ORIGINAL ARTICLE

Surface and the Build-up Dose Distribution Due to Applying Thermoplastic Masks in External Radiotherapy

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Abstract

Background: Thermoplastic immobilization devices are used to position the patient on the table in order to correctly reposition the patient during treatment courses.

Objective: The Purpose of this work is investigating the degradation of surface dose and the dose distribution in the build-up region for photon beams associated with immobilization devices using Gafchromic films.

Materials and Methods: After heating, these masks are stretched and fitted over the considered location of body before treatment simulation for insuring the reproducibility of patient position during treatment fractions. In this research, dosimetry was carried out using Gafchromic EBT3 film and three kinds of thermoplastic masks (Orfit with thickness 2.2mm, holes diameter 2.5mm, Orfit with thickness 2mm, holes diameter 1mm, and Klarity mask, thickness 2mm, holes diameter 3mm). Measurements were made with and without the mask materials on the surface of the Perspex phantom for 6 and 15 MV X-ray beams of a LINAC machine.

Results: The results showed that surface dose increases 2.1 to 6.7 times and 2 to 3.9 times than the surface dose in the open field for 15 MV and 6 MV photons, respectively. According to the obtained results from the Analyses of Variances (ANOVA) test , it is defined that there is a significant difference in surface dose among three kind of thermoplastic masks (χ^2=49.78 and df=3 and P<0.0001). The surface dose in Klarity has a significant difference in comparison of other masks according to PostHoc exams and there is no significant difference among two other masks (P>0.05).

Conclusion: According to the results, Klarity mask is more acceptable immobilization device when compared with other masks in the test.

Keywords: Thermoplastic Mask; Linear Accelerator; Surface Dose.

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1. Introduction

Treatment of cancers requires a high level of accuracy in the positioning of the patient for daily treatments, especially in the regions of high mobility such as head and neck. In order to correctly reposition the patient on the table during treatment course some immobilization masks are used. Typically, masks made of polyvinyl chloride (plastic) (PVC) or thermoplastic material such as Orfit or Klarity masks (Orfit Industries America, Wijnegem, Belgium) are used as immobilization systems for fixation. The thermoplastic mask can increase the surface dose to the patient and compromise the skin-sparing effect of high energy X-ray beams [1].

Skin cells originate from rapidly reproducing differentiated stem cells in the dermis, and therefore are highly radiosensitive [2]. Skin reactions observed during radiation treatment occur due to an inflammatory response and depletion of these actively reproducing cells by the accelerated cellular loss caused by radiation. Acute skin reactions are common with patients undergoing radiation therapy for different parts of the body. Skin color changes resulting from radiation exposure can become apparent within days of the first exposure, which include complications such as erythema, hyperpigmentation, dry desquamation, and moist desquamation [3].

Imperfection of treatment planning systems has been studied in several works [4, 5]. However, one of the issues regarding treatment planning systems is the lack of dosimetric accuracy in the surface and buildup region. Chung et al. [6] used radiochromic films to measure shallow IMRT doses and reported that commercial treatment planning systems overestimated surface dose by 7.4%–8.5%.

Several studies reported increases in skin dose due to immobilization masks [7-12]. These masks, after forming to fit the body shape, are inserted into a carbon fiber base to increase the reproducibility of the positioning. Imad Ali et al. [10] reported that the surface dose under the mask is significantly larger by up to 3.1 and 4.2 times than the surface dose in the open field for 6 MV and 18 MV photons, respectively. Radaideh [8] reported that the Klarity mask used for patient immobilization increased the surface dose by

10.83% more than that without the mask, in which the average variations were in ranges of 10.26 to 11.83%. Lee et al. [3] measured about 18% average increase in skin dose underneath an immobilization mask. Hadley et al. [11] and Kelly et al. [9] were also showed a remarkable increase in surface dose in using immobilization masks.

Our clinic noticed an earlier onset of skin toxicity in different parts of patients' body especially in head, neck, and breast by implementing this immobilization system. So, despite previous reports, we decided to perform our experiments to clarify the issue.

