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Original research article

Characterization of natural rubber as a bolus material for electron beam radiotherapy

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ABSTRACT

Background: Bolus is an accessory that is directly placed on the surface region to shift the radiation dose up to the skin during high energy photon and electron beam irradiations. The aim of this study was to mold the bolus using natural rubber material and assess both the physical and dosimetric characteristics.
Materials and methods: A natural rubber with additional plasticizer material was fabricated as a bolus sheet. The physical properties of natural rubber bolus sheets have been investigated using computed tomography (CT) images. Gafchromic EBT3 films were used to acquire the dose at depth of 0, 2, 3, and 3.5 cm for the 9-MeV therapeutic electron beam. A comparison of our natural rubber bolus sheets to the commercial bolus sheets was studied.
Results: The in-house natural rubber bolus sheets with the thickness of 0.32 and 0.52 cm were successfully made. Relative electron density of the two sheets was consistent with each other. However, similar to the commercial boluses, the natural rubber boluses were not provided with the same CT number over the whole sheet. Different bolus material gave different dose at the surface. Both material and thickness of the bolus showed a stronger impact on the dose beyond the depth of maximum dose.
Conclusion: Because of the density, simple fabrication, and vast availability, natural rubber material has an effective potential to be used as a bolus sheet in radiotherapy

1. Background

Electron beam irradiation in the range of 6–18 MeV energies is commonly used to treat the lesion on superficial to shallow depths in radiotherapy. It provides a uniform dose in the treatment region and minimizes the dose to deeper tissue. Gunhan et al[1] has shown that the surface dose was 81.7% of the maximum dose at 9 MeV. Placing the bolus thickness of 0.6 and 1.25 cm increased the surface dose by about 11% and 16%, respectively.

Bolus is a tissue-equivalent material placed directly on the patient's skin to enhance the superficial dose and compensate the missing tissue within the irradiated field. Ideally, the density of a bolus should be similar to water or tissue medium. It can be formed by either a natural or synthetic material. A study of Vyas et al[2] listed the bolus materials and their compositions used in the field of radiation therapy. Water-bag is the first material reported for bolus during total body irradiation by Saw et al.[3] At present, there are numerous types, thicknesses and dimensions of bolus available in the market. Superflab[4] (Radiation Products Design Inc, Albertville, MN) is one of the commercial boluses which is composed of a synthetic gel. It is designed to increase radiation dose at the surface, and conform the patient's contour without an air gap during both photon and electron beam treatment. Moreover, it is provided in several sizes and thicknesses to support dose enhancement in various treatment conditions. A typical bolus thickness combined in a clinical radiation treatment varies form a few mm to 20 mm. The effect of bolus thickness on surface doses has been studied by Gunhan et al.[1] They measured the surface doses in a solid phantom and Alderson Rando phantom by using a parallel-plate ionization chamber and thermoluminescense dosimeter (TLD), respectively. They found that the surface dose increased with increasing electron energies, field sizes and bolus thickness, especially for the low-energy electron beam.

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Rubber is a material that can be processed into many various products. Natural rubber (NR) is a natural resource which can be found in the South-East Asia region.[5] The chemical composition of NR is *cis*-Polyisoprene. Most commercial NR is tapped from the latex sap of a tree; Hevea brasiliensis species. Generally, the formation of rubber compound consists of 10 or more ingredients added to prolong the deterioration and improve the properties such as tensile, modulus, hardness, abrasion resistance, tear strength, electrical conductivity, etc. The property of NR product is based on the amount of these ingredients per total of 100 parts of the rubber.[6] Because of its superior properties and low cost, NR is mostly used to produce many medical products. It can be fabricated and cut into different sizes and shapes. In 2018, Supratman et al.[7] succeeded in developing bolus using NR. They found that the relative electron density and mass attenuation coefficient value of NR bolus is similar to water and lung tissue.

