Volume 18, No 4 | International Journal of Radiation Research, October 2020

Investigation of surface and buildup region doses for 6 MV high energy photon beams in the presence of a thermoplastic mask

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[DOR: 20.1001.1.23223243.2020.18.4.2.2]

[DOI: 10.52547/ijrr.18.4.623]

▸ ***Original article***

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Revised: August 2019
Accepted: October 2019

Int. J. Radiat. Res., October 2020; 18(4): 623-631

DOI: 10.18869/acadpub.ijrr.18.4.623

ABSTRACT

Background: The accuracy and the reproducibility of radiotherapy can be provided by using immobilization devices such as thermoplastic masks. In head and neck cancer radiotherapy, the patients are mostly immobilized by using thermoplastic masks. In this study, the effect of the thermoplastic mask to the surface and buildup region doses was investigated by using Markus parallel plate ion chamber, Gafchromic EBT3 film and MOSFET detector for the same field size and different beam angles. ***Materials and Methods:*** The measurements were made in a water equivalent solid phantom at the surface and in the buildup region of the 6 MV photon beams at 100 cm source-detector distance for 10 × 10 cm^2 field size and beam angles of 0°, 30°, 60° and 80° with and without thermoplastic mask. ***Results:*** The surface doses in 0.07 mm depth using 6MV photon beams without a thermoplastic mask for 10 × 10 cm^2 field size were found 20.3%, 18.8%, and 41.5% for Markus chamber, EBT3 film, and MOSFET detector, respectively. The surface doses using 6 MV photon beams with a thermoplastic mask for 10 × 10 cm^2 field size were found 38.4%, 51.7% and 50.2% for Markus chamber, EBT3 film, and MOSFET detector, respectively. ***Conclusion:*** The thermoplastic masks placed on the surface of the medium affect the surface and buildup region doses. The effect of thermoplastic masks to surface and buildup region doses should be determined before use clinically.

Keywords: *Thermoplastic mask, surface dose, MOSFET, EBT3 film.*

INTRODUCTION

The dose that occurs at the boundary between air and phantom/patient is called surface dose. The contaminant electrons from the air and scattering materials in the path of the beam and the secondary electrons produced from irradiated patients are the two main components of surface dose. Due to the absence of electron equilibrium, a steep dose gradient takes place in the shallow depths of the buildup region which is called skin-sparing effect (1). In radiotherapy, megavoltage photon beams are utilized in most cases. When the photon energy increases, the surface dose decreases as a result of the skin-sparing effect. The use of beam modifiers such as blocks, Perspex trays, and immobilization devices causes an increase in the electron contamination of photons, which alleviates the skin-sparing effect of high energy photon beams. The dose in these depths is also related to the energy of the beam, source to skin distance (SSD), field size and obliquity of the beam (2).

The accuracy and reproducibility of radiotherapy treatments are extremely important. These parameters can be provided by using immobilization devices such as thermoplastic masks. In head and neck cancer radiotherapy, the patients are mostly immobilized by using thermoplastic masks. The use of plastic masks in daily treatment might have a side effect of increasing the surface dose. The published studies reported that the partial reduction of the skin-sparing effect of high energy photon beams is related to the use of thermoplastic masks (3). The reduction of the sparing effect leads to an increased risk of over-exposure of the skin that might result in acute radiation dermatitis, radiation burns or delayed effects [4]. In AAPM Task Group 176, it was reported that clinically relevant skin reactions can be produced by skin doses over about 25 Gy at 2 Gy per fraction. In addition to that, doses above 45 Gy can cause dry desquamation [5]. The knowledge of changes in surface dose while using immobilization masks could be useful for making treatment decisions.

The doses at the surface and buildup regions are difficult to measure. Nowadays, there are several commercial devices on the market to measure the doses in shallow depths, but none are as accurate as of the extrapolation ion chamber. An extrapolation chamber is a type of parallel plate ion chamber with a sensitive volume that can be changed by altering the distance between the collecting electrode and the entrance window [6]. Unfortunately, not all institutes have extrapolation chambers. The parallel plate ionization chambers with fixed electrode separation are commonly used for surface and buildup region doses measurements after making Gerbi's over-response corrections [7]. Due to their physical properties, these ion chambers can only be used with the phantom and cannot be performed in *in-vivo* dose measurements. Metal oxide semiconductor field-effect transistors (MOSFETs) and radiochromic films are good alternatives for surface and buildup region dose measurements and are appropriate for *in vivo* measurements.

