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Dosimetric Effects of Thermoplastic Immobilizing Devices on Surface Dose

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Abstract

Thermoplastic immobilizing masks have dosimetric effects on the patient's skin dose. The thermoplastic percentage depth dose (PDD), equivalent thickness of water for the masks and surface doses were determined. The surface dose factors due to the thermoplastic mask was found to be 1.7949, 1.9456, 2.0563, 2.1967, 2.3827, 2.5459 and 2.6565 for field sizes of 5 × 5, 8 × 8, 10 × 10, 12 × 12, 15 × 15, 18 × 18 and 20 × 20 cm^2 respectively which shifted the percentage depth dose curve to lower values. The physical thermoplastic thickness was measured to be between 2.30 and 1.80 mm, and the equivalent thicknesses of water, d_e, were determined to be between 1.2 and 1.00 mm. This meant that, as the mask thickness decreased, its water equivalent thickness also decreased. The presence of the mask material increased the skin dose to a factor of 1%. The thermoplastic mask factor was also found to be 0.99.

Keywords

Thermoplastic Mask, Percentage Depth Dose, Equivalent Thickness of Water, Skin Dose

1. Introduction

Thermoplastics are organic materials which are ductile in nature. They can be formed after softening and retain their final shape when cooled. The chemistry of thermoplastics is comparable to that of rubber, while the strength is similar to aluminium. They are light in weight with densities ranging from 0.9 to 2 g/cm^3. These properties, along with their low cost make them appropriate for several applications [1]. The essential aim of radiotherapy is to deliver a specified dose to a tumor volume accurately while protecting healthy tissues and critical structures [2]. This accuracy requires that the error in total dose be within ±5%, as recommended by the International Commission on Radiation Units and Measurements (ICRU) [3]. The set-up margin in radiotherapy is affected by the following factors: mechanical uncertainty of the equipment, dosimetric uncertainties, patient positioning variations, transfer set-up errors and other human factors [3]. These factors may differ from one radiotherapy center to another. Therefore, radiotherapy for patients, particularly those with cancers of the brain or head and neck, need to be immobilized in order to reproduce the set-up throughout the whole treatment course. Otherwise, critical structures adjacent to targets may be irradiated unnecessarily [4]. Thus, treatments that involve conformal radiotherapy or Intensity-Modulated Radiotherapy (IMRT) techniques, such as head and neck protocols using thermoplastic mask immobilization devices to immobilize the patients during the treatment course [5]. These thermoplastic masks are produced to be simple to use, and they balance patient comfort against rigidity [6] [7].

There are special head-and-neck immobilization devices which are used for patient position reproducibility on the treatment couch. The dosimetric effect from external devices is a complex combination of increased skin dose, reduced tumor dose and altered dose distribution. Devices close to the patient act primarily as boluses while those away act like attenuators and scatterers, increasing the skin dose and shifting the depth dose curve toward the surface of the patient. Maximizing radiotherapy outcomes usually require dose delivery accuracy to be in a range of 3% to 5% based on theoretical radiobiological considerations [8] [9]. With modern dosimetry protocols, such as TG-51 [10], the calibration uncertainty is from 1% to 2%, for the calibration factor, $k = 1$ while modern calculation methods have greatly enhanced dose calculation accuracy for treatment planning. Many radiotherapy centers normally make very small corrections for the Monitor Unit (MU) to account for dose perturbations caused by blocking trays, and also use the Treatment Planning System (TPS) to account for tissue inhomogeneities. While it is routine to consider these small corrections, many workers in the radiotherapy units overlook the possibly larger dosimetric effects caused by devices like couch tops and immobilizers. Reports show that patient positioning reproducibility can be as good as a few millimeters, which when combined with IMRT can further minimize errors in the inter-fraction positioning reproducibility to the sub-millimeter level [11] [12]. However, the immobilization devices in the path of the radiation beam cause a reduction of dose at depth, thereby increasing the dose to the skin, just as with treatment couch tops. Even thin coverings present on skin wounds can increase the skin dose [13].