The purpose of this work was to determine the increase in surface dose and also the dose distribution in the build-up region as a result of using three types of thermoplastic masks in two different field sizes and two different beam angles using Gafchromic EBT film. Learning the effect of these masks on surface dose allows selecting materials that best preserve skin sparing. The results of these experiments help clinicians anticipate potential dose limitations.

2. Materials and Methods

For this work, three kinds of thermoplastic masks (Orfit with thickness 2.2mm, holes diameter 2.5mm (hereafter, Orfit(L)), Orfit with thickness 2mm, holes diameter 1mm (hereafter, Orfit(s)), and Klarity mask, thickness 2mm, holes diameter 3mm) and also one sheet of Gafchromic EBT3 film, a water phantom for calibration, 10 sheets of Perspex phantom each with 1cm width (a 10cm Perspex phantom) were used. For scanning the irradiated films, a reflective flatbed color scanner (HP Officejet J4580) was used. Irradiating of the samples were carried out using LINAC machine (Siemens Primus) with output of 200cGy/min, 1cGy/MU at dmax in 10×10 field, with two photon modes (6 and 15MV) (Figure 1).

The EBT3 film was cut into 2×2 cm^2 pieces from a single sheet 1 day prior to irradiation to allow the relaxation of mechanical disturbances around the film edges. The film was then placed over the Perspex phantom facing the radiation source to provide sufficient backscattering conditions (Figure 1-c).
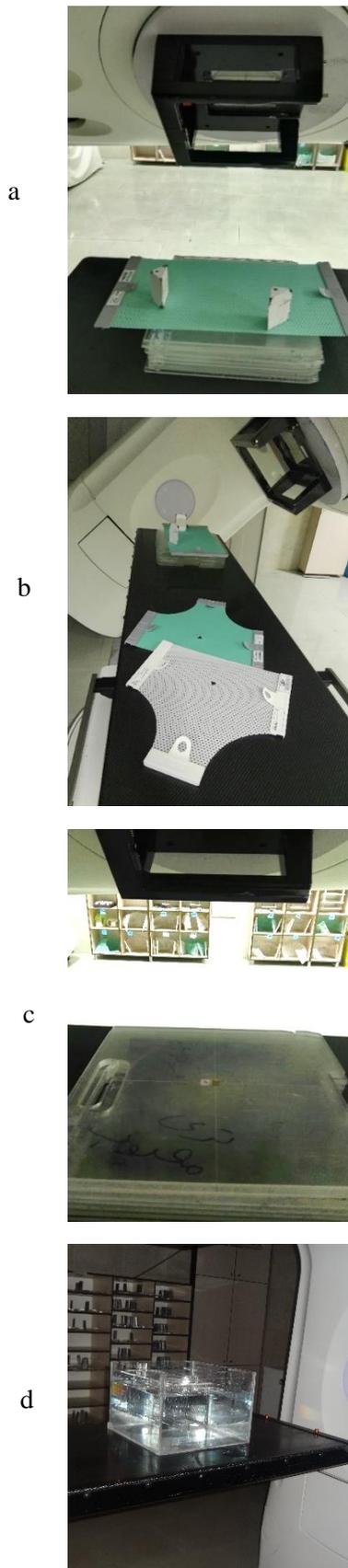
Figure 1. a) Machine set up, b) Masks, c) Perspex sheets, and d) Water phantom for calibration

The films were positioned at a Source to Surface Distance (SSD) of 100 cm. The field sizes used were $10\times10cm^2$ and $20\times20cm^2$. Film pieces were irradiated to 20MU in both 6 and 15MV energies in two different gantry angles, i.e., 0 and 45°. The calibration films were irradiated to 5, 10, 15, 20, 50, and 100 cGy at the depth of 7cm using a $30\times30\times30$ water phantom (Figure 1-d). The film doses were calibrated against the ion chamber (0.6cc Farmer type ionization chamber) measurement at the same location and depth. The output was calibrated per AAPM TG-51 protocol [13] with 2% uncertainty. The irradiated EBT3 films were scanned in the reflective mode of scanner in 48-bit RGB mode, and 300-dpi resolution with regarding consideration of Alva *et al.* [14].