Thermoplastic masks are mostly used for immobilized patients in head and neck cancer radiotherapy. However, any material placed between the radiotherapy field and the patient will affect the surface dose of the patient. In addition to that, treatment planning systems (TPSs) only predict surface and buildup region doses by calculations using their algorithms, but they still do not have enough accuracy for such shallow depths [8].

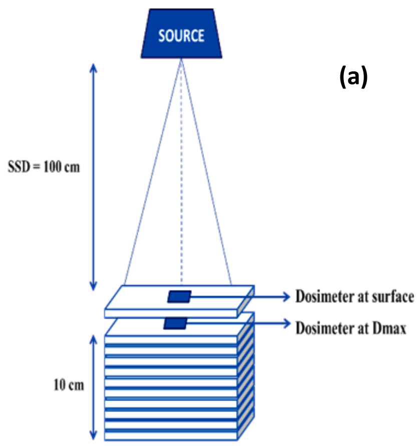
In our study, it was aimed to investigate the effect of thermoplastic masks on surface and buildup region doses by using the parallel plate ionization chamber which is the reference dosimeter for surface and buildup region dose measurements. Film and MOSFET dosimeters which can be used as in vivo dosimeters in patient dose measurements were compared with surface dose reference measurements obtained by parallel plate ionization chamber. The surface dose behaviors of Film and Mosfet dosimeters in the presence and absence of thermoplastic masks were investigated.

MATERIALS AND METHODS

Setup conditions

Surface and buildup region dose measurements were made using 6MV photon beams by utilizing Varian Trilogy linear accelerator (Varian, Palo Alto, CA). The doses in the buildup region were measured in water equivalent RW3 slab phantoms (SP34, PTW Freiburg, Freiburg, Germany). The RW3 water equivalent phantoms have a density of 1.045 $g.cm^{-3}$ and size of 40 x 40 cm^2. When compared to liquid water, RW3 has negligible uncertainties [9]. The Aquaplast thermoplastic mask, which has a thickness of 1.6 mm, was used on the phantom.

Markus parallel plate ionization chamber (Markus 23343, PTW Freiburg, Freiburg, Germany), Gafchromic EBT3 film (International Specialty Product, NJ, US), and a commercial MOSFET (TN-502, Thomson and Nielson Ltd., Ottawa, Canada) were used for surface and buildup region dose measurements. The irradiations were made for a field size of 10 x 10 cm^2 with SSD of 100 cm at 0, 1, 2, 3, 4 and 5 mm phantom depths (figure 1a).



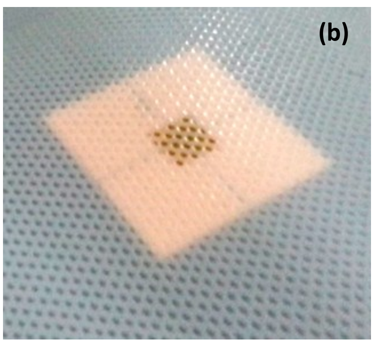


Figure 1. The setup condition of measurements **(a)** and the irradiation field in the presence of thermoplastic mask **(b).**

The doses at 15 mm (the D_{max} for 6 MV photon beams) were measured for each dosimeter to obtain percentage depth doses (PDDs). Source to detector distance was fixed in irradiations and then SSD corrected for 100 cm was applied to the results. In this study, the phantom surface was assumed to be the surface depth. The measurements with all dosimeters were repeated 3 times for an average value with and without the thermoplastic mask (figure 1b). The surface dose measurements were made perpendicular to the beam axis.

The dosimeters have different physical properties and different effective measurement depths. The effective depths of measurement are 0.023 mm, 0.153 mm and 0.8 mm for Markus chamber, Gafchromic EBT3 film, and MOSFET, respectively.