2. Materials and Method

A plastic phantom was set up on the cobalt-60 (Cirus Cobalt-60, France) couch, perpendicularly along the beam central axis. Farmer type ion chamber of 0.125 cc measuring volume together with PTW UNIDOS electrometer (PTW, Freiburg, Germany) was used to collect and measure electric charges. For an open field at SSD of 80 cm and without the mask on the phantom (PTW, Freiburg, Germany), several field sizes of 20×20 cm^2, 18×18 cm^2, 15×15 cm^2, 12×12 cm^2, 10×10 cm^2, 8×8 cm^2 and 5×5 cm^2 were used to irradiate the ionization chamber for 60s at different depths of 2, 4, 6, 8 and 10 cm. Charges were collected and measured as indicated in the set-up in Figure 1. Five successive readings were taken for each field size and their average estimates calculated. The measurements were corrected for temperature and pressure. An unstretched mask (CIVCO, United States of America) was then placed on the surface of the water phantom and the same procedure repeated. The mask was then stretched by different amounts of 5, 10, 15, and 20 cm to create different openings in the holes and the same procedure was repeated for the different stretches of the mask. The initial and final temperatures and pressures were also recorded in each case and corrections for temperature and pressure performed. The doses for the various mask thickensses at various field sizes and depths were determined from the PDD curve obtained.

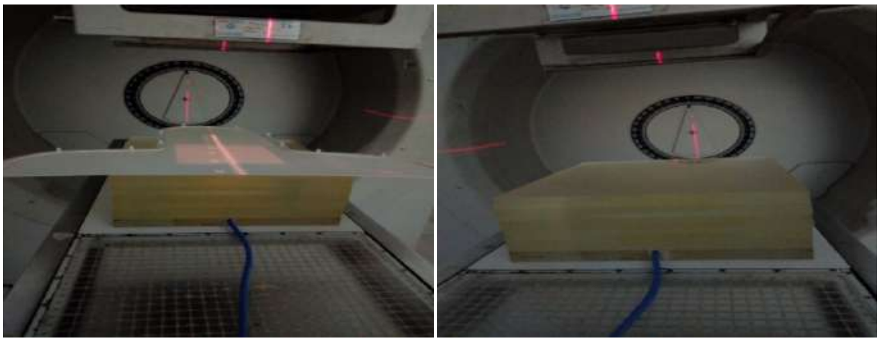
Determination of Thermoplastic Mask Factor, TF

In order to assess and correct for the effects that the thermoplastic masks has on skin dose, the thermoplastic factor variation with field size and depth was determined. Just like the tray factor, the thermoplastic mask factor was estimated.

$$T_f = \frac{\text{corrected ion chamber readings with mask}}{\text{corrected ion chamber readings without mask}} = \frac{I_1}{I_0} \tag{1}$$

3. Results and Discussion

The use of thermoplastics for immobilization during treatment of patients can be analyzed on the basis of Percentage Depth Dose (PDD) effect, equivalent thickness of water for the thermoplastic used and surface dose effect on the patient. The inferential statistics was used to discuss and draw conclusions on the dose deposition from the surface of the thermoplastic per unit distance travelled



(a) (b)

Figure 1. Experimental setup of procedure with and without a mask.

into the water phantom along the central axis of the radiotherapy beam.

3.1. Percentage Depth Dose Determination

The buildup effect of the mask material was assessed by determining the PDDs without and with the mask material on the solid water phantom. Hadley *et al.* measured the build-up effect for masks that have been extended by various amounts to be equal to 2.2 and 0.6 mm for 6 MV and 15 MV X-ray beams respectively. The surface dose changed from 12% and 16% for 15 MV and 6 MV, respectively, to 18% to 40% for 15 MV and 27% to 61% for 6 MV with the samples of the mask [14]. **Figure 2** is the resultant PDD curves with and without the thermoplastic material as a beam modifier. The presence of the mask material shifted the position of the PDD curve towards maximum PDD value of 2.7% by an amount equal to the equivalent thickness of solid water of 1.2 mm that the mask represented. The variation is due to the material used as a bolus material.

3.2. Variation of Percentage Depth Dose with Field Size and Depth

Field size, which is a scatter factor, is proportional to percentage depth dose. The contribution of the scattered radiation to the dose absorbed at a point in the patient increases with respect to field size, and therefore the increase in scattered dose occurs at greater depths than at depth of maximum dose. Percentage depth dose increases from the surface to a depth of maximum dose (0.5 cm) and then decreases with increasing depth. The variation of PDD as a function of field size and depth for various thicknesses of mask as obtained from the study are depicted in **Figure 3(a)** and **Figure 3(b)**.

