RESEARCH ARTICLE

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A Study to Analyze Impact of Treatment Couch and Immobilization Devices on Surface Dose for Megavoltage Photon Beams

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Abstract

Purpose/Objective: The purpose of this study is to investigate the effect of treatment couch and immobilization devices on surface dose for megavoltage photon beams. **Material/Methods:** Percentage surface dose (PSD) measurement was carried out in Elekta Synergy™ Linear accelerator using PTW Markus® Parallel plate ionization chamber of volume 0.05cm3 with water equivalent RW3 Slab phantom (PTW, Germany). The measurement depth was considered at 0.07mm. The reference PSD was measured at 0° gantry angle with 10×10cm^2, 20×20cm^2 and 30×30cm^2 field sizes and 100cm SSD for 4MV, 6MV and 15MV photon beams. For comparison, PSD measurement was carried out at 180° gantry angle inclusion of treatment couch (TC), All in One positioning system (AIO – PS) and Vac lok Cushions (VLC). **Results:** Beam angle at 0°, for field sizes 10×10cm2, 20×20cm2 and 30×30cm^2, the PSD was observed as 30.9%, 40.5%, 48.7% for 4MV; 23.7%, 33.8%, 42.2% for 6MV; and 17.0%, 29.6%, 38.6% for 15MV respectively. Beam angle at 180° with TC, an increase in PSD by maximum of 65.0% for 4MV, 64.9% for 6MV and 55.9% for 15MV as compared to 0° angle. The PSD increased when beam angle was 180° with TC and AIO – PS were 65.0% for 4MV, 67.4% for 6MV, and 60.9% for 15MV than 0° angle. Similarly, increased PSD for beam angle at 180° with TC and VLC were 66.8% for 4MV, 66.8% for 6MV and 61.3% for 15MV as compared to 0° angle. **Conclusion:** For all three-photon energies, at 180° gantry angle, the PSD increased significantly in case of TC, VLC, and AIO – PS for all the field sizes as compared to gantry angle at 0°. It is necessary to consider TC, AIO – PS and VLC during dose calculation to ensure accuracy of patient treatment delivery.

Keywords: Surface dose- Photon beams- Treatment couch- Immobilization devices

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Introduction

Surface dose is the dose that is deposited at the surface of two media (air and Phantom) (Ugur et al., 2016). Skin comprises three layers such as epidermis, dermis and subcutaneous adipose tissue. A typical epidermis depth is 0.05-0.15 mm and dermis is 1.0-2.0 mm (Yadav et al., 2009; kucuk et al., 2002; Sigamani et al., 2017). Surface dose is impartment in radiotherapy treatment. During radiotherapy treatment; the skin is susceptible to side effects such as erythema, desquamation, and necrosis (Sigamani et al., 2017). The surface dose results from contaminant electron from the air, collimator, scattering materials in the beam path and secondary electron from the patient (kucuk et al., 2002; Sigamani et al., 2017; Mackie et al.,1982; Beauvais et al.,1993). Radiotherapy Treatment couch (TC) combined with different immobilization devices is used to maintain patient positioning and reproduce the patient setup for daily treatment. The TC is made up of two thin carbon fiber plates that are about 2.0 mm to 4.0 mm thick and sandwich air-equivalent polymeric foam between them. And it contains a low attenuation property, high mechanical strength, rigidity, low density and lightweight in order to use in radiotherapy treatments (Olch et al., 2014; Sheykhoo et al., 2017). The immobilization devices such as Vac lok Cushions (VLC), All in One positioning system (AIO-PS) and thermoplastic mask are employed to ensure patient positioning during the course of the treatment. The VLC provides a firm patient position when a vacuum is drawn through its quick release valve by maintaining its shape and stability, to ensure reproducibility of patient positions. The AIO-PS is made from a low-density carbon fiber with excellent dosimetric properties for reproducing the patient positioning of