Markus parallel plate ion chamber measurements

The Markus parallel plate ion chamber was used for surface and buildup region dose measurements. The Markus chamber has a plate separation of 2 mm and the sidewall to collector distance is 35 mm. A Unidos dosimeter (PTW Freiburg, Freiburg, Germany) was used to obtain the relative ionization. The polarity effect of the dosimeter was corrected by using the equation (1) to acquire accurate ionization readings:

$$Q_{avg} = (Q_{+} + Q_{-}) / 2 \quad (1)$$

where the Q_{avg} is the average charge used for relative ionization and the Q_{+} and Q_{-} are the charges with positive and negative polarities, respectively. As mentioned above, the fixed separation parallel plate ion chambers require over-response corrections. The over-response problem occurs from the scattering electrons from the sidewall of the chamber. The overdoses in the buildup region were corrected for the Markus chamber according to Gerbi's method [10]. Calculated correction factors for PDDs are shown in table 1.

Gafchromic EBT3 film measurements

Gafchromic EBT3 films were utilized for surface and buildup dose measurements. EBT3 film is more sensitive compared to the previous version named EBT2, with its dose range from 1 cGy to 40 Gy. Also, EBT3 has some beneficial features such as its matte polyester substrate that prevents Newton's ring formation and the symmetrical form of the structure which allows for both-side scanning [11].

Table 1. Calculated correction factors for 6 MV photon beam.

Phantom Depth (mm)	Correction factor (%)
0	10,14
1	7,03
2	4,87
3	3,38
4	2,34
5	1,62
10	0,26
15	~0

The procedures described in the AAPM TG-55 report were applied to film measurements [12]. Before surface and buildup dose measurements, the films were cut into pieces sized 2.5 × 2.5 cm², placed between the slab phantoms at 5 cm where linac was calibrated 1 cGy equals to 1 MU and irradiated perpendicularly to 6 MV photon beams to create a calibration curve. The films were exposed with 0–800 cGy at field size of 10 × 10 cm². A flatbed Epson Expression 10000XL scanner (Epson America, Long Beach, CA, USA) was used to read the films 24 hours after irradiation. ImageJ software was utilized to find the red channel of the film which has the highest contrast through blue and green. The average readings of optical densities (OD) were obtained by using PTW Mephysto mc² software. A non-irradiated film piece (background) from the same batch was used to acquire the net ODs of the irradiated films. The background OD was subtracted from the exposed films. Then, the net ODs were paired with known absolute dose values to create a calibration curve which was used for converting net ODs to absolute doses.

The same setup condition of surface and buildup region dose measurements using a parallel plate ion chamber with and without of the thermoplastic mask was used for films.

[DOR: 20.1001.1.23223243.2020.18.4.2.2]

[DOI: 10.52547/ijrr.18.4.623]

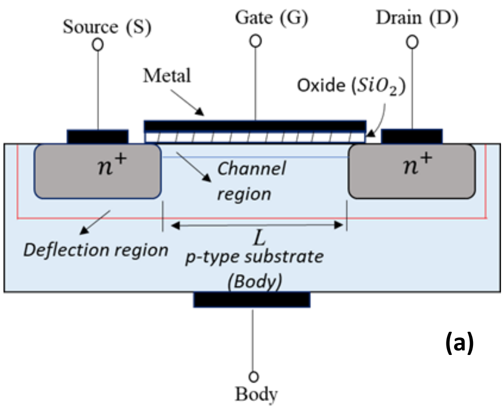
MOSFET measurements

In this study, TN502RD mobile MOSFET detector with standard sensitivity was used for surface and buildup region dose measurements. The components of MOSFET detectors are a P-type silicon semiconductor substrate, a metal gate, and an insulating oxide layer. Irradiation produces electron-hole pairs in the oxide layer and some of the holes move through to silicon substrate under a bias voltage and get trapped. This leads to a change in the gate threshold voltage for the source-drain conductivity. The change in the threshold voltage is a function of the absorbed dose [13].

The dosimeter used in this study is 2.5 mm long, 2 mm wide, and 0.3 mm thick, with an active area of 0.2 mm^2 which is covered by an epoxy bulb. The dose verification system of the MOSFET has a TN RD 70 W reader module, a wireless transceiver, and software program for dose verification. In this study, the bias setting of the reader module was chosen to be 1 mV/cGy (standard bias), instead of 2.7 mV/cGy (high sensitivity bias).

