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# Fabrication and Characterization of Bolus Material Using Propylene Glycol for Radiation Therapy

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## ABSTRACT

***Introduction:*** This study aimed to evaluate the efficacy of a synthesized bolus in the reduction of damage to body tissues and the protection of the organ at risk (OAR) in radiotherapy application. Several properties of the synthesized bolus, including density, transmission factor, and effective mass attenuation coefficient, were investigated.

***Material and Methods:*** The materials used comprising of propylene glycol (PG), silicone rubber (SR), and aluminum (Al). The dimension of the synthesized bolus was measured using an acrylic case with a size of 11×11 cm² and thickness sizes of 0.5, 1, and 1.5 cm. Furthermore, the boluses were irradiated by linear accelerator with the photon beam energies of 6 and 10 MV, using linier accelerator (LINAC) Varian 2300ix.

***Results:*** In this research, the density of synthesized bolus was evaluated by mass per volume equation. The results showed that the density of bolus was similar to the density of tissue/water, fat, and air. . Furthermore the bolus with the composition of PG 24%, SR 8%, and Al 1.5% of all energies, transmission factors of 0.978 and 0.984, thickness of 1.5 cm, and effective mass attenuation coefficients of 0.0144 and 0.0107 cm²/g had the closest properties to the body tissues in terms of dosimetry characterization.

***Conclusion:*** The results revealed that the synthesized bolus could increase the percentage surface dose, reduce skin-sparing effect, and protect OAR. The findings indicated that the synthesized bolus had a potential application in clinical therapy.

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## Introduction

Linear accelerator (Linac) is a device that uses high-frequency electromagnetic waves and is usually used for radiotherapy applications that can produce two sources, namely electron beam and photon beam [1, 2]. By utilizing megavoltage radiation therapy, photons offer a different advantage in terms of dose uniformity in the target, compared to electrons. However, megavoltage photons represent a dose build-up effect in the tissues with absorbed doses, which are maximal in a certain depth and are related to the presence of secondary Compton electrons [2, 3]. This phenomenon causes a decrease in the percentage of photon surface dose with energy, and a skin-sparing effect can be an issue for the treatment of superficial [3]. Therefore, to reduce the risk of skin-sparing effect, the surface dose can be increased by adding a substitute material called bolus. The bolus acts as a second skin to shift the maximum dose closer to the surface and protect the organs at risk [3-5].

The characteristic of a good bolus material is that it has the same scattering and absorption properties as water and muscle tissue [6]. In addition, bolus must be non-toxic, transparent, and non-sticky, easy to make, durable, and cost-effective and has the potentiality to maintain its shape. In addition, they should have the tensile properties of less than 0.1 Gpa, computed tomography range of 130-160 HU, average atomic number Z of around 5.4, and electron density of about $3.05\times10^{23}$ eV/cm [7-9]. Furthermore, several studies provided a comprehensive review of various bolus materials and particularly, an easy and informative medical use. For example, paraffin wax, polystyrene, polymethyl methacrylate (PMMA), Lucite, super stuff, super flex, and Superflab are materials that are usually used for the production of bolus [2, 10-12].

However, the custom fabrication of some bolus materials, such as paraffin wax, requires a long time and complicated process which is unstable at certain temperatures [10]. Play-Doh material has properties that are less able to maintain shape and do not last long [13]. Although gelatin-based materials are useful, several practical problems, such as moldiness and dosimetric distortion, can occur if there is an air gap between the bolus and surface [10, 14]. Regardless of

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the bolus material aspect, the selection of bolus thickness is an equally significant aspect because of its ability to increase surface doses.A thicker bolus can provide a reduction in dose transmission, which can be checked using the reference dose depth data [15]. On the other hand, increasing surface doses can be achieved by using high-density metal sheets, such as lead. Lead has been introduced as a bolus because it has a high absorption interval [16]. Moreover, materials with high *Z,* such as lead, have several advantages, including large and easy to use treatment intervals [15, 17]. Nevertheless, the use of these materials requires considerable costs and is difficult to obtain.One alternative to overcome this problem is the introduction of a new material, namely propylene glycol (PG), as the base material for bolus fabrication. The PG is an organic compound that is commonly used in industrial and commercial fields (e.g., for therapeutic, additional humectant, moisturizer, and cosmetic purposes) [18, 19]. This compound has water-like properties and excellent thermal stability; moreover, it is considered safe. The PG is a clear, thick, odorless, and good humectant. In dentistry, this substance has been used as a calcium hydroxide paste since it is easy to obtain and inexpensive [18].