3.3. Equivalent Thickness of Water

The presence of the mask material shifted the position of the PDD curve to the left by an amount equal to the equivalent thickness of water, d_e, PDD_o and PDD_m represented the PDD acquired when there was no mask present and with mask material present in the beam, respectively. The horizontal distance which

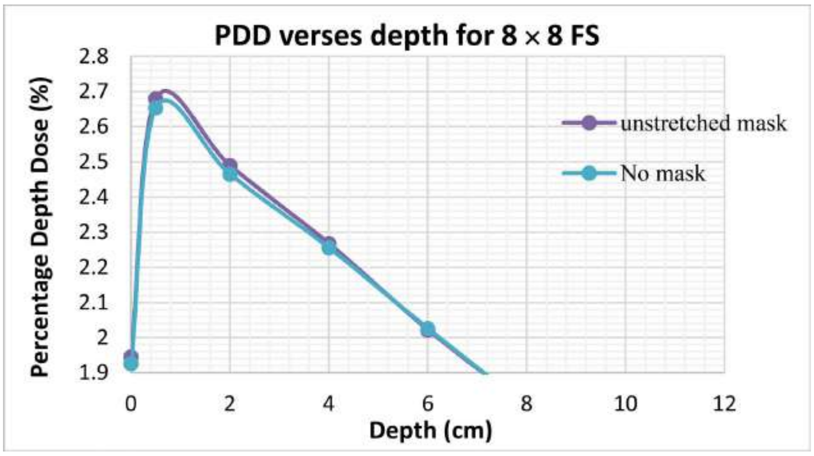
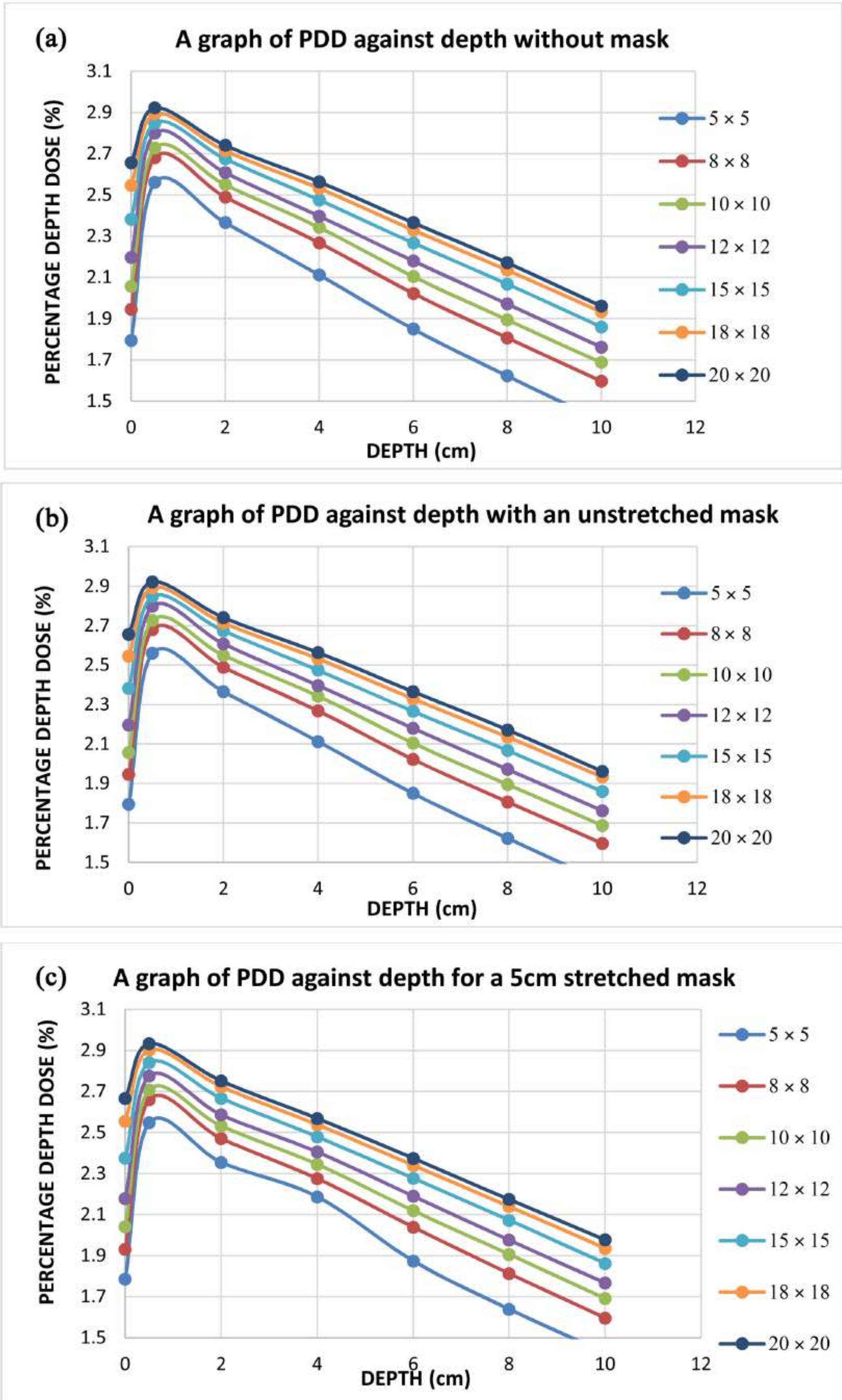