The calibrations of the detectors were carried out for a 10 × 10 cm^2 field size with SSD of 100 cm, performing 6 MV photon beams, using water -equivalent slab phantoms and a special acrylic phantom at a specific phantom depth where 1 cGy equals 1 MU before the measurement (figure 2). The physical dimension of the acrylic phantom is 30 × 30 × 1 cm^{3}and it has 5 hollows on the surface in which to place the detectors. After the calibration process, the calibration factors for each detector were obtained.

The detectors which have the appropriate calibration factors and smallest deviation values were chosen for surface and buildup region dose measurements under the same irradiation conditions as the Markus chamber and film measurements. The results were presented in the format of average and standard deviation. We used Wilcoxon *T-test* to determine the variations between the masked and unmasked measurements taken by Markus parallel plane ion chamber, EBT3 film, and MOSFET dosimeters. P<0.05 was defined as statistical significance.



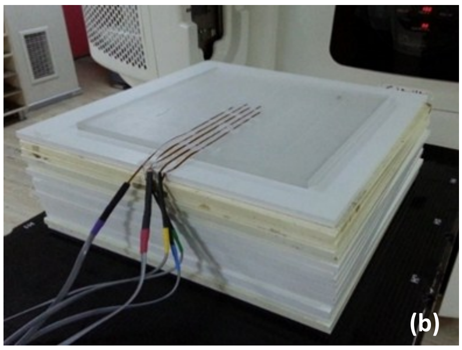


Figure 2. The schematic structure of the MOSFET detector **(a)**; The setup condition of the MOSFET detectors with the acrylic phantom **(b)**.

RESULTS

The percentage depth doses at the surface and buildup regions for 6 MV high energy photon beams for a field size of 10 ×10 cm^2 measured with and without of a thermoplastic mask using the Markus parallel plate ion chamber, Gafchromic EBT3 film, and MOSFET dosimeter are shown in figure 3.

The figures demonstrate that the presence of a thermoplastic mask reduces the skin-sparing effect of megavoltage photon beams and shifts the maximum dose depth closer to the surface. The use of a thermoplastic mask increased the surface and buildup region doses for all measurements. The differences were found to be lower at deeper depths of the phantom due to a gain of charged particle equilibrium.

The PDDs were also calculated for the first 5 mm of phantom by using polynomial and interpolation under consideration of the effective depths of measurement for each dosimeter with and without the thermoplastic mask (figure 4). The water phantom is the best tool for dosimetric measurements but it is not appropriate for the surface and buildup region dose measurements due to physical properties of water and dosimeters. Therefore, the water equivalent thickness (WET) of the phantom was used for this calculation to obtain the doses as were measured by utilizing the water phantom.

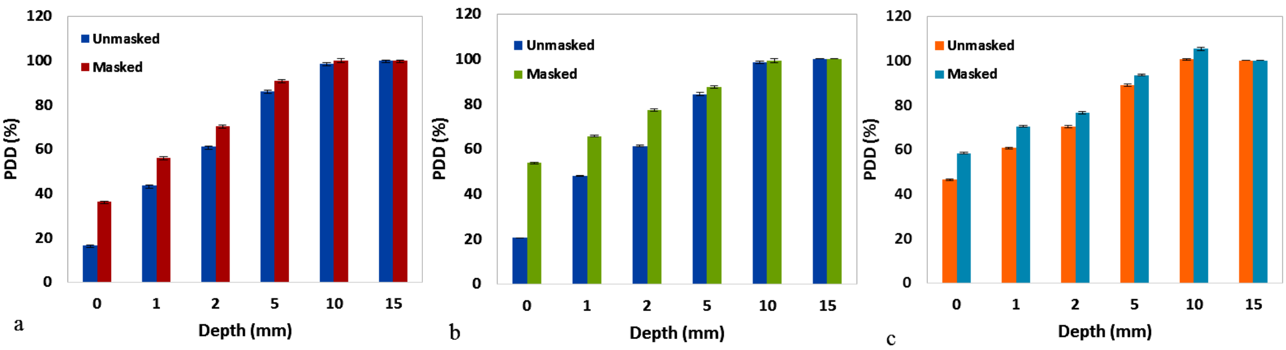


Figure 3. Percentage depth doses (PDDs) at surface and buildup regions for 6 MV photon beams with and without thermoplastic mask using **(a)** Markus parallel plate ion chamber (p=0.043); **(b)** Gafchromic EBT3 film (p=0.043) and **(c)** MOSFET (p=0.043).

