semiconductor field effect transistor

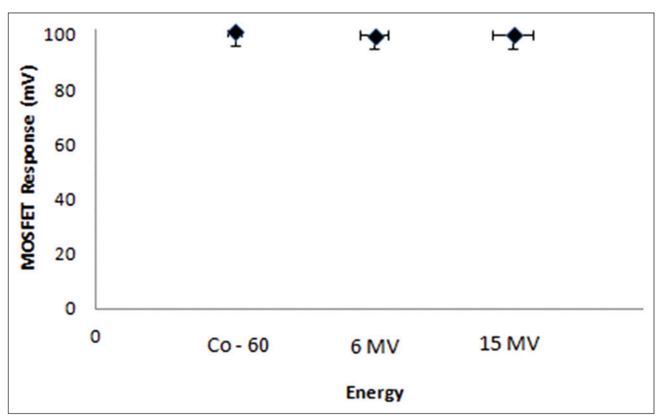

Figure 4: Energy response of the MOSFET dosimeter at different photon beam energies

It can also be observed from Figure 7, which is a plot of angular response without the build-up cap in Co-60 gamma rays that the MOSFET shows increased response of about 6% at 270° and 90° gantry angles for both parallel and perpendicular orientations. In case of 6 MV photon beams, the increase in MOSFET response was 25% for 270° and 90° gantry angles (angle of incidence 30°) and for 15 MV the increase in response was 60% for the same gantry angles. The variation in MOSFET response could be attributed to the construction of the MOSFET dosimeter with an inherent build-up and the path length traversed by the beam in the MOSFET dosimeter at these angles of incidence.

Variation in response with threshold voltage

Figure 8 shows the plot of the response of the MOSFET dosimeter (mV) at varying threshold voltage (V_{TH}). It is observed from this study that the variation of threshold voltage (V_{TH}) has negligible effect on the MOSFET response for the threshold voltage in the range of 5000 to 15000 mV.

Measurements of PDD and dose build-up

The variations in the response of the MOSFET dosimeter with depth including the build-up region for 6 and 15 MV photon beams are shown in Figure 9. From the

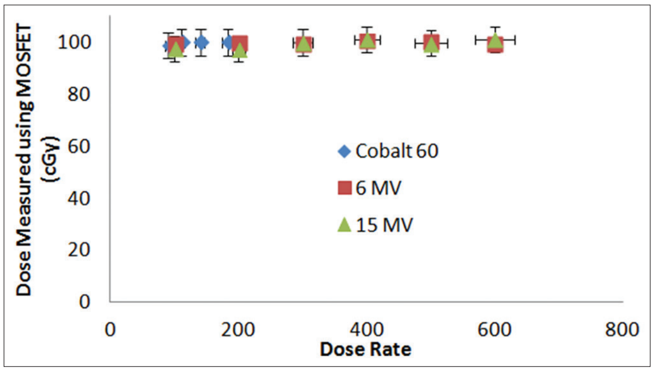

Figure 5: Response of the mobile MOSFET at varying dose rates for Co-60 gamma rays and 6 and 15 MV x-rays