Several dosimeters can be used to measure the dose in a high gradient region in radiotherapy. Radiochromic film is one of the dosimeters widely used to measure the irradiated dose.[8] It provides a two-dimensional dose distribution with high spatial resolution and does not require the darkroom for processing. It has been developed in various models and introduced for medical application. Gafchromic EBT3 film is the released model suited for high energy photons. According to manufacturer specification, Gafchromic EBT3 film can be used to measure the absorbed dose ranging from 0.2–10 Gy. The thickness of the active layer is 28 μm sandwiched between two sheets of matte-polyester substrates.[9] Actually, Gafchromic EBT3 film has a similar performance as EBT2 film that eliminated the newton rings artifact. Molina-Romero et al.[10] studied the response of Gafchromic EBT3 film irradiated in electron beam energy ranging from 6 to 22 MeV. The optical density obtained in the red color channel is independent from electron beam energies for the dose between 2 and 10 Gy.

2. Aim

The aim of this study was to mold the in-house bolus using NR material vastly available in our country and to determine the physical and dosimetric properties of NR bolus sheet.

3. Materials and methods

3.1. In-house bolus forming

An in-house bolus was made from NR material with additional 3 parts of aromatic oil per hundred weight of NR material. Aromatic oil is one of the plasticizer materials to accelerate the processing and reduce the viscosity of rubber. NR and aromatic oil were mixed by Magnetic stirrer with hotplate (Coming, model PC-420D) at the speed of 800 rpm. The mixtures were molded using an aluminum tray size of 20 × 20 cm^2. With the amount of 206 mL of NR material and 5.7 g of aromatic oil, the bolus thickness of 0.5 cm was produced. The 0.7 cm thickness of bolus was created by using 275 mL of NR material and 7.6 g of aromatic oil. The samples were covered with straining cloth, and left for 5 days at the room temperature. After this process, the samples were inserted in a hot-air oven (Lenton, model WF-60) and heated at 60 °C for 3 h to get rid of fluids and give a lift from the tray.

3.2. CT image acquisition

The physical properties of the NR and commercial bolus sheet in terms of homogeneity, thickness, and density were assessed by computed tomography (CT) images. The CT images of the NR and commercial bolus sheet with different thickness were acquired using a Philips Brilliance Big Bore 16-slice CT scanner (Philips Healthcare, Amsterdam, Netherlands) with a slice thickness of 3 mm. During the image acquisition, all of bolus sheets were placed on a foam surface 10 cm in thickness. Scanning parameters were set to 120 kV X-ray beam with 250 mA and obtained over the whole volume of bolus sheet. The thickness of bolus sheet was measured in the transverse view. In the coronal view, the region of interest (ROI) size of 100 mm^2 was drawn on the bolus images to gain the CT number and assess the uniformity. Relative electron densities of a bolus sheet as a function of the CT number were determined from the CT scan images of various materials embeded in the RMI phantom[11] (Gammex-RMI Ltd, model 467, Nottingham, United Kingdom) introduced by Knoss et al.[12] The CT calibration curve is the relationship between the electron density of materials and their corresponding CT number in Hounsfield units (HU).

To ensure the density of our NR bolus sheet, we compared the obtained electron density with that from the equation proposed by Martinez et al.[13] This equation calculated the relative electron density values from the CT number as given by

$$\rho_e = (HU + 1000)/1000 \text{ where; -1000 = HU = 47} \tag{1}$$

where p_e is the relative electron density and HU is Hounsfiled units for the different materials.