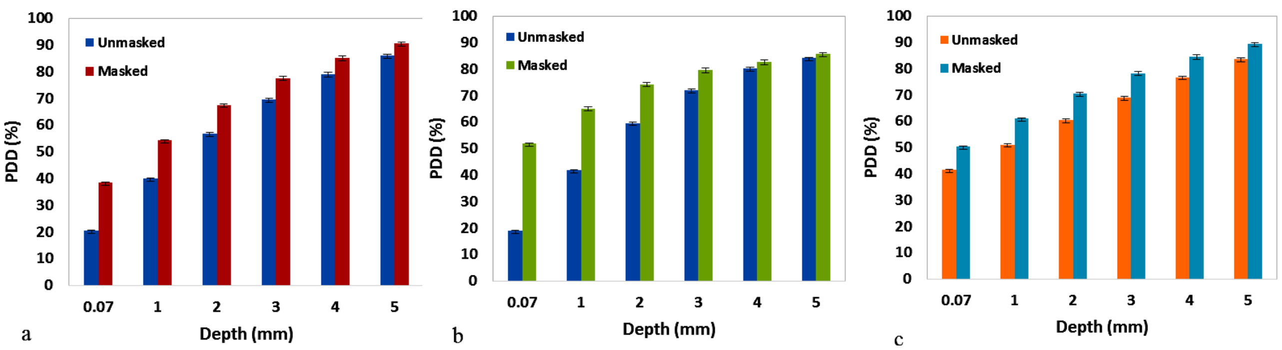


Figure 4. Interpolated percentage depth doses (PDDs) at the first 5 mm of the phantom for 6 MV photon beams with and without of a thermoplastic mask using the **(a)** Markus parallel plate ion chamber (p=0.028), **(b)** Gafchromic EBT3 film (p=0.028), and **(c)** MOSFET (p=0.028).

The use of a thermoplastic mask increased doses at the first 5 mm of the phantom for all measurements. The average differences between the open and the masked field were found to be 10.3%, 14.1% and 8.6% for the Markus chamber, EBT3 film, and MOSFET, respectively.

The angular response of each dosimeter was investigated with measuring the PDD at the surface of the phantom using oblique beam angles of 30º, 60º and 80º. A fixed SSD of 100 cm and a field size of 10 × 10 cm^2 were used. The measured doses were normalized to the maximum dose using a gantry angle of 0º to obtain PDDs. The results are shown in figure 5.

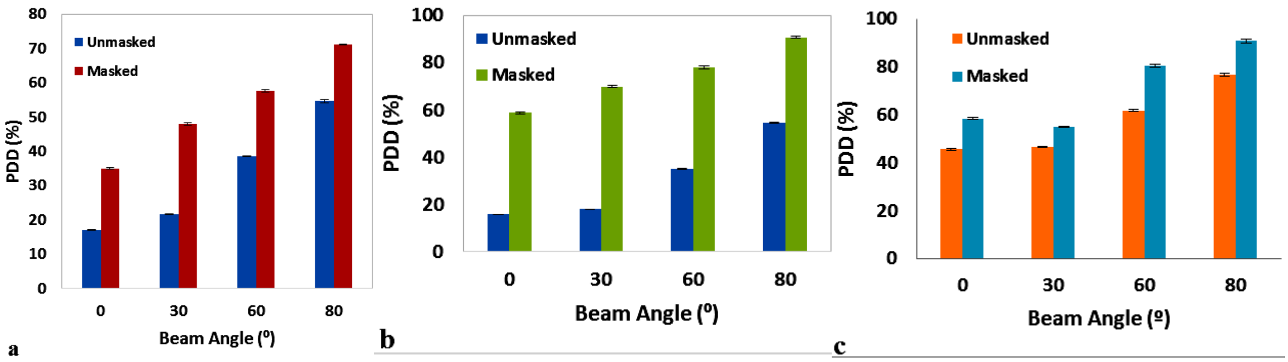


Figure 5. Percentage depth doses (PDDs) for 6 MV oblique incident beams measured with the **(a)** Markus chamber ($p < 0.05$); **(b)** EBT3 film ($p < 0.05$) and **(c)** MOSFET ($p < 0.05$) respectively, at the phantom surface for unmasked and masked fields.