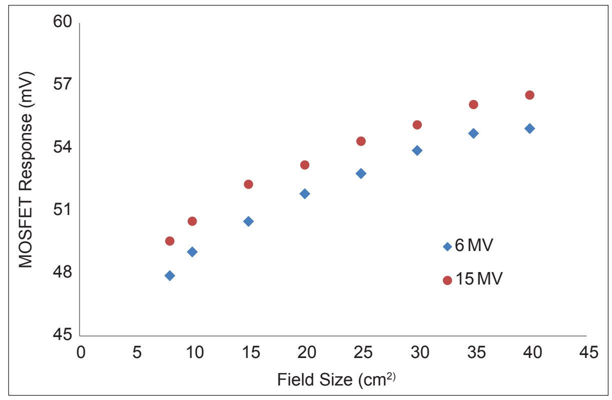

Figure 6: Response of MOSFET dosimeters for different field sizes

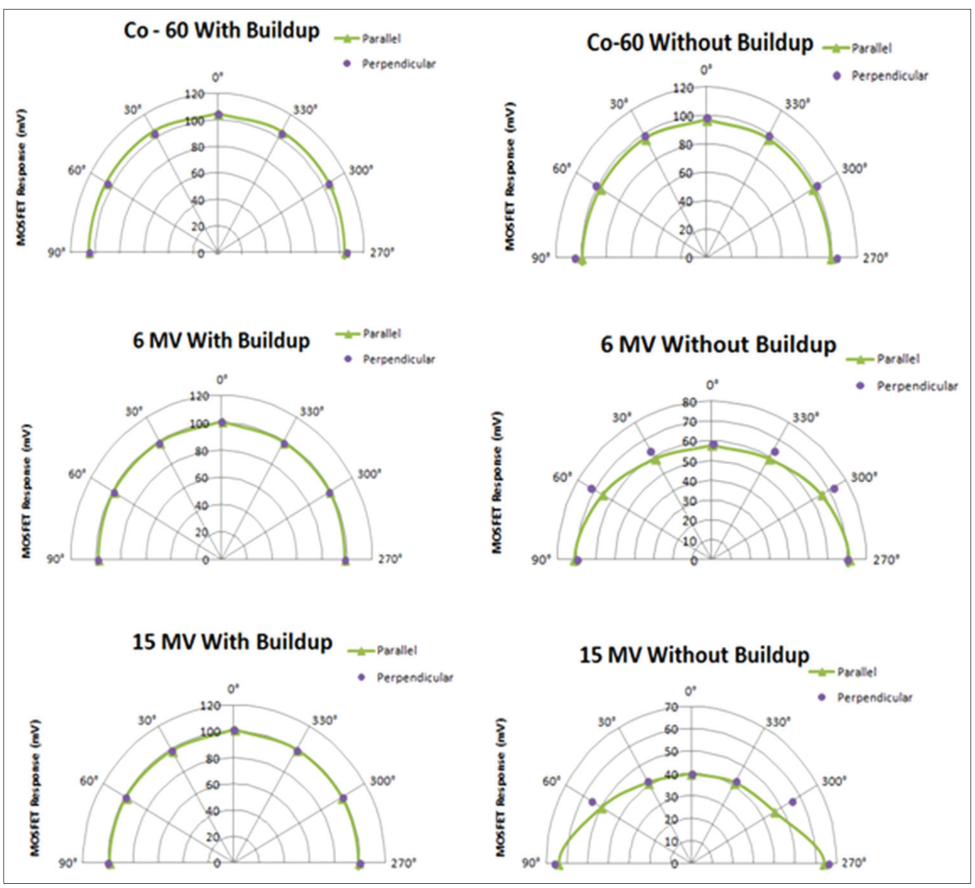

Figure 7: Angular dependence of the mobile MOSFET dosimeter for Co-60 gamma rays, and 6 and 15 MV X-rays

figure, it could be noted that the MOSFET response at the surface (without any build-up sheet) is equal to the dose measured at 0.7 mm using parallel plate chamber, suggesting that the inherent build-up of the MOSFET dosimeter is 0.7 mm, which is very close to inherent build-up of 0.8 mm given by the manufacturers.

Discussion

The dosimetric characteristics of the commercially available mobile MOSFET dosimetry system were studied. In this study, the MOSFET response was found to be linear for Co-60, 6 MV, and 15 MV photon beams. The energy dependence was found to be negligible (±1%) for the beam energy used in this study, and it compares well with the observations of other investigators [Table 2]. Similarly, it was also observed that the MOSFET response is independent of dose rate variations and for variable field size.

In routine *in vivo* dosimetry, the MOSFETs are placed on the surface of the patient to analyze the entrance or exit dose. In this study, we investigated the variation in the MOSFET response due to the angle of incidence of the beam, both with and without the brass build-up cap.

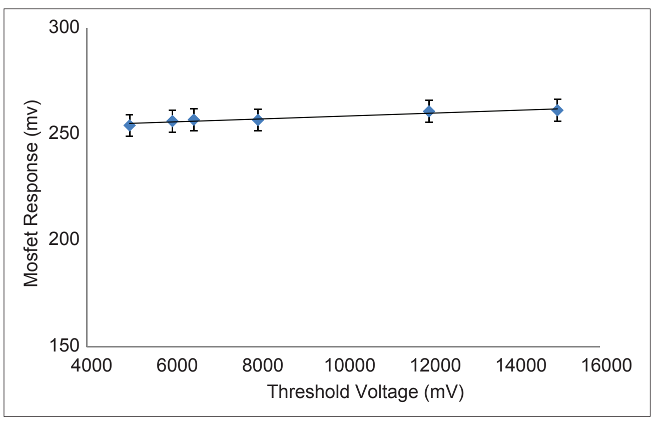

Figure 8: Threshold voltage vs. MOSFET response

The variation in the MOSFET response for the gantry angles from 0° to 180° was found to be ±2% when the brass build-up was used. However, if the proper build-up cap was not used, the MOSFET response showed major variations of about 6%, 25%, and 60% (max) for Co-60, 6 MV, and 15 MV photon beams, respectively. This study closely agrees with the study carried out by Ramaseshan *et al*. using micro MOSFET where the angular dependence was found to be ± 2% in a cylindrical phantom. While performing measurements on the surface of the patients, the MOSFETs should be used with the build-up.

Since the MOSFET dosimeters accumulate charge for every measurement, their threshold voltage gradually increases. The dependence of the MOSFET response with the threshold voltage was studied by irradiating the MOSFET dosimeter to the same dose at different threshold voltages, and it was observed that the MOSFET response did not depend on the threshold voltage. This observation is consistent with the results of Ramani *et al.*, who had also observed a uniform MOSFET response for various threshold voltages.