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all parts of the body. An increase in dose buildup on the posterior surfaces of the patient's skin through the treatment couch and immobilizing devices on the posterior side and it acts as a bolus; As a result, it shifts the depth dose curve in the direction of the patient's skin (Sheykhoo et al., 2017). There is a significant portion of the dose delivered from the posterior side of the body in the case of Intensity modulated radiotherapy (IMRT) and Volumetric modulated arc therapy (VMAT) plans, which requires an evaluation of the effects of TC and immobilization devices on the dose distribution (Tugrul,2018). Various types of detectors such as Radiographic and Radio chromic film, diode, Thermoluminescent dosimeter (TLD), Metal oxide semiconductor field effect transistor (MOSFET), Extrapolation chamber and parallel plate ionization chamber can be used to measure the surface dose (Ugur et al., 2016; Sigamani et al., 2017; Tugrul,2018).The adjustable electrode separation of the extrapolation chamber will be more accurate to measure the surface dose for the megavoltage photon beam; Parallel plate chamber is generally available for most radiation therapy facilities and more convenient for measuring the surface dose for megavoltage photon beams in clinical situations. However, the fixed electrode separation of parallel plate ionization chamber needs to correct the perturbation effects due to sidewall of the chamber (Ugur et al., 2016; Tugrul, 2018; Bilge et al., 2008; Attalla et al., 2017). Therefore, the purpose of this study is to investigate the effect of TC, VLC and AIO-PS on surface dose for megavoltage photon beams on the posterior beam using parallel plate ion chamber.

Materials and Methods

Water Equivalent Solid Phantom

The PSD and buildup region were measured in a water equivalent PTW RW3 slab phantom. The physical density is 1.045g/cm^3 and its dimension of 30×30cm^2 with varying slab thicknesses of 1.0mm, 2.0mm, 5.0mm and 10.0mm. The slab phantom has negligible uncertainty in relation to water phantom and contributes to reducing the uncertainty in the depth dose measurements (Ugur et al., 2016; Tello et al., 1995). And density corrections of slabs have been applied for water equivalent (Gursoy et al., 2018).

Parallel plate ionization chamber

Fixed electrode separation of Markus Parallel plate (PTW, Freiburg, Germany) ionization chamber of volume 0.05cm^3 was used for PSD measurements which has 2mm of electrode separation and 0.35mm of sidewall collector distance. The polarity effects of chamber were taken into account by taking the average of +300V and -300V ionization reading. The inner surface of the chamber window at its centre of the Markus parallel plate chamber was oriented towards the source. The over response of the parallel plate chamber due to secondary electrons scatter from the wall of the chamber and it is corrected by the Gerbi's formula (Ugur et al., 2016; Sigamani et al., 2017; Tugrul,2018; Gursoy et al., 2018; Mellenberg., 1990).

$P'(d,E)=P(d.E)- \xi(0,E)le^{-\alpha(d/dmax)}$ (Gerbi et al.,1990)

$\xi(0, E) = [-1.666 + (1.982IR)] \times (C - 15.8)$ (%/mm).

$\xi(0, E)$ = Energy dependent chamber factor which indicates the overresponse per mm of chamber plate separation at the phantom surface. The values −1.666, 1.982, and 15.8 are constants.

IR = ionization ratio at depths of 20 cm and 10 cm, measured at a fixed source-detector distance and 10×10 cm^2 field size.

P' = corrected percentage depth dose

P = relative depth ionization,

E = energy,

d_{max} = depth of maximum dose,

C = sidewall collector distance

l = plate separation

α = 5.5, constant,

d = the chamber's front window's depth

Measurement Setup

Percentage surface dose (PSD) and buildup region measurement was carried out in Elekta Synergy™ (Stockholm, Sweden) linear accelerator using Markus parallel plate ionization chamber (PTW, Freiburg, Germany) with water equivalent solid phantom (PTW-RW3). The international commission on radiation unit and Measurements (ICRU) and international commission on radiation protections (ICRP) recommends assessing the skin dose at the depth of 0.07mm (Ugur et al., 2016; Tugrul, 2018; ICRP 60, 1991; ICRU 39, 1985; Devic et al., 2006).This usually corresponds to the interface between the dermis and the epidermal layers of the skin for the evaluation of the dose to the skin (Ugur et al., 2016; kucuk et al., 2002). In our study, the surface is defined at a depth of 0.07mm as per literature (ICRP 60, 1991; ICRU 39, 1985). The measurement depth was considered from 0 to 10mm with increment of 1.0 mm and normalized at depth of dose maximum. By interpolating between depth of 0 and 1.0 mm, the PSD value for 0.07mm was determined. Supplemetary Figure 3 shows the data presented in Table 1. The reference PSD was measured at 0° gantry angle with 10×10cm^2, 20×20cm^2 and 30×30cm^2 field sizes and 100cm SSD for 4MV, 6MV and 15 MV photon beams by delivering 100 MU. For comparison, PSD measurements were carried out at a 180° gantry angle, including TC, AIO – PS and VLC as shown in Figure1.