In film handling and storing the recommendations of the AAPM TG-55 report [15] were used; such as minimizing exposure to light and keeping films together to avoid differences in thermal histories. The scanner was initialized by acquiring 3 blank scans and a consistent direction for films was maintained for all scans.

In practice, it is necessary to distinguish if the orientation is portrait or landscape when the film is scanned and scan all films in the same manner. This may be challenging after the film is cut, so it is particularly important to clearly mark pieces of the film obtained from whole sheets to indicate their orientation with respect to the original.

Data extraction was performed in all three channels and then images were processed with an in-house program written with MatLab (The Mathworks, Inc, Natick, MA).

Films were scanned at least 24 hours after exposure. For maximizing the uniform response of the scanner, the central area of the scanner (10×15 cm^2) was used and other parts were covered with dark paper.

The net optical density of exposed, unexposed, and dark film samples (netOD) were calculated using Devic *et al.* [16] proposed formula (Equation 1):

$$NetOD(D) = log_{10}\left(\frac{I_{unexp}-I_{bckg}}{I_{exp}(D)-I_{bckg}}\right) \qquad (1)$$

Where I_{unexp}, and $I_{exp}(D)$ are the readings for unexposed and exposed film, while I_{bckg} is the reading from the dark image.

The reflective scanner readings (I_{unexp} or I_{exp}) as well as the standard deviations (σI_{unexp} or σI_{exp}) were determined for every film piece as a mean pixel value over the ROI ($5\times5mm^2$) in three separate measurements and two consecutive scans.

The zero-light transmitted intensity value (I_{bckg}), which characterizes the background signal of the scanner, as well as its corresponding standard deviation (σ_{bckg}), were determined over the same ROI with an opaque piece of film. The dose and netOD deviations of sample films were calculated using Devic et al. [16] applied formula (Equation 2, 3):

$$\sigma_{netOD} = \frac{1}{ln10} \sqrt{\frac{\sigma^2 I_{unexp} + \sigma^2 I_{bckg}}{(I_{unexp} - I_{bckg})^2} + \frac{\sigma^2 I_{exp} + \sigma^2 I_{bckg}}{(I_{exp} - I_{bckg})^2}} \qquad (2)$$

$$\sigma_D = \sqrt{(b + n.c.netOD^{n-1})^2 . \sigma_{netOD}^2} \qquad (3)$$

The buildup effect of the masks was determined by measuring PDDs with and without the mask on the surface of the phantom. Percentage dose depth was determined by using the Equation 4.

$$PDD\ (d, A, SSD, E) = \frac{D\ (d)}{D\ (dMax)} \times 100\% \qquad (4)$$

Where d represents depth of measurement, A, radiation field size, SSD, Source Skin Distance, E, energy, $D(d)$ represents dose at depth d and $D(d_{max})$, the maximum dose

3. Results

Figure 2 illustrates response curves of radiochromic films exposed to different doses of LINAC in both energies for all three channels of the flatbed scanner.

As the Figure demonstrates the red channel has the highest sensitivity to dose especially in low doses and the blue channel has nearly identical responses for all ranges of doses.

