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Dosimetry analysis of homemade bolus using propylene glycol for photon MegaVoltage and electron radiation therapy

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Abstract. Bolus is widely used to protect and reduce irradiation in organ at risk in the process of radiotherapy. Generally, the bolus was made from polymer material due to had property is similar or equivalent to tissue. This study aimed to determine the density, transmission factor, effective mass attenuation coefficient on bolus with radiation of photons and electrons. The bolus material (B) was used Propylene Glycol (PG), Silicon Rubber (SR) and Aluminium Powder (Al), and had four types of bolus namely B - PG 24%, B - PG 24%; SR 8%, B - PG 24%; SR 8%; Al 0,5%, and B - PG 24%; SR 8%; Al 1,5% with dimensions of 11×11 cm and thickness of 1 and 1.5 cm. The bolus density is evaluated through the mass of each volume. The measured data revealed that all of the boluses have density values which are similar to tissue or water and air in the range from 0.864 - 1.202g/cm³. For dosimetry testing, the bolus is irradiated using Linear Accelerator with 6 and 10 MV for photon source and 6 and 12 MeV for an electron source. The results showed that B - PG 24%; SR 8%; Al 1.5% for dosimetry testing both 6 and 10 MV photons obtained properties that resemble soft tissue. Meanwhile, for both dosimetry testing of 12 MeV electrons, the B - PG 24%; SR 8% with addition silicone rubber and aluminum have nature closest to soft tissue. All of the boluses that have been fabricated have properties similar to soft tissue for photon therapy whereas the addition of more aluminum making a bolus has features as a shield on the process of radiotherapy.

1. Introduction

Radiotherapy as a treatment that utilizes ionizing radiation is very rapidly developing. According to Cancer Research UK, in the UK there are 300,000 new cancer patients each year, and more than 90,000 patients receive radiotherapy treatment as part of periodic treatment [1]. Besides that radiotherapy has the principle to kill dangerous cells such as tumors and cancer without causing deadly things to healthy tissue around it [2]. Linear accelerator (LINAC) is a modality that used commonly in radiotherapy due to capable of producing high-energy electrons so that can be used to treat superficial tumors. In the radiotherapy, the process used several treatment techniques, including superficial X-ray, brachytherapy, tangential photon beams and therapeutic electron [3]. In photon and electron therapy, surface doses can be increased according to the dosage needed to healthy tissue using a compensation tissue that is in direct contact with

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the patient's surface [4]. The compensation tissue used in photon and electron therapy is called bolus. A good bolus must have several characteristics such as non-toxic, non-sticky, has good visibility, can maintain its shape and has a computed tomography (CT) number between 130 to 160 HU [5]. The right material selection is needed to fulfill these characteristics. As a tissue compensator, bolus should have features that are equivalent to body tissue. In this study, Propylene Glycol material was used as the primary material for synthesizing bolus. The addition variation with silicon rubber and aluminum in the Propylene Glycol material will be evaluated to compare the characteristics of the bolus from the photon and electron beam.

2. Material and Methods

2.1 Bolus Fabrication without Silicone Rubber.

Propylene Glycol (PG) was used to fabricate of bolus (B), it which is dissolved in agar solution with the composition variation was 24%:2%, respectively. The mixture of 9 g of agar and 2.25 g of NaCl were dissolved into aquades with a volume of 331 mL and was then stirred using a hot plate magnetic stirrer 10 min Subsequently, 108 mL of PG was mixed with agar solution and stirred again for ± 3 h at 100 °C. Furthermore, the solution is poured into acrylic molds with a varies of thickness was 5, 10 and 15 mm with area dimensions of 11×11 cm² and flattened until evenly distributed and let it dry at room temperature.

2.2 Bolus Fabrication with Silicone Rubber and Aluminium Powder.

Fabrication of bolus with the addition either Silicone Rubber (SR) or Aluminium Powder (Al) was almost the same as fabrication of boluses without SR. The solution was then added with SR 8% and stirred using a wooden stick until the solution blends perfectly and becomes homogeneous before poured into acrylic molds; then let it stands at \pm 15 min. Subsequently, the mixture is molded with variations in the thickness of 5, 10 and 15 mm with dimensions of 11×11 cm² and flattened until evenly distributed for the synthesized boluses with addition aluminum powder. Before the solution is molded, the solution then added aluminum powder 0.5 or 1.5%, and stir until it becomes homogeneous and then poured into the mold with variations in the thickness of 5, 10, and 15 mm with dimensions of 11×11 cm². The composition variations used in the study were B - PG 24%; SR 8%, B - PG 24%; SR 8%; Al 0.5%, and B - PG 24%; SR 8%; Al 1.5%.

2.3 Density Test.

All the synthesized boluses mass are measured using a digital scale (Scout Pro SPS401F, OHAUS Corp., USA) whereas the volume of the bolus is calculated using its dimensions. So that the bolus density can be calculated using equation as follows:

$$\rho = \frac{m}{v} \tag{1}$$

with ρ is the mass of the material and m is mass (kg), and V is the material volume (m³) [6].