Results

The PSD and buildup regions were measured using the Markus parallel plate ionization chamber (PTW, Freiburg, Germany) for beam angles of 0° and 180°. The measurements were taken for 4MV, 6MV, and 15MV with different field sizes of 10×10cm^2, 20×20cm^2, and 30×30cm^2.For the beam angle at 0°, the PSD values were observed as 30.9%, 40.5%, and 48.7% for 4MV; 23.7%, 33.8%, and 42.2% for 6MV; and 17.0%, 29.6%, and 38.6% for 15MV. Additionally, for comparison purposes, the beam angle at 180° was measured with the inclusion of TC, TC with AIO-PS, and TC with VLC.

For beam angle at 180° with inclusion of TC, for field sizes 10×10cm^2, 20×20cm^2 and 30×30cm^2, the PSD was obtained as 95.9%, 96.5%, 97.1% for 4MV; 88.6%, 91.7%, 93.2% for 6MV; and 72.9%, 79.9%, 83.9% for 15MV. For

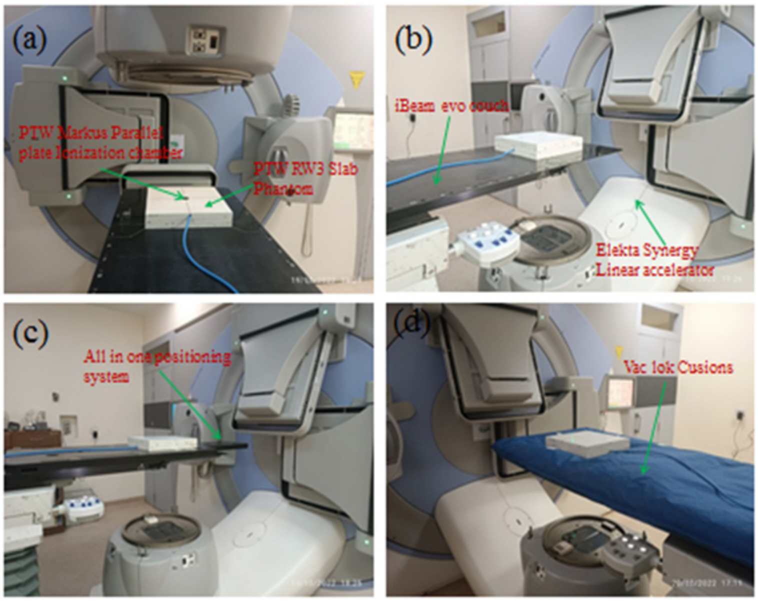

Figure 1. PSD Measurement Setup for Gantry Angle at 0° (a) and 180° Gantry Angle Inclusion of TC (b), TC with AIO – PS (c) and TC with VLC (d) for 4MV, 6MV and 15MV Photon Beams.

Table 1. PSD for Gantry Angle at 0° and 180° with Inclusion of TC, TC with AIO – PS and TC with VLC for 4MV, 6MV and 15MV Photon Beams at Field Sizes of 10x10cm^2, 20x20cm^2 and 30x30cm^2.

Measurement Setup	Percentage Surface dose (%)								
	4MV			6MV			15MV		
	10x10cm²	20x20cm²	30x30cm²	10x10cm²	20x20cm²	30x30cm²	10x10cm²	20x20cm²	30x30cm²
G0°	30.9	40.5	48.7	23.7	33.8	42.2	17.0	29.6	38.6
G180° with TC	95.9	96.5	97.1	88.6	91.7	93.2	72.9	79.9	83.9
G180° with TC and AIO-PS	95.9	96.5	96.5	91.1	93.5	94.4	77.9	84.1	87.7
G180° with TC and VLC	97.7	98.7	98.9	92.6	95.6	96.5	78.3	85.9	89.5

beam angle at 180° with inclusion of TC and AIO-PS, for field sizes 10×10cm^2, 20×20cm^2 and 30×30cm^2, the PSD was found that 95.9%, 96.5%, 96.5% for 4MV; 91.1%, 93.5%, 94.4% for 6MV; and 77.9%, 84.1%, 87.7% for