In the calibration curves net optical density of films were depicted against dose. Figure 3 demonstrates the calibration curves in both energies for both red and green channels of the scanner. The data points for red
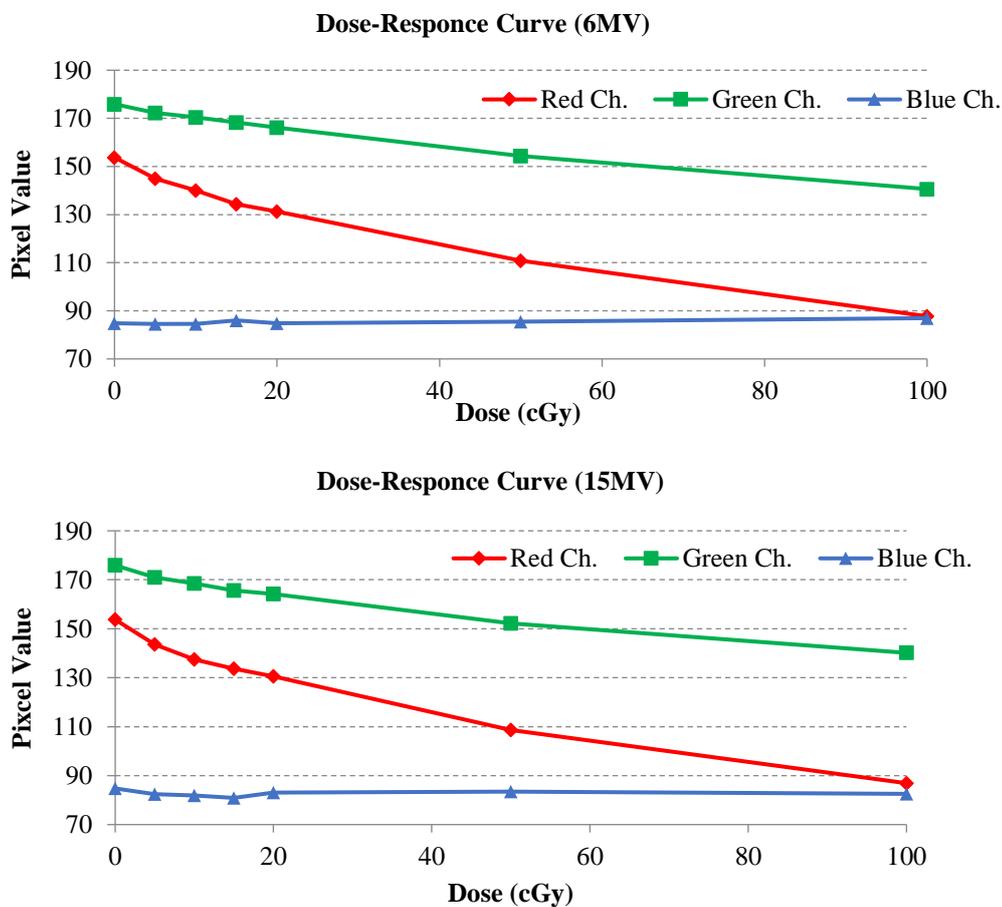
Figure 2. Response curves of radiochromic films exposed to different doses of LINAC in both energies for all three channels of the flatbed scanner
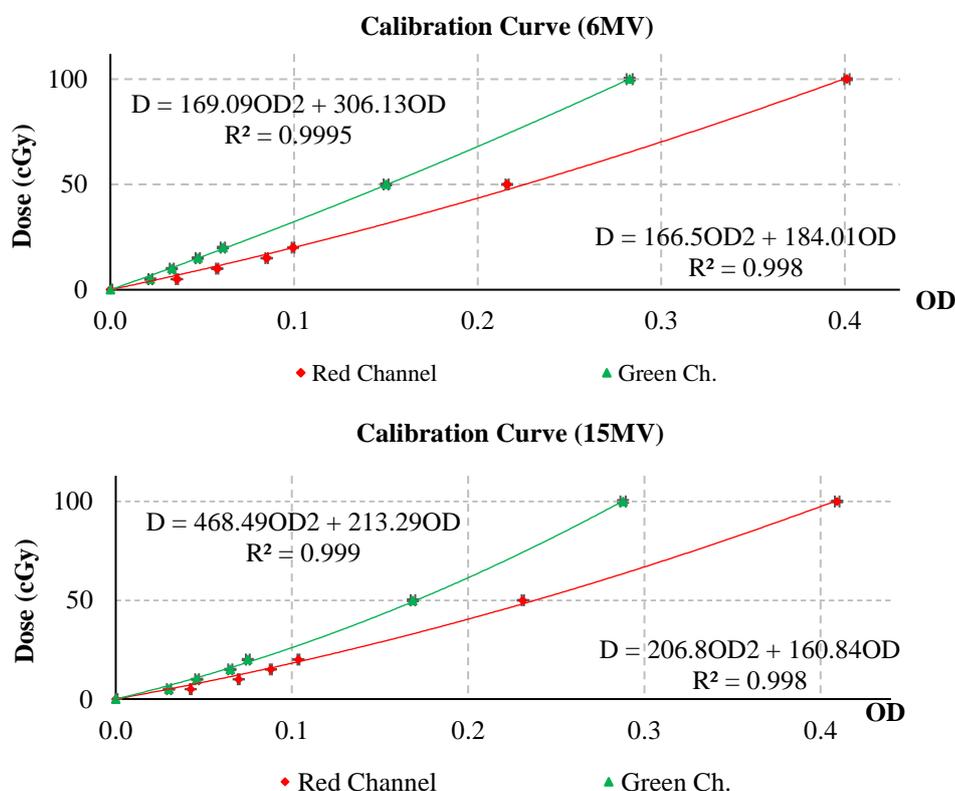
and green color channels were fitted to a two-order polynomial (Figure 3).