3.3. Gafchromic EBT3 film measurement

Each sheet of nominal Gafchromic EBT3 film[9] size was cut into the dimension of 5 × 3 cm^2 for irradiation with the 9 MeV therapeutic electron beam collimated using a 10 × 10 cm^2 electron applicator from a Varian Clinac 21EX linear accelerator (Varian Medical Systems, Palo Alto, USA). All pieces of Gafchromic EBT3 film were taken from the same lot (#A02271802, Expiry: February 2020) and scanned using an Epson Perfection V800 Photo flat-based scanner (Seiko Epson Corp., Nagano, Japan). For practical reasons, a 92 h delay from irradiation to read-out have been selected in our study to ensure the accuracy of optical density better than 0.2%.[14] All pieces of film were placed in the center of the scanner and scanned using the Epson scan software operating in the RGB (Red Green Blue) transmission mode without color correction. All digital images from the pre- and post-irradiation were obtained at a resolution of 150 dpi, saved in 48 bit tagged image file format (TIFF).[15] These images were imported into ImageJ software version 1.52a (National Institute of Health, Bethseda, USA) to read out the pixel values in the red color channel using a ROI size of 15 × 15 mm^2 as recommended by Moylan et al.[16] For each piece of the film, net optical density (OD_{net}) values were determined by the following relationship[17]

$$OD_{net} = \log_{10}\left(PV_{un\,\exp}/PV_{\exp}\right) \tag{2}$$

where PV_{unexp} and PV_{exp} represent pixel value measured for unexposed and exposed films, respectively.

Each piece of the film was placed in a 30 × 30 × 14.5 cm^2 solid water slab phantom (Gammex467; Gammex Inc., Middleton, WI, USA). To create the film calibration curve, Gafchromic EBT3 films were irradiated to the doses ranging from 0 to 5 Gy at the depth of maximum dose for the 9-MeV electron beam with the applicator size of 10 × 10 cm^2. The pixel values for each irradiated dose were converted to the net optical density (OD_{net}). The OD_{net} values were plotted against the delivered dose.

To investigate the dose attenuation of the NR bolus, film pieces were placed at the depths of 0, 2, 3 and 3.5 cm in a solid phantom at a source to surface distance (SSD) of 100 cm. Three repeated measurements were made to obtain the dose at each condition. The measured doses were compared with two commerical boluses; Superflab and tissue-equivalent (TE) gel bolus (CIVCO Radiotherapy, Iowa).[18] These two bolus materials are routinely used to

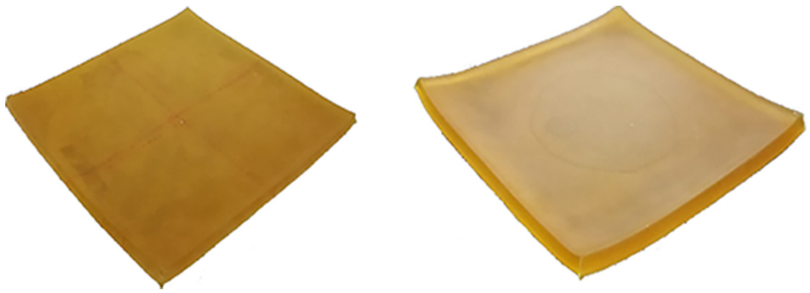

Fig. 1. Dried NR bolus sheet with the thickness of 0.32 and 0.52 cm.

Table 1
The Hounsfield units of different bolus types on the CT image. Each location was measured using an area of 100 mm^2.

Location (X,Y)	Bolus material			
	NR (∼0.3 cm)	NR (∼0.5 cm)	Superflab (0.3 cm)	TE gel (0.5 cm)
Center (0,0)	−161.7 ± 2.8	−169.5 ± 2.3	−152.7 ± 2.5	−19.2 ± 5.9
5 cm off axis in X or Y direction				
(0,+5)	−155.7 ± 3.1	−165.7 ± 2.3	−156.9 ± 2.5	−10.2 ± 3.0
(0,-5)	−159.2 ± 2.7	−155.7 ± 2.2	−167.0 ± 5.1	−15.7 ± 6.3
(+5, 0)	−131.8 ± 1.7	−147.2 ± 3.5	−114.0 ± 3.5	−30.3 ± 9.6
(-5,0)	−168.3 ± 2.5	−141.2 ± 3.1	−166.4 ± 5.2	−17.3 ± 3.7
5 cm off axis in both X and Y direction				
(+5,+5)	−133.1 ± 2.1	−146.9 ± 2.4	−100.5 ± 4.5	−30.6 ± 6.3
(+5, −5)	−129.7 ± 1.6	−142.5 ± 2.7	−118.6 ± 4.8	−32.2 ± 7.5
−5, −5)	−158.3 ± 2.3	−156.9 ± 3.5	−126.3 ± 3.2	−18.7 ± 9.6
(−5,+5)	−156.8 ± 2.6	−143.5 ± 2.8	−132.2 ± 3.9	−23.2 ± 7.1