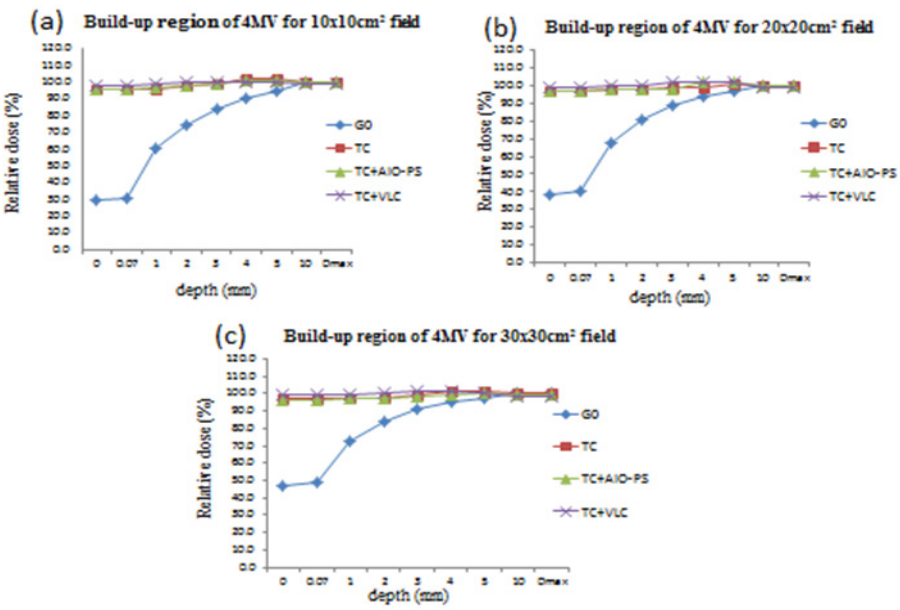

Figure 2. Build-up Regions for Gantry Angle at 0° and 180° with Inclusion of TC, TC with AIO – PS and TC with VLC for 10x10cm^2(a), 20x20cm^2(b) and 30x30cm^2 (c)of 4MV photon beam

15MV. For beam angle at 180° with inclusion of TC and VLC, for field sizes 10×10cm^2, 20×20cm^2 and 30×30cm^2, the PSD was observed as 97.7%, 98.7%, 98.9% for 4MV; 92.6%, 95.6%, 96.5% for 6MV; and 78.3%, 85.9%, 89.5% for 15MV as shown in Table 1.

Discussion

The surface dose depends on the secondary electrons that are produced from scatter radiation generated by the collimator head. The collimator head contains various components, including the target, collimator jaws, multileaf collimators (MLCs), flattening filter, monitor chamber, and secondary collimators. When radiation interacts with these components, some of it may scatter, leading to scatter radiation. Furthermore, there may be leakage radiation from the collimator head. Scattering can also occur within the collimator head due to interactions with the different materials and structures present.

The scatter component primarily occurs when high-energy X-ray or gamma ray beams used in radiotherapy interact with the materials in the immobilization system. The immobilization system typically includes materials like thermoplastic masks, molds, or cushioning materials, which can be made of different plastics and polymers. When these high-energy radiation beams pass through these materials, they can undergo interactions such as Compton scattering and photoelectric absorption. During these interactions, the photon loses energy and changes direction, while the ejected electron can also contribute to further scatter. Some of the scattered photons can then contribute to the dose on the patient's skin. This scattered radiation can contribute to the surface dose, potentially increasing it in the regions of the patient's body that are close to the immobilization material.

iBEAM evo couch tops contain a form core with an electron density of 0.1 g/cm^3. It has a thickness of 15 mm and is sandwiched between two layers of carbon fiber shell. Each layer of the carbon fiber shell has a thickness of 4 mm and an electron density of 0.52 g/cm^3. Zhang R et al., (2018) conducted a study on the impact of the treatment couch on radiation delivery with two different couch models were evaluated in Monaco™ Treatment planning system (TPS). Model A, which is constructed from the contoured outline of the couch top with a thickness of 23 mm and a uniform electron density value of 0.26 g/cm^3, and Model B, which is constructed from two components - form core with an assigned electron density of 0.1 g/cm^3 and carbon fiber shell with an assigned electron density of 0.52 g/cm^3. The iBEAM evo couch model, using the uniform couch model A with an electron density of 0.26 g/cm^3, achieved the best agreement between measured and Monaco TPS calculated doses compared to the two-component model B. and also they measured couch attenuation for 6MV which they observed percentage deviation was 2.51%.