Figure 2. PDD vs depth for 8 × 8 cm² field size.


(a)
A graph of PDD against depth without mask
PERCENTAGE DEPTH DOSE (%)
DEPTH (cm)
5 × 5
8 × 8
10 × 10
12 × 12
15 × 15
18 × 18
20 × 20
(b)
A graph of PDD against depth with an unstretched mask
PERCENTAGE DEPTH DOSE (%)
DEPTH (cm)
5 × 5
8 × 8
10 × 10
12 × 12
15 × 15
18 × 18
20 × 20
(c)
A graph of PDD against depth for a 5cm stretched mask
PERCENTAGE DEPTH DOSE (%)
DEPTH (cm)
5 × 5
8 × 8
10 × 10
12 × 12
15 × 15
18 × 18
20 × 20

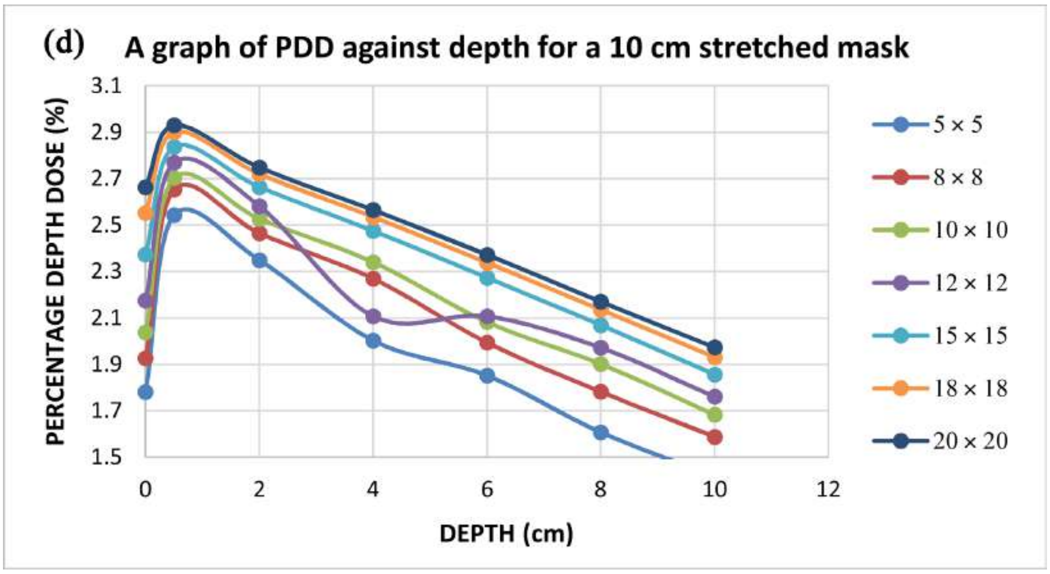


Figure 3. (a) PDD against depth without mask at different field sizes; (b) PDD against depth with an unstretched mask at different field sizes; (c) PDD against depth with 5 cm stretched mask at different field sizes; (d) PDD against depth with 10 cm stretched mask at different field sizes.