If appropriate build-up caps were used, there will not be a need for correction factors for the build-up for various energies. Hence, the build-up thickness required for the 6 and 15 MV beams were determined for the MOSFETs in acrylic, and one can fabricate appropriate build-up cap for each photon beam energy.

Conclusion

The performance characteristics of mobile MOSFET dose verification system were analyzed for megavoltage photon beams. It was observed that the MOSFET response is energy and dose rate independent for measurements at depth beyond d_m. Hence, this dosimeter can be used over a range of photon beam energy with no correction for energy and dose rate dependence. However, care should be taken to use the appropriate build-up cap

Table 2: A comparison of the characteristics of the mobile MOSFET dosimeter with the results of other investigators

Characteristics	*Soubra et al.*	*Ramaseshan et al.*	*Chung et al.*	*Cheng et al.*	*Varadhan et al.*	*Present study*
Reproducibility	±2%	-	±2%	±3%	-	±1%
Linearity	-	Linear	Linear	-	Linear	Linear: Co-60 and 6 MV Supralinear: 15 MV
Energy dependence	-	Uniform	-	-	<1% @ dm	±1% @ depth (Co-60, 6 MV, and 15 MV)
Dose-rate dependence	-	Independent (4 MV and 18 MV)	±3%	Uniform	±1%	Independent (Co-60, 6 MV, and 15 MV)
Angular dependence	-	±2% (4 MV and 18 MV)	±2%	-	±2%	With build-up: Independent Without build-up: Co-60: 6%, 6 MV: 25%, and 15 MV: 60%

MOSFET: Metal oxide semiconductor field effect transistor

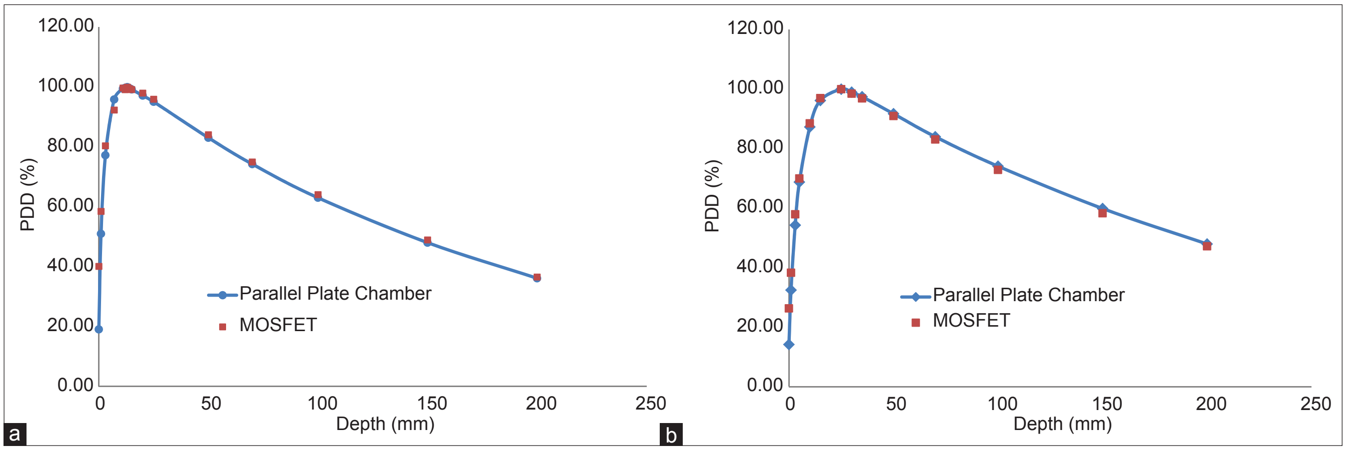

Figure 9: A comparison of MOSFET and parallel plate chamber measured percentage depth dose (PDD) for (a) 6 MV, and (b) 15 MV photon beams

while surface dose measurements are performed using this dosimeter. The build-up caps are required to attain the electronic equilibrium. This study explains the need for using build-up during surface dose measurements as insufficient build-up may affect the accuracy of the dosimeter readings. In this study, the use of brass build-up cap provided by the manufacture was studied; it was found to be sufficient for surface dose measurements. However, the brass build-up cap requires certain correction factors for photon beam energy other than 6 MV. The angular dependence of the MOSFETs for surface dose has been studied, and it is observed that without the build-up cap the MOSFETs exhibit angular dependence. Hence, the MOSFET dosimeter should be used with the build-up cap for entrance dose measurements. The ease of use and online readout makes the MOSFET an efficient *in vivo* dosimeter having the characteristics suitable for *in vivo* dose measurements in radiotherapy.

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