DISCUSSION

The absorbed dose at any point in the medium produced by electron fluence is characteristic of photon energy fluence some distance upstream of megavoltage energies. In this distance, photon attenuation occurs. This attenuation is felt much more in the first few millimeters of the medium because the charged particle equilibrium does not exist [(14)]. Therefore, the maximum dose is deposited at depth in medium instead of on the surface. In the presence of any material in the pathway of the photon beam, secondary electron contamination occurs, which is one of the reasons for the surface dose increase. A thermoplastic mask is an immobilization tool that is generally used in head and neck cancer radiotherapy. In this study, the effect of the thermoplastic mask on the surface dose of the high energy photon beam is investigated by using a parallel plate ion chamber, radiochromic film, and MOSFET. Also, the angular response of the dosimeters was studied in the presence of the mask.

In our study, the surface dose was found to be 16.6±0.9% for 10 × 10 cm^2 open field by using the Markus parallel plate ion chamber. Jong *et al.* [(15)] performed surface dose measurements at a depth of 0 mm for 6 MV (Varian Clinac 2100 C/D linear accelerator) photon beam. The dose at the surface was found to be 15.8±0.03% for a field size of 10 × 10 cm^2. Bilge *et al.* [(16)] measured the surface dose with the Markus parallel plate ion chamber for 6 and 18 MV (Siemens Oncor Impression Plus linear accelerator) photon beams and the result was found to be 15.0% for a field size of 10 × 10 cm^2.

Devic *et al.* [(17)] used radiochromic EBT film in their skin dose investigation. They measured the dose at 0.153 mm depth 19.9% for 6 MV (Varian Clinac 2100 C/D linear accelerator) photon beams. The field size for measurement in their study was 10 x 10 cm^2. Bilge *et al.* [(16)] also used EBT model radiochromic film and found the surface dose at the top of the phantom 20.0±2% for a field size of 10 x 10 cm^2. Qi *et al.* [(8)] investigated the dose at 0.153 mm for the same field size stated above and the result was 23.5%. Our investigation presents coherency with the previous studies.

MOSFET dosimetry has some advantages such as physical properties, rapid response, reproducibility, and suitability for *in vivo* surface dosimetry [(18)]. The surface dose was found to be 46.4±1.6% at the top of the surface for an open field with a size of 10 × 10 cm^2 by using MOSFET detector. Jong *et al.* [(15)] also measured the surface dose with the MOSkin detector which has an effective measurement depth of 0.07 mm and the surface dose was found to be 20.27±0.03%. The difference between our study and that of Jong is strongly related to the effective depths of dosimeters. Qi *et al.* [(7)] used MOSkin which has a 0.145 mm WET and the surface dose for a field size of 10 × 10 cm^2 was found to be 46.0±1.5%, which is close to our results with the MOSFET detector.

The surface doses were found to be 38.4%, 51.77% and 54.6% in the presence of a

[DOR: 20.1001.1.23223243.2020.18.4.2.2]
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thermoplastic mask for the Markus parallel plate ion chamber, Gafchromic EBT3 film, and MOSFET, respectively. These values reached 56.1%, 65.6% and 70.4% in the first mm of the phantom for Markus parallel plate ion chamber, Gafchromic EBT3 film, and MOSFET, respectively. Halm *et al.* [18] reported that the percentage depth dose under the mask for 4 and 6 MV photon beams increased from 49.5% to 63.2% at the first 0.5 mm and from 59% to 70.1% at 1 mm depth. Oh *et al.* [20] studied the effect of Aquaplast on surface dose for 6 MV (Siemens Mevatron 6740 linear accelerator) photon beams by using the Markus chamber and reported that the surface dose increased from 13.6% to 43.6% for a field size of 10 × 10 cm^2. Półtorak *et al.* [21] supported that the use of a thermoplastic mask causes the increasing of the therapeutic area which is located directly below the surface of the body. The group reported that by the use of thermoplastic masks, surface dose increases from 10% to 42% for 6 MV.