Table 1. Physical mask thickness, d, and the equivalent thickness, d_e, of the masks.

	Physical mask thickness d (mm)	Equivalent thickness d_e (mm)
Unstretched mask	2.30	1.20
5 cm stretched mask	2.19	1.15
10 cm stretched mask	2.00	1.10
15 cm stretched mask	1.90	1.09
20 cm stretched mask	1.80	1.00

between points of equal PDD can be derived from the equation:

$$PDD_m(d_m) = PDD_o(d_o) \tag{2}$$

was used to estimate d_e. The depths d_m and d_o for several different points before d_{max} were used in a linear correlation to determine d_e. The y-intercept of the best-fit line through the points d_m and d_o was taken to be d_e. The physical thermoplastic thickness was measured to be between 2.30 mm and 1.80 mm and the equivalent depths of water, d_e, were determined to be 1.2 mm, 1.15 mm, 1.10 mm and 1.09 mm and 1.00 mm for the unstretched, 5 cm stretched, 10 cm stretched, 15 cm stretched and 20 cm stretched masks respectively as shown in Table 1.

3.4. Determination of Skin Dose

The surface dose increase as a result of the mask was compared to the PDD measurements at depth 0.0 mm without the mask samples. The use of thermoplastic masks for patient immobilizing resulted in an increased skin dose due to an increase in dose in the buildup region. Michał Póltorak *et al.* (2016) also studied the influence of thermoplastic masks material having various hole diameters (φ 0.25 cm and φ 0.40 cm) for photon beams on the dose distribution in the build-up region. Two photon energies of 6 MV and 15 MV, at 90 cm source to skin distance, for four fields were used. They found out that surface dose had increased from 5% to 28% for 15 MV X-Rays and from 10% to 42% for 6 MV and [15]. **Figure 4** shows the effect of mask samples on surface dose. The PDD increased from average of 0.75% for unmasked skin to 0.76% - 0.79% for masked skin at a depth of 0.0 mm and field size of 5 × 5 cm^2. The skin dose was highest when the unscratched mask was used and lowest when there was no mask present. Even though the skin dose decreased as the mask was extended, the variation was within 1%. This shows that, the skin sparing effect is increased when the mask is stretched to its maximum length. Extending the mask to increase diameter of the holes reduced the buildup effect and decreased the surface dose. However, overstretching the mask material to minimize the buildup effect could compromise the mask rigidity and, therefore, decrease its ability to assist in the positioning of patient. **Figure 4** shows the increase in skin dose due to the presence of a mask.

3.5. Field Size Effect on Skin Dose

Figure 5 shows an increase in skin dose as field size increases. This increase in skin dose with field size occurred for both plastic measurements with and without the mask material. This is primarily due the increase in electron scattering from the air, collimators, and any other material in the beam path. For a field size of 5 × 5 cm^2, the skin dose was measured to be 1.75 and increased to 2.66 to a field size of 20 × 20 cm^2. Yadav *et al.* carried out skin dose estimations for various beam modifiers and found out that, the skin sparing is largely minimized for the bigger field sizes [16]. This is in agreement with other results in literature, all of which reported an increase in skin dose with increasing field size. The increase in skin dose with field size is represented in **Figure 5**.