increase the surface in clinical radiotherapy. There were four conditions for Gafchromic EBT3 film irradiation: 1) without bolus material placed on the anterior surface of the solid phantom; 2) with 0.3 cm thick Superflab bolus; 3) with 0.5 cm thick TE gel bolus; 4) with ∼0.3 and ∼0.5 cm thick NR bolus. For each setup, 15 pieces of films were irradiated at the dose of 3 Gy with the dose rate of 400 MU/min.

4. Results

The successfully made NR bolus with two thicknesses was presented in Fig. 1. The surface is flat in most of the area except near the edge. Air bubble is not seen on the surface. After the bolus sheets become dried and hardened, they were kept in a square shape but the thickness of bolus sheet shrank from 0.5 and 0.7 cm to 0.32 and 0.52 cm, respectively.

The CT number for the NR and commercial bolus on various locations is presented in Table 1. At the center, the NR bolus with different thickness, i.e. ∼0.3 and ∼0.5 cm, had a consistent CT number of -161.7 ± 2.8 HU and -169.5 ± 2.3 HU, respectively. The CT number at the center of Superflab and TE gel bolus was -152.7 ± 2.5 HU and -19.2 ± 5.9 HU, respectively. We observed that the CT number on both NR and commercial bolus at each location was not clearly the same. For ∼0.5 cm NR bolus, the high CT number was found at 5 cm off-axis in the X or/and Y direction, while the low CT number was found at the center. The same results were also observed with the ∼0.3 cm NR bolus. For TE gel bolus, the highest and lowest CT number was found at 5 cm off-axis in the Y direction and 5 cm off-axis in both X and Y direction, respectively.

Table 2 shows the value of average CT number and relative electron density of the NR and commercial bolus. Comparing with the average CT number, the maximum differences of the CT number obtained from the NR bolus with the thickness of ∼0.3 and ∼0.5 cm were 20.81 HU and 17.38 HU, respectively. The largest deviation of the CT number was found in the 0.3 cm Superflab bolus.

From the CT dataset of RMI phantom, the calibration curve was created as illustrated in Fig. 2. The relative electron densities of both NR and commerical bolus were investigated using Fig. 2 and, also, by Eq. (1). From the calibration curve, the relative electron density of NR bolus with ∼0.3 and ∼0.5 cm thickness also presented in the similar values, i.e. 0.8561 and 0.8548, and close to that of Superflab bolus. The relative electron densities varied ranging from 0.8471 to 0.8711 for ∼0.3 cm NR bolus, and from 0.8409 to 0.8635 for ∼0.5 cm NR bolus. As presented in Table 2, the values of relative electron density calculated using the method of Martinez et al.[13] were lower than that of the calibration curve

Table 2
The average CT number and relative electron density of the NR and commercial bolus.

Bolus	Average CT number (HU)	Relative electron density	
		Calibration curve	Martinez et al.[13]
∼0.3 cm NR	−150.51 ± 14.71	0.8561	0.8495
∼0.5 cm NR	−152.12 ± 10.37	0.8548	0.8479
0.3 cm Superflab	−137.18 ± 24.35	0.8668	0.8628
0.5 cm TE gel	−21.93 ± 7.65	0.9590	0.9781

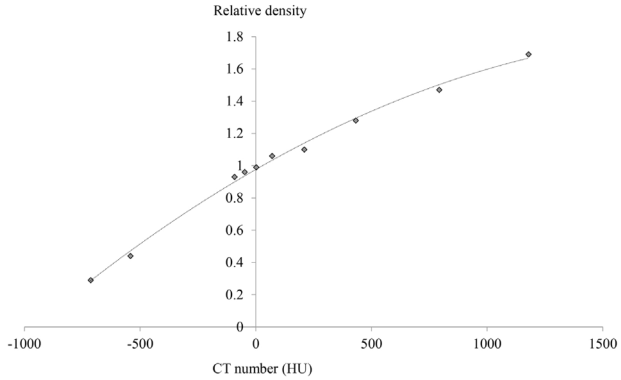

Fig. 2. CT calibration curve for determining the relative electron density of bolus sheet.