2.4 Dosimetry Test.

Dosimetry testing was carried out by medical physicists at the Radiotherapy Installation of Dr. Soetomo. In this test, the sample will be irradiated by two sources, namely electrons with energies 6 and 12 MeV and Photons with energies 6 and 10 MV using Linear Accelerator (Variant 2300iX). Radiation is done by setting the phantom source to surface distance (SSD) of 100 cm, the radiation area of 10×10 cm², and the dose rate of 100 MU/min. Ionized charge measurements, using the PPC40 parallel type detector plan for irradiation with electron and cylinder detector type FC 65G chamber for irradiation with photons. Every irradiation, the detector is placed at the maximum depth that depends on the energy used. Furthermore, the phantom water slab is irradiated with a set up that has been determined as shown in Figure 1.(a). Next, on the surface of the phantom water slab, a bolus is placed and irradiated with a predetermined set up as seen in Figure 1.(b) for photons and Figure 1.(c) for electrons.

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Figure 1. Schematic diagram of the study (a) without a bolus and (b, c) using bolus [7].

3. Result and Discussion

In this study, bolus has been successfully made as tissue compensation for radiation therapy which is shown in Figure 2. According to Kirkpatrick et al. and Vyas et al., a good bolus has a transparent and oily nature, good visibility and has similar characteristics with soft tissue [5, 8]. Bolus with composition B- PG 24% has a characteristic that is transparent so that the surface of the clipped skin can be seen. The bolus transparent physical form corresponds to the study conducted by Dubois et al. and Adamson et al. The results of their study stated that bolus which has high visibility could facilitate the radiation therapy process. While the bolus composition with the addition of silicone rubber and aluminum has a poor transparent nature. The same thing was found in a study conducted by Nagata et al. which made bolus with a base flour maker called Play-Doh, having properties that had low transparent properties [9, 10]

3.1 Density Bolus.

Based on the results of density measurements for all bolus variations shown in Figure 3. that as the bolus thickness increases, the density value will also decrease. It is because the density value is proportional to the volume of the bolus. Density bolus was also obtained have range 0,864 1,202 g/cm³ which is density equivalent to fat, tissue or water, and air with their respective value of 0.91 g/cm³, 1 g/cm³ and 1.29 g/cm³[11,12]. The results of the test also show similarities with the value of bolus density with the addition of silicon carried out by Dubois et al., [9].



Figure 2. The synthesized bolus with variations in composition B PG 24%, B PG 24%; SR 8%, B PG 24%; SR 8%; Al 0.5%, dan B PG 24%; SR 8%; Al 1.5%.

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Figure 3. Density as a function of the thickness of the synthesized bolus.

3.2 Radiation Test.

Dosimetry testing is carried out by irradiating boluses with photons 6 and 10 MV, as well as electrons 6 and 12 MeV. The test was conducted to determine bolus characteristics such as transmission factors and effective mass attenuation coefficients. The determination of bolus transmission factors refers to Montaseri et al. [13]. The study states that transmission factors can be obtained from comparing bolus loads with no bolus loads. The results of the calculations performed are shown in Tables 1 and 2.

Material	Thickness (cm)	Charge Without Bolus (nC)		Charge (nC)		Transmission Factors	
		6 MV	10 MV	6 MV	10 MV	6 MV	10 MV
PG 24%	1	18.255	18.37	18.22	18.31	0.998	0.997
	1.5			18.06	18.16	0.989	0.989
PG 24%; SR	1			18.17	18.19	0.992	0.995
8%	1.5	18.31	18.29	17.97	17.99	0.981	0.984
PG 24%; SR	1			18.23	18.20	0.996	0.995
8%; Al 0.5%	1.5			17.96	17.99	0.981	0.984
PG 24%; SR	1			18.14	18.15	0.991	0.992
8%; Al 1.5%	1.5			17.91	17.99	0.978	0.984

Table 1. Transmission factors of boluses for photon energy with radiation area 10×10 cm²

Table 2. Transmission factors of boluses for an electron beam with radiation area 10×10 cm²

Material	Thickness (cm)	Charge Without Bolus (nC)		Charge (nC)		Transmission Factors	
		6 MeV	10 MeV	6 MeV	10 MeV	6 MeV	10 MeV
PG 24%	1	10.75	11.73	10.680	11.700	0.9935	0.9974
	1.5			7.655	11.170	0.7121	0.9523
PG 24%; SR	1			8.671	11.090	0.8066	0.9454
8%	1.5			4.541	10.120	0.4224	0.8627
PG 24%; SR	1			9.715	11.340	0.7912	0.9668
8%; Al 0.5%	1.5			3.576	9.821	0.4835	0.8373
PG 24%; SR	1			8.505	11.080	0.9037	0.9446
8%; Al 1.5%	1.5			5.198	10.270	0.3327	0.8755