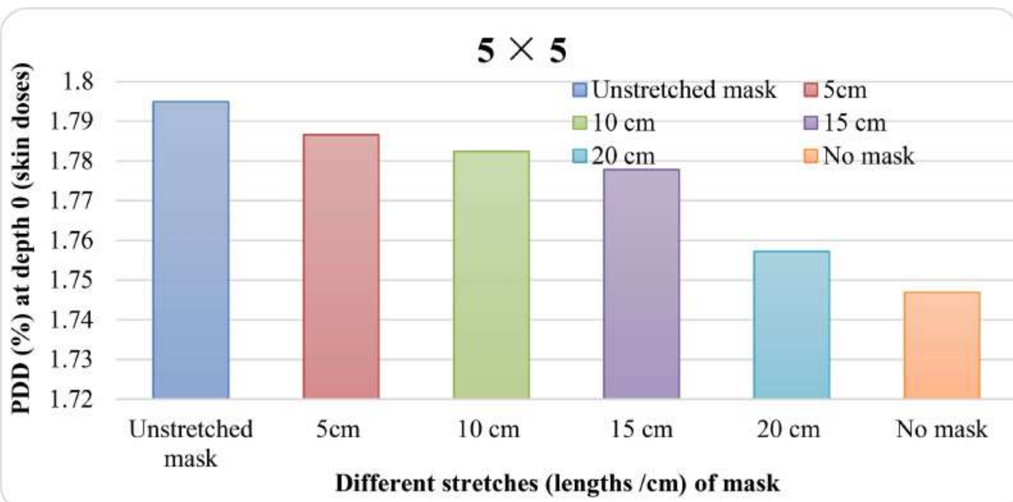


Figure 4. A graph showing the effects of different thicknesses of mask on skin dose.

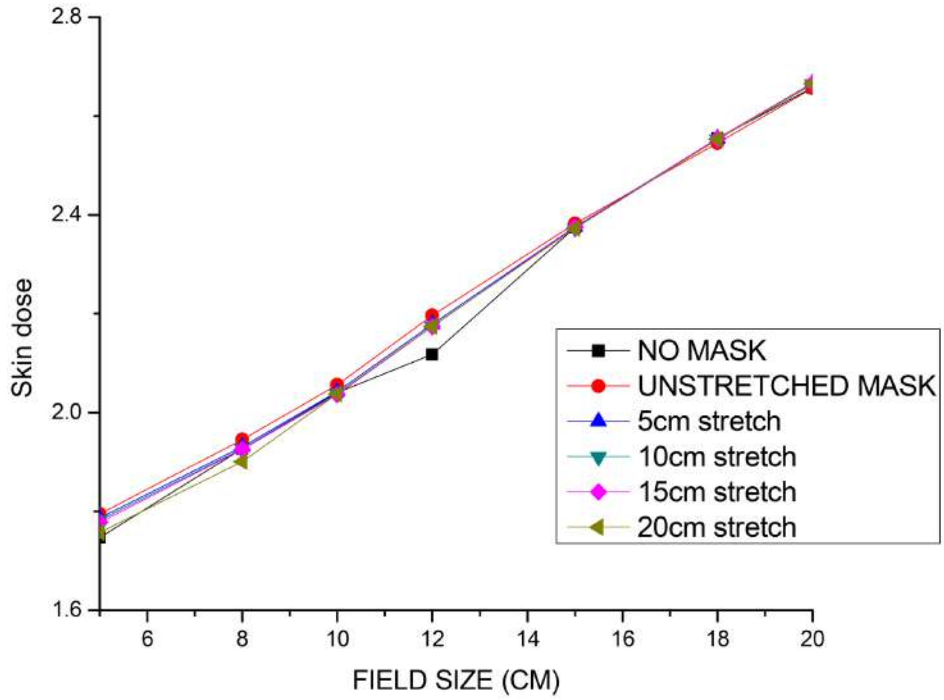


Figure 5. Comparison of the skin dose for different thicknesses of mask materials at various field sizes.

4. Conclusion

The purpose of this work was to determine the dosimetric properties for the thermoplastic material with different thicknesses used as beam modifiers in terms of percentage depth doses, equivalent thickness of water represented by the thermoplastic material, the change in the dose buildup, and skin dose in the use of the thermoplastic mask material for head-and-neck immobilization. Hadley *et al.* (2005) investigated the increase in surface dose caused by the mask material and quantified the difference between the two samples of masks available [14]. They measured the change in the dose building up by measuring Tissue Maximum Ratios (TMRs) using solid water phantom with and without the mask material for 6-MV and 15-MV X-ray beams respectively. The buildup effect was measured to be equivalent to 2.2 mm to 0.6 mm for masks that have been stretched by different amounts. In this work, the buildup effect of the mask decreased as the physical thickness of the mask decreased. The equivalent thickness of water was found to decrease as the mask thickness decreased. The presence of the mask material shifted the position of the PDD curve horizontally to lower depth values by an amount equal to the equivalent thickness of solid water that the mask represented. It was observed that the dosimetric effect of the thermoplastic mask was minimized as the mask was extended. The skin dose was highest for the presence of an unstretched mask and lowest when there was no mask present. Even though the skin dose decreased as the mask was extended, the variation was less than 1%. This work was only limited to Cobalt 60. Further work should be done using 6 MV and 15 MV to study the energy effect on the mask material.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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