Table 3
The absolute and percentage surface dose obtained using Gafchromic EBT3 film for the 9 MeV electron beam with a cone size of 10 × 10 cm^{2}.

Surface dose	Without bolus	NR bolus		Superflab bolus 0.3 cm	TE gel bolus 0.5 cm
		~0.3 cm	~0.5 cm		
Absolute dose (Gy)	2.36 ± 0.08	2.71 ± 0.03	2.84 ± 0.01	2.75 ± 0.01	2.76 ± 0.06
Relative dose (%)	77.79	89.11	93.48	90.54	91.05

for both NR and Superflab bolus. Only the TE gel bolus, the relative electron density derived from Eq.(1), were higher than that from the calibration curve, because of the effect of selected kilovoltage during image acquisition.[11] Changing the kilovoltage peak will alter the beam penetration, and this affected its attenuation in the medium. The relative electron density of these bolus materials was not similar to that of water. The densities of the NR and Superflab bolus were closed to the adipose tissue, while the density of TE gel bolus was ~0.96 that is equal to the density of breast tissue.[11]

The unknown doses at the depth of 0.0, 2.0, 3.0, and 3.5 cm in each studied conditions were obtained by polynomial fitting on the OD_{net} obtained from the red color channel. With the red color channel, the difference of percentage dose from the measurement and the calibration curve at the 2 cm depth was about 3%, which is consistent with the study of Kairn et al.[19] The absolute dose (AD) can be written as in Eq (3).

$$AD = 4783.8(OD_{net})^2 + 837.7\,(OD_{net}) + 0.8202 \tag{3}$$

where AD is the absolute dose value in the unit of Gy and OD_{net} is the net optical density.

Table 3 shows the surface doses measured by Gafchromic EBT3 film for the 9 MeV electron beam at the various conditions. The dose at the surface was mainly absorbed by bolus. A thicker bolus absorbed more electron beam than a thinner one. With the ~0.3 cm NR bolus and 0.3 cm Superflab bolus, the percentage surface dose was equal to 89.11% and 90.54%, respectively. The percentage surface doses with the ~0.5 cm NR bolus was about 93.48%. As shown in Table 3, the bolus thickness of 0.3 and 0.5 cm cannot increase the percentage surface dose up to 100% of the maximum dose for the 9 MeV electron beam. Compared with no bolus condition, the surface doses increased to ~12% with the ~0.3 cm NR bolus and 0.3 cm Superflab bolus, while the surfaces doses increased to 13% and 15% with the 0.5 cm TE gel bolus and ~0.5 cm NR bolus, respectively. From the result, it shows that the surface doses were greatly dependent on the bolus thickness. Furthermore, the NR bolus gave a higher dose at the surface region than the TE gel bolus when compared with the same thickness. The different bolus density also gave different surface dose.

Using the bolus thickness of 0.3 cm, the dose at maximum depth increased with the ratio of 1.29 and 1.154 for NR and Superflab bolus. While the doses at the 3 cm depth beyond the surface region decreased with the same ratio. The effect of bolus greatly presented at deeper depths as shown in Fig. 3. The dose differences between the ~0.3 cm NR bolus and 0.3 cm Superflab bolus were mostly less than 1% except the 3.5 cm depth beyond the surface region. While the dose differences between the ~0.5 cm NR bolus and 0.5 cm TE gel bolus at the depth of 2.0, 3.0, and 3.5 cm were equal to 4%, 8%, and 7%, respectively.