Fontenla DP et al., (1994) a study conducted to analyze how the use of immobilization devices with beam modifiers can affect the dose to the skin and build-up region. The researchers measured the depth dose along the central axis in polystyrene phantoms using 6 and 15 MV photons. For 6MV photons, they found that the use of solid (3mm) thermoplastic casting material had the greatest impact on the surface dose in a 12 x 12 cm field. When they treated through the material, they measured 79% of the maximum dose, compared to only 22% when no beam modifiers or immobilization devices were used. A study conducted by Hadley SW et al., (2005) examined the impact of mask material on the increase in surface dose. The study also measured and compared two different mask samples. The measurements were taken with and without mask material on the surface of solid water using 6-MV and 15-MV X-rays. The results showed that the estimated surface dose varied from 27% to 61% at 6 MV and from 18% to 40% at 15 MV for the mask samples.

PSD increases with larger field sizes because of an increase in contaminated electrons from the collimator and air (Yadav et al., 2009; kucuk et al., 2002; Khan et al., 1994; Ding, 2002). Flattening filter reduces the surface dose by causing beam hardening effects. However, it also produces a significant amount of scatter radiation that deposits energy at shallow depths, resulting in an increase in surface dose. This effect is strongly influenced by the field size (Sigamani et al., 2017). The energy spectrum changes depending on the field size and depth, and the mean energy increases with smaller field sizes and depth. The PSD decreases for smaller fields due to an increase in the mean energy spectrum (S. Hidetoshi et al., 1999). In our study, we observed the effect of different photon energies on field sizes of 10×10cm^2, 20×20cm^2 and 30×30cm^2.For a beam angle of 0°, the PSD increases by 8.2% to 9.6% for 4MV, 8.4% to 10.1% for 6MV, and 9.0% to 12.6% for 15MV, with increments of 10×10cm^2 in field sizes. When the beam angle was 180° and includes TC, the PSD increases by 0.6% for 4MV, 1.5% to 3.0% for 6MV, and 4.0% to 7.0% for 15MV.When the beam angle was 180° and includes TC and AIO-PS, the PSD increases by 0 to 0.6% for 4MV, 0.9% to 2.4% for 6MV, and 3.6% to 6.2% for 15MV. For a beam angle of 180° with inclusion of TC and VLC, the PSD increases by 0.2% to 1.0% for 4MV, 0.9% to 3.0% for 6MV, and 3.6% to 7.3% for 15MV, respectively, as shown in Supplemetary Figure 3. The results indicate that the PSD increases more for a beam angle of 0° as the field sizes increase, compared to the combination of TC, TC with AIO-PS, and TC with VLC.

The presence of TC, AIO-PS and VLC in a beam path it causes attenuation.it also causes a shift in the depth of maximum dose towards the surface. Additionally, it acts as a bolus and leads to an increase in PSD (Olch et al.,2014; Poppe et al.,2007; Chiu-Tsao et al.,2010; Munjal et al.,2006; Carl et al.,2000). In our study, we observed the results of dose buildup for gantry angles at 0° and 180°. We included TC, TC with AIO-PS, and TC with VLC for beam sizes of 10×10cm^2, 20×20cm^2, and 30×30cm^2 using 4MV, 6MV, and 15MV photon beams. These results are shown in Figure 2 and Supplemetary Figure 1, 2. The most attenuation portion of the TC was center spinal and side rail when the beam intersected from posteriorly (Olch et al., 2014; Pulliam et al., 2011). The results showed that when the beam angle was at 180° and the TC was included, the PSD increased by 65.0%, 56.0%, and 48.4%

for field sizes of 10×10cm^2, 20×20cm^2, and 30×30cm^2, respectively, for 4MV. For 6MV, the PSD increased by 64.9%, 57.9%, and 51.0% for the same field sizes, and for 15MV, the increase was 55.9%, 50.3%, and 45.3%. These values were compared to the PSD at a 0° angle. The PSD increased when the beam angle was 180° and included TC and AIO-PS values were 65.0%, 56.0%, and 47.8% for 4MV; 67.4%, 59.7%, and 52.2% for 6MV; and 60.9%, 54.8%, and 45.5% for 15MV compared to a 0° angle. Similarly, the PSD increased for a beam angle of 180° with the inclusion of TC and VLC. The PSD values were 66.8%, 58.2%, and 50.2% for 4MV; 68.6%, 61.8%, and 54.3% for 6MV; and 61.3%, 56.3%, and 50.9% for 15MV compared to a 0° angle, as shown in Supplemetary Figure 3. The PSD increases when using combinations of TC, TC with AIO-PS, and TC with VLC in radiotherapy treatment.