Error bars in Figure 3 represent 95% certainty for measured and calculated values of netOD and dose.

Table 1 lists surface dose (cGy) for both 6 and 15MV energies with and without applying three different thermoplastic masks that are routinely used in our clinic. Because of the red channel's maximum sensitivity to dose response, i.e., greater color variation per unit dose, for deriving the effects of thermoplastic mask on the surface dose, the red channel's data were used.

As it is depicted in Table 1, the surface dose significantly increases when we use thermoplastic masks. According to the obtained results from the Analyses of Variances (ANOVA) test , it is defined that there is a significant difference in surface dose among three kind of thermoplastic masks $\chi^2 = 49.78$ and df = 3 and P<0.0001). In 6MV energy, the surface dose, in 10×10 open field, is 3.3±1.7 cGy (16.5% of d_{max} dose), whilst this increases up to 12.6±2.0 (63% of d_{max} dose), 13.1±2.0 (65.5% of d_{max} dose), and

9.5±1.9 cGy (47.5% of d_{max} dose), when we use Orfit(L), Orfit(s), and Klarity masks, respectively and in 15MV energy, in 10×10 open field, is 1.3±1.7 cGy (6.5% of d_{max} dose), whereas this increases up to 8.5±1.9 (42.5% of d_{max} dose), 6.9±1.8 (34.5% of d_{max} dose), and 6.5±1.8 cGy (32.5% of d_{max} dose), when we use Orfit(L), Orfit(s), and Klarity masks, respectively. According to statistical tests for all circumstances, the surface dose in Klarity has a significant difference in comparison to other masks according to PostHoc exams (P<0.05) and there is no significant difference among two other masks (P>0.05). As expected, surface dose, in low energy (6 MV), because of more scattering to surface, is higher than high energy (15MV) and corresponding surface doses under the masks are higher in low energy than high energy. Moreover, the Table also clarifies that Klarity mask creates lower surface dose than Orfit masks. It is also demonstrated in Table 1 that surface dose, except a few cases, in 20×20 fields are higher than10×10 fields, and also with tilting the gantry to 45° it increases for both field sizes.

Calibration Curve (6MV)

$$D = 169.09OD2 + 306.13OD$$
$$R^2 = 0.9995$$

$$D = 166.5OD2 + 184.01OD$$
$$R^2 = 0.998$$

Red Channel   Green Ch.

Calibration Curve (15MV)

$$D = 468.49OD2 + 213.29OD$$
$$R^2 = 0.999$$

$$D = 206.8OD2 + 160.84OD$$
$$R^2 = 0.998$$

Red Channel   Green Ch.