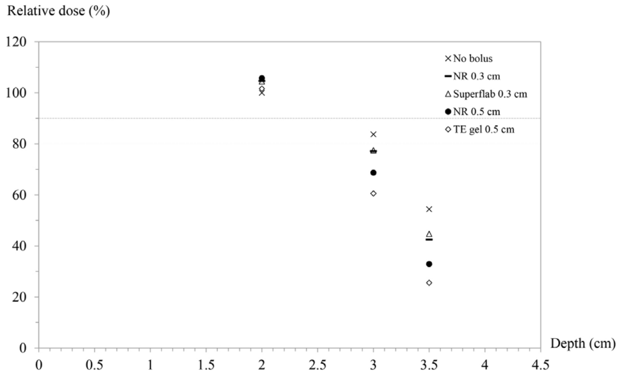

Fig. 3. The percentage dose at the depth of 2.0, 3.0, and 3.5 cm obtained from the NR and commercial bolus.

5. Discussion

The bolus fabricated by NR material was first introduced by Supratman et al.[7] The relative electron densities of our NR bolus were different from the previous study, because of the rubber types and the elemental compositions. In the study of Supratman et al.,[7] the bolus sheet was made from NR with additional 90% of formic acid and the relative electron density was equal to 0.893. When the bolus sheets become dried, they were shrunk in all directions. The edge of NR bolus sheets were more shrunk than the center of NR bolus sheets, because of the difference of thermal expansion coefficient between the rubber and aluminum mold.[20] Variations of bolus thickness and bolus density were observed. We found that the thicker bolus sheets were more uniform than the thinner bolus sheets as shown in Table 1. The deviations of CT number varied more than 20 HU in both ~0.3 cm NR bolus and 0.3 cm Superflab bolus, because the ROI size of 100 mm^2 is too large to collect the Hounsfield units in the thinner bolus thickness.The relative electron density of our study was mostly in good agreement with the method of Martinez et al.[13] as shown in Table 2.

Variations in the CT number and relative electron density of the bolus sheet represented the differential attenuation of the electron beam. The amount of beam attenuation depended on bolus thickness, bolus type and bolus density as presented in Table 3. As the bolus thickness increased, more electron beams were attenuated. The doses were shifted toward the surface as much as the bolus thickness used. Higher surface doses were found for a thicker bolus sheet. The ~0.5 cm NR bolus and 0.5 cm TE gel bolus may have the same thickness, but the composition will be different. The NR is composed of hydrocarbon, carbohydrate, protient, lipid, organic acid, mineral, and water.[21] For the TE gel bolus, the content of water was higher, the values of CT number close to 0 HU as shown in Table 1. The NR bolus was more densely packed and, therefore, attenuated the dose more than TE gel bolus. For the Superflab bolus, it was composed of a synthetic oil gel. Superflab bolus had the same relative electron density as NR bolus, but they differed in the compactness.

Because of the depth dose charactetistic of the electron beam, the doses rapidly fell off at the depth apart from the therapeutic range. Lower deeper doses are found for a thicker bolus thickness. The highest dose difference at the 3.5 cm depth was found between the ~0.5 cm NR bolus and 0.5 cm TE gel bolus as shown in Fig. 3. The bolus density strongly impacted the doses at the depth beyond the surface region.

6. Conclusions

An advantage of radiotherapy bolus fabricated by NR material was homogeneous, compatible density, and availability in our country. The relative electron densities of the NR bolus were very similar to that of the Superflab, but differed from that of the TE gel. By placing the different thickness and material of bolus on the anterior surface of the medium, the surface dose and dose at the relevant depths were modified. The differences of the surface dose and dose at the deeper depth between the ~0.5 cm NR and 0.5 cm TE gel bolus were observed. Dosimetrically, the strong effect of bolus thickness and material showed in the rapid fall-off region of the therapeutic electron beam.

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Conflict of interest

None declared.