Fiorino *et al.* [3] investigated the reduction of skin-sparing effect in the presence of thermoplastic masks. They found that the surface and buildup region doses were increased with different types of masks but the maximum dose differences between the open field and masked field were found to be lower than 0.5% at the dose maximum depth. The differences in the results between our study and the published studies are strongly related to linear accelerators and the thermoplastic masks used.

The effective measurement depth of the dosimeters and the WET values was studied in our previous study [22]. We calculated the dose using extrapolation and interpolation at 0.07 mm which is recommended by The International Commission on Radiation Units and Measurements (ICRU) and the International Commission on Radiological Protection (ICRP) for the surface dose assessment. The doses at 0.07 mm were found to be 20.3%, 18.8% and 25.5% without a thermoplastic mask, 38.4%, 51.7% and 36.4% with a thermoplastic mask using the Markus chamber, EBT3 film, and MOSFET, respectively. These differences of the PDDs that depend on the mask show the size of the effect of Aquaplast thermoplastic material on the surface dose. Qi *et al.* [8] took WET values into account and found the surface dose at an open field size of 10 x 10 cm^2 to be 18.9%, 23.5%, and 19.5% for Attix chamber, EBT film and MOSkin detector, respectively.

The previous studies reported that the oblique beams create an increase in the surface dose due to the charged particle equilibrium region moving towards the surface [14]. In this study, the angular response of the dosimeters with and without the Aquaplast thermoplastic mask was investigated. Maximum increases in the surface dose were found at 80º beam angle for all dosimeters in all setup conditions. Qin *et al.* [23] studied the angular dependence of the MOSFET dosimeter and found the maximum increase at a beam angle of 72º. Some investigators found that the relative dose might be 50% larger at a beam angle of ~55º [24, 25]. Figure 5 shows that the MOSFET measurements gave the highest results at all beam angles compared to the Markus ion chamber and EBT3 film ($p < 0.05$). Figure 5 also shows that the presence of the Aquaplast thermoplastic mask gave an extra increase to the surface dose at all beam angles for all dosimeters in addition to the oblique incident of beams. The biggest increase due to the presence of a thermoplastic mask was obtained from the EBT3 film. We assume that this result of EBT3 film was related to its physical property. Devic *et al.* [17] reported that even the thin structure of EBT film could increase the surface dose due to a steep dose gradient of the buildup region.

Hadley *et al.* [26] studied the effect of thermoplastic mask on surface dose by using the Attix chamber and found that the surface dose was increased from 16% to 61% with a mask but the dose at the surface changed to 48% or 29% by stretching the mask by 125% or 525%, respectively. They also pointed out that the measured dose had two components which include the dose under the hole and the dose under the mask material. In the daily use of a thermoplastic mask, it is not possible to know how much the mask is stretched. Therefore, in our study, a standard type thermoplastic mask with 1.6 mm thickness was used to assess the average increase in surface dose measurement with the Markus ion chamber, EBT3 film, and MOSFET.

The MOSFET dosimeter gave the highest results for all conditions of irradiation compared to the Markus chamber and EBT3 film at the physical phantom depths as a result of the WET value of the dosimeters. The biggest differences in surface doses between the with and without of mask material were found in the EBT3 film due to its physical properties. However, in the open field irradiation, EBT3 showed a close agreement with the Markus ion chamber. Both EBT3 film and the MOSFET dosimeter are suitable for *in-vivo* surface dosimetry. The EBT7 film has advantages like tissue equivalency and homogeneity, but it is not practical and also time -consuming, requiring a calibration curve and time for scanning to acquire the absolute dose. However, the MOSFET dosimeter gives the results rapidly and is easy to use. The MOSFET dosimeter can be calibrated with reference dosimeter for its over-estimation problem in the surface dose measurements.

According to our results, in *in-vivo* surface dose measurements, the over responses of the MOSFET and the EBT3 film are not same in the presence and absence of the thermoplastic mask. Thus, correction factors should be determined for these dosimetric tools in the presence of the thermoplastic mask.

CONCLUSIONS

In the presence of the thermoplastic mask, for buildup region measurements, MOSFET and EBT3 film give close results to each other. According to the results, both of the dosimetry systems measure the doses in the surface and buildup region more than Markus parallel plate ion chamber which is accepted as a reference dosimeter. This should be taken into account in the assessment of the surface and buildup region doses.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not for profit sectors.

Conflicts of interest: *Declared none.*

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