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According to the Table 1 and 2, bolus with a thickness of 1 and 1.5 cm have a transmission factor value less than 1, so that condition explains that bolus can reduce the intensity of photons and electrons from the original intensity. These results are consistent with the research conducted by Paliwal et al. [14]. Furthermore, Table 1 and 2, it shows that irradiation with photons 6 and 10 MV produces transmission factors greater than irradiation with electrons 6 and 12 MeV. The statement is appropriate with the theory that photon irradiation has greater permeability than electrons so that irradiation of photons is very suitable for therapy with deep targets [3]. On the other hand, bolus with the addition of silicone rubber and silicone rubber + aluminum produces a transmission factor that tends to decrease from bolus with PG composition of only 24%. Decreasing the value of the transmission of factors with the addition of silicone and aluminum in research conducted by Malaescu et al. [15].

Based on the transmission factor obtained, bolus thickness of 1.5 cm with PG composition of 24%; SR 8%; Al 1.5% has the most similar properties to soft tissue for irradiation with photons 6 and 10 MV. While the bolus is 1 cm in thickness with a composition of PG 24%; SR 8% with aluminum has similar properties with soft tissue for irradiation with 12 MeV photons. This transmission factor with a range of 0.96 - 0.98 indicates that the bolus has similar properties to soft tissue. This result is appropriate for the study by Montaseri et al. [13]. On the other hand, bolus with 1.5 cm thickness with PG composition of 24%; SR 8% with the addition of aluminum can act as an important organ of protector in electron radiation therapy. Malaescu et al. stated that bolus which has a 10 20% reduction in transmission factor could be used as an essential protective material for organs [15].

Material	Thickness (cm)	Density (g/cm ³)	effectiv attenuation cm ²	e mass coefficient (²/g)	effective mass attenuation coefficient (cm²/g)		
			6 MV	6 MeV	10 MV	10 MeV	
PG 24%	1	0.864	0.0025	0.0086	0.0039	0.0033	
	1.5	0.865	0.0085	0.2979	0.0092	0.0416	
PG 24%;	1	1.183	0.0065	0.2021	0.0052	0.0489	
SR 8%	1.5	1.091	0.0115	0.5857	0.0114	0.0931	
PG 24%;	1	1.115	0.0043	0.1125	0.0051	0.3061	
SR 8%; Al 0.5%	1.5	1.106	0.0127	0.8217	0.0114	0.1274	
PG 24%;	1	1.202	0.0078	0.2073	0.0064	0.0486	
SR 8%; Al 1.5%	1.5	1.031	0.0144	0.4998	0.0107	0.0881	

Table 3. Effective mass attenuation coefficient for boluses with 6 and 10 MV photon energies, and 6	6
and 12 MeV electron energy with radiation size 10×10 cm ²	

The determination of the effective mass attenuation coefficient was chosen because of the process of interaction with irradiation of megavoltage photons, and Megavolt electron is Compton scattering according to Khan [3]. The calculation of the coefficient is conducted by Tagoe et al. [16]. The results of calculating the effective mass attenuation coefficient shown in Tables 3 and 4 where the effective attenuation coefficient of the bolus mass of 1 to 1.5 cm in thickness with energy continues to increase the attenuation coefficient. The increasing phenomenon is appropriate with the study conducted by Paliwat et al. When compared with previous studies, similar results have been made by Nagata et al. [17] who measured the value of bolus attenuation by using Superflab and plastic water with thicknesses between 1.1 to 2.5 cm using the energy range of 5 to 12 MeV. In addition to this article published by Montaseri et al. [13] who used bolus made from Ethyl Methacrylate with a thickness of 1 cm with 6 MV photons and 18 MV. While the attenuation coefficient value will increase with the thickness of the material [14], based on the type of irradiation used, bolus by irradiation of photons has a lower attenuation coefficient than irradiation with electrons. It is also appropriate with the statement of Paliwat et al. and Tanir et al. [14, 18].

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4. Conclusions

The synthesized bolus density demonstrated similar property to fat, muscle, and air density. Besides that, the bolus material has the potential for dose reduction on the surface. The results revealed that the bolus material provided better surface dose reduction at each photon and electrons. The transmission factor and the effective mass attenuation coefficient of the synthesized bolus had greater values when it was irradiated with the megavoltage photon compared to irradiated with the electron beam. Moreover, the bolus with a composition of PG 24%: SR 8%: Al 1.5% with a thickness of 1.5 cm for dosimetry testing both 6 and 10 MV energies obtained properties resembling soft tissue. While bolus is 1 cm in thickness with a composition of PG 24%; SR 8% with the addition of aluminum has similar properties with soft tissue for irradiation with 12 MeV photons. All of the boluses that have been fabricated have properties as a shield on the process of radiotherapy.

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