Figure 3. Calibration curves of radiochromic films exposed to different doses of LINAC in both energies in terms of OD versus dose for red and green channels of flatbed scanner

Table1. Surface dose (cGy) in presence of masks and open field for 6 and 15MV energies

Energy	FieldSize	Angle	Klarity	Orfit(S)	Orfit(L)	Open Field
6MV	**10×10**	0	9.5±1.9	13.1±2.0	12.6±2.0	3.3±1.7
		45	10.8±1.9	16.9±2.1	16.7±2.1	5.5±1.8
	20×20	0	14.1±2.0	14.8±2.0	15.0±2.1	5.4±1.8
		45	15.2±2.0	15.8±2.0	17.5±2.2	6.5±1.8
15MV	**10×10**	0	6.5±1.8	6.9±1.8	8.5±1.9	1.3±1.7
		45	7.5±1.8	10.1±1.9	9.9±1.9	1.9±1.7
	20×20	0	9.0±1.9	9.7±1.9	9.1±1.9	3.4±1.7
		45	9.7±1.9	10.8±1.9	12.2±2.0	4.6±1.8

In Table 2, the ratio of surface dose with masks to open field was listed. As it could be observed, the surface dose increases 2.1 to 6.7 times and 2 to 3.9 times than the surface dose in the open field for 15 MV and 6 MV photons, respectively.

4. Discussion

One of the issues regarding treatment planning systems is the lack of dosimetric accuracy in the surface and buildup region.

In our study, as it is demonstrated in Table 1, there are significant differences ($P<0.05$) in surface dose between Klarity and both Orfit masks and also between them and open field. Some differences also exist between two different field angles, and between two different field sizes, however, regarding the amount of uncertainties and significance level, they are not significant, except in one case (between

different field sizes in applying Klarity mask) and in a number of instances, because of low level of radiation, high deviations exist within the data sets (i.e., in 15 MV energy with 10×10 field size in open fields of both angles).

Apparently, higher thickness of Orfit(L), which increases the surface dose, predominates larger hole size which decreases the surface dose. Therefore, the surface dose rising with applying Orfit(L) is a little higher than those of Orfit(S).

As it could be concluded from Table 2, increase of surface dose in open fields in most instances is proportion to the masked fields except in two cases (20×20 field in applying Orfit(L) mask in both energies) and by tilting the gantry the role of scattered

Table 3 exhibits the depth of 90% and the depth of dmax measured with and without a mask for both fields and both energies.

Table 2. The ratio of surface dose with masks to "open field" (OF)

Energy	FieldSize	Angle	Klarity/OF	Orfit(S)/OF	Orfit(L)/OF
6MV	10×10	0	2.9±0.9	3.9±1.4	3.8±1.4
		45	2.0±0.3	3.1±0.6	3.0±0.6
	20×20	0	2.6±0.5	2.8±0.5	2.8±0.5
		45	2.3±0.3	2.4±0.2	3.2±0.6
15MV	10×10	0	5.2±5.4	5.5±5.8	6.7±7.4
		45	4.0±2.7	5.4±3.9	5.3±3.8
	20×20	0	2.6±0.8	2.8±0.9	2.6±0.8
		45	2.1±0.4	2.4±0.5	2.7±0.6

Table3. The depths of 90% and depths of maximum dose [mm]

Energy	FieldSize	PDD (%)	Klarity	Orfit(S)	Orfit(L)	Open Field
6MV	**10×10**	90%	5	6.5	5.2	7.1
		100%	13	14.2	14	15.5
	20×20	90%	4	5.1	4.7	5.9
		100%	12.1	12.9	12.5	14.1
15MV	**10×10**	90%	9.5	10.8	10.1	11.8
		100%	25.1	26	25.2	27.2
	20×20	90%	8.2	8.5	8.3	9.2
		100%	18.8	20.9	19.2	22

radiation in surface dose elevation in open fields preponderate the increase of scattering for masked fields. The reason for declared exceptions isn't clear. It seems, repeated experiments with higher amounts of MUs and so lower uncertainty can clarify the issue.