A study conducted by Ugur et al., (2016) compared the surface dose measurements of the Markus Parallel-plate ionization chamber, EBT3 film, and MOSFET for 6MV and 15MV radiation beams at SSD of 100 cm using a solid phantom. The results obtained using the Markus parallel-plate ionization chamber were 20.3% and 31.4% for the 6MV beam, and 14.9% and 27.9% for the 15MV beam, respectively. Simamani et al., (2017) analyzed the surface doses of unflattened 7MV and flattened 6MV radiation beams using different detectors, including the parallel plate ionization chamber, gafchromic film, cylindrical ionization chamber, and diode. The results obtained using the NACP parallel plate ionization chamber showed that for a flattened 6MV beam with field sizes of 5×5cm^2, 10×10cm^2, 15×15cm^2, 20×20cm^2, and 30×30cm^2, the surface doses were observed to be 34.3%, 36.4%, 40.6%, 44.2%, and 56.4%, respectively. Based on our study, the results for beam angles at 0° and field sizes of 10×10cm^2, 20×20cm^2, and 30×30cm^2 were as follows: for 6MV, the results were 23.7%, 33.8%, and 42.2%, and for 15MV, the results were 17.0%, 29.6%, and 38.6%.

According to Tugrul (2018), the absorption ratio of carbon fiber couches decreases as the field size and energy increase, while the gantry angles vary. Tugrul also measured the surface dose at a field size of 10x10cm^2 with gantry angles of 0° and 180° for photon beams of 6 MV and 15 MV. With 6 MV, the couch effect increased the surface dose from 14% to 70%, and with 15 MV, it increased from 11.3% to 53%. Our study showed that the PSD increased when the gantry angle changed from 0° to 180° for 10×10 cm^2 fields at a 100 cm SSD. This increase was from 23.7% to 88.6% for 6MV and from 17% to 72.9% for 15MV.

Sheykhoo et al., (2017) investigated the use of a carbon fiber couch affected Monte Carlo simulations of 6MV photon beams with different field sizes. They also measured the skin dose without and with the couch, finding that the skin doses were 13.68%, 18.92%, 28.76%, and 91.68%, 97.35%, 99.53% for field sizes of 5×5cm^2, 10×10cm^2, and 20×20cm^2, respectively. Our study found that the PSD for 6MV fields of 10×10cm^2 and 20×20cm^2 without and with the couch were 23.7%, 33.8%, and 88.6%, 91.7%, respectively. In a study conducted by Galvan De et al., (2019), the percentage depth dose was determined for field sizes of 10×10cm^2, 5.0×5.0cm^2, and 1.0×1.0cm^2 using radiochromic films and a solid water phantom. The results were 26.1%, 21.3%, and 20.2%, respectively. Additionally, our study found that the result for the Markus parallel plate ionization chamber with a water equivalent solid phantom of 10×10cm^2 was 23.7%.

The use of IMRT and VMAT became more widespread, and beam intersections with absorbing parts of the couch became more common. As a result, the beam angle may need to be adjusted to avoid couch intersections or the TC may need to be considered in dose calculations. The same couch top should be used for computed tomography (CT) simulation and radiotherapy treatment. It is important to ensure that during the CT simulation procedure the field of view extends across the entire width of the couch top. If the entire couch top is not included in the field of view, a TPS should allow the couch top to be superimposed onto planning CTs, thereby allowing dose calculations to encompass it. Most of the TPS will not calculate doses for structures outside the patient body contour, even if they have been contoured. Therefore, immobilization devices must be contoured and included inside the patient body contour.

In conclusion, The presence TC, VLC, and AIO – PS and combinations of these can have a significant impact on dose calculation. To improve the accuracy of dose calculations needs to be models the TC in TPS and the immobilization devices to be store in a planning software library, which can be used for dose calculation. If neither, the planner has to draw in, include it as an external structure, and incorporate it into the calculations. For all three-photon energies, at 180° gantry angle, the PSD increased significantly in case of TC, VLC, and AIO – PS for all the field sizes as compared to gantry angle at 0°. It is necessary to consider TC, AIO – PS and VLC during dose calculation to ensure accuracy of patient treatment delivery.

Author Contribution Statement

All authors contributed equally in this study.

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Ethical Consideration

This study is not involved the human or living organism, so ethical approval is not applicable

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