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References

1. Gunhan B, Kemikler G, Koca A. Determination of surface dose and the effect of bolus to surface dose in electron beams. *Med Dosim*. 2003;28(3):193–198.
2. Vyas V, Palmer L, Mudge R, et al. On bolus for megavoltage photon and electron radiation therapy. *Med Dosim*. 2013;38:268–273.
3. Saw CB, Wen BC, Anderson K, et al. Dosimetric considerations of water-based bolus irradiation of extremities. *Med Dosim*. 1998;23:292–295.
4. Superflab bolus specifications, https://www.rpdinc.com/index.php?controller=attachment?id_attachment=559; 2015 [accessed 13 November 2015].
5. Cornish K. *Biosynthesis of natural rubber (NR) in different rubber-producing species*. USA: Woodhead Publishing Limited; 2014:3–27.
6. Harris CM, Piersol AG. *Harris' shock and vibration handbook*. 5th edition McGRAW-HILL; 2002. ISBN0-07-137081-1.
7. Supratman AS, Sutanto H, Hidayanto E, et al. Characteristic of natural rubber as bolus material for radiotherapy. *Mater Res Express*. 2018;5, http://dx.doi.org/10.1088/2053-1591/aad5ca.
8. Niroomand-Rad A, Blackwell CR, Coursey BM, et al. Radiochromic film dosimetry: recommendations of AAPM radiation therapy committee task group 55. *Med Phys*. 1998;25(11):2093–2115.
9. GAFChromic$^{\text{TM}}$ EBT3 film specifications, www.gafchromic.com/gafchromic/whitePapers/whitePapers.asp; 2014 [accessed April 2014].
10. Molina-Romero M, Figueroa-Medina E, Gamboa-deBuen I. Response of EBT3 gafchromic films exposed to high energy electrons. *AIP Conf. Series*. 2016, http://dx.doi.org/10.10631/1.4954107.
11. *Tissue characterization phantom model 467 user's guide.*; 2004 https://www.cspmedical.com/content/102-1492_tissue_phantom_user_guide.pdf:.
12. Knoos T, Nilsson M, Ahlgren L. A method for conversion of Hounsfield number to electron density and prediction of macroscopic pair production cross-sections. *Radiother Oncol*. 1986;5(4):337–345.
13. Martinez FH, Villafuerte MR, Davalos AM, et al. Electron density calibration for radiotherapy treatment planning. *AIP Conf Proc*. 2006;854:104–107.
14. Sipila P, Ojala J, Kaijaluoto, et al. Gafchromic EBT3 film dosimetry in electron beams-energy dependence and improved film read-out. *J Appl Clin Med Phys*. 2016;17(1):360–373.
15. Sorriaux J, Kacperek A, Rossomme S, et al. Evaluation of Gafchromic$^{@}$ EBT3 films characteristics in therapy photon, electron and proton beams. *Phys Medica*. 2013;29:599–606.
16. Moylan R, Aland T, Kairn T. Dosimetric accuracy of Gafchromic EBT2 and EBT3 film for in vivo dosimetry. *Australas Phys Eng Sci Med*. 2013;36:331–337.
17. Nashrulhaq T, Raizulnasuha AR, Siti NAA, et al. Effect of scanning parameters on dose-response of radiochromic films irradiated with photon and electron beams. *Holiyon*. 2018;4:1–17.
18. *Tissue-equivalent gel bolus specifications.*; 2017 https://civcort.com/ro/resources/Technical-Spec-Sheets/BolusTechnicalDataSheet_2017P1300_A.pdf.
19. Kairn T, Aland T. Calibration of radiochromic film for electron radiotherapy dosimetry. *IFMBE Proc*. 2013;39:1153–1156.
20. *Coefficient of thermal expansion for various materials at different temperatures.*; 2004 https://www.balseal.com/wp-content/uploads/2019/06/Coefficient_Of_Thermal_Expansion_Of_Bal_Seal_MaterialsTR_18.pdf [accessed 25 June 2004].
21. Jacob JL, d'Auzac J, Prevot JC. The composition of natural latex from Hevea brasiliensis. *Clin Rev Allergy*. 1993;11:325–337.