Table 3 revealed that, the PDD and isodose is reached at shallower depth, in case of using thermoplastic masks. In some techniques of radiotherapy this shift in PDD can be useful and behaves like a bolus but dose changes should be considered. As it illustrates in Table 3, compared to the situation without mask, build-up region occurs more rapidly and near to the surface, this may possibly an advantage in providing the full prescribed dose for organs positioned very superficially and negate the skin sparing effect of megavoltage photons, however this dose proliferation may not always be sufficient. For 6 MV, the average depth shift in the entire area of the build-up region towards the surface was 1.3 mm, and for 15 MV it amounted to 1 mm.

As it is depicted in Table 3 of Hadley *et al.* 2005 [11], surface dose in open field for 6 and 15MV energies are 16% and 12% of d_{max} and increases to 52% and 34% of d_{max} for un-stretched masks and reduces to 27% and 18%, by maximum stretching for large hole masks and for small hole masks increases to 61% and 40% of d_{max} for un-stretched masks and reduces to 29% and 19% by maximum stretching, respectively. It is obvious in comparing the results of our work with the others we considered the unstretched masks that are relatively similar to Hadley's findings. Our findings are also somewhat similar to results of Imad Ali *et al.* [10] who reported that the surface dose under the mask is significantly larger by up to 3.1 and 4.2 times than the surface dose in the open field for 6 MV and 18 MV photons, respectively. There are also similarities in the amount of surface dose increase between this research and other studies. Kelly *et al.* [9] showed surface dose promotes by 35% to 60% by changing hitted beam angle and mask thickness even with no mask above the measurement point and with mask the dose promotes up to 55% of the dose at d_{max}, which is similar to the result found by Hadley *et al.* [11] of 61%.

With attention to Table 1 it could be calculated and derived that our results about the Klarity masks in most instances are very close to results of Półtorak *et al.* [17]. For 6MV beam the surface dose in 10×10 and 20×20 open fields (for Półtorak *et al.*s' within parentheses) are 16.5% (17%) and 27% (26%) and in masked fields are 47.5% (48%) and 70.5% (58%), and for 15MV beam in open fields are 6.5% (12%) and 17% (28%) and in masked fields are 32.5% (32.5%) and 45% (52%), respectively. It seems, relatively high differences between our study and Poltorak's for 15MV beam in 10×10 and 20×20 open fields are because of high amounts of uncertainty due to low level of radiation.

According to the results, surface dose underneath the immobilization masks increases considerably and may contribute to patient skin complication during the treatment course. There are various approaches to suppress the skin doses under the mask. First, it is recommended using thermoplastic masks with wide open laces such that most of the continuous strip material is positioned outside the treatment field. Further, in case of occurring complications in a patient, it is suggested that the mask section covering

the area of complication be removed such that still possess good immobilization integrity [18].

Moreover, as noted by Kelly *et al.* [9], Hadley *et al.* [11] and Chiu-Tsao and Chan [19] masks with more stretching could have thinner thickness and thereof less increase in surface dose. So, it is suggested that to reduce the promotion of surface dose due to applying thermoplastic masks, it must be stretched to be as thin as possible whereas still retaining enough structural integrity for accruing accurate and confident immobilization. The study demonstrates that different hole diameters of thermoplastic mask have impact on the characteristics of the percentage depth dose curve and it must be considered. In conclusion, Klarity mask is more acceptable immobilization device when compared with other masks that, on average, increases the surface doses by about 2.4 and 2.9 times in 6 and 15 MV, respectively.

The skin reactions resulting from thermoplastic masks should be monitored and corrective measures should be taken during treatment such as partially removing the mask over skin areas with complications and optimizing the skin dose in radiotherapy planning.

Acknowledgements

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