In addition, the bolus made by researchers contains a mixture of silicon rubber (SR) and aluminum (Al). The reason for the selection of SR is that it has good properties, such as heat resistance, chemical stability, low toxicity, abrasion resistance, and formability, offering the potential for application in various fields [20]. However, Al is used to increase the absorption of megavoltage photons since in a study conducted by Malaescu et al., the addition of Al powder and SR was reported to increase the value of absorbed doses with the electron beam [21]. Therefore, this study was conducted to evaluate the characteristics of the synthesized bolus, based on PG with the addition of SR and Al, using megavoltage photons. To this end, the bolus density, transmission factor, attenuation coefficient, and percentage surface dose compared to references were investigated.

## Materials and Methods

### *Fabrication of Bolus without Silicone Rubber*

The mixture of PG and agar used in the study had two compositions of 24%:2% and 34%:2%, respectively. The selection of the percentage of these two compositions was based on the total volume applied in this study, which was 450 mL. In the current research, 2% of the solution of agar was made by dissolving 9 g agar and 2.25 g NaCl with distilled water in 330.75 mL PG 24% and 285.75 mL PG 34%. Furthermore, the agar solution was poured into 1000 mL beaker and stirred using a magnetic stirrer for 10 min to achieve a homogeneous state. Subsequently, the PG (108 mL for 24% and 153 mL for 34%) was poured slowly into the agar solution, while continuing stirring for 3 h at 100°C and the beaker mouth was covered with aluminum foil sheet. The mixture was then poured into an acrylic mold with the dimensions of 11×11 $cm^2$ and thickness sizes of 0.5, 1, and 1.5 cm, and finally flattened until being evenly distributed. The samples were allowed to harden (with no change in shape) to be removed easily from the mold. Finally, the samples were covered by a plastic wrap to prevent any fungal growth

### *Fabrication of Bolus with Silicone Rubber and Aluminum*

The same process was used to fabricate bolus with SR RTV-586 only and Al 1.01056.0250, Germany. As opposed to before, the percentage of compositions ware based on a the total volume of 1080 mL. Thus, a 2% agar solution was made by dissolving 21.60 g agar and 5.40 g NaCl with distilled water in 707.4 mL for PG 24%. Accordingly, similar steps were taken by fabricating 2% agar solution and mixing PG (259.20 mL for 24%) with 2% agar solution. The next stage involved the addition of SR 8% (86.40 g) into the mixture solution, followed by stirring with a wooden stirrer until obtaining a homogeneous solution. Subsequently, the mixture solution let stand for 15 min. Furthermore, 0.5% (5.4 g) or 1.5% (16.20 g) Al was added into the mixture and stirred until it became homogeneous. Afterward, the resultant mixture was poured into an acrylic mold with the dimensions of 11×11 $cm^2$ and thickness sizes of 0.5, 1, and 1.5 cm, and then flattened until being evenly distributed. The composition proportions included 24% PG: 2% agar: 8% SR, 24% PG: 2% agar: 8% SR: 0.5% Al, and 24% PG: 2% agar: 8% SR: 1.5% Al. The base of the selection of Al 0.5% and 1.5% was Al with a percentage of 5.5% that could give a transmission dose of up to 82% with an irradiation electron beam, as reported by Malaescu et al. [21]. This condition showed that Al served as a protective material (shield), not as a scattering provider, while the selection of 8% of SR with this composition resulted in a good abrasion resistance texture in the bolus.

### *Bolus Density*

All the synthesized boluses mass was weighed using digital balance (Scout Pro SPS401F, OHAUS Corp., USA), however, the volume was determined from the bolus dimension. Furthermore, bolus density can be calculated using *Equation (1)*:

$$\rho = m/V \tag{1}$$

where $\rho$ is the synthesized bolus density (kg/$m^3$), $m$ is the synthesized bolus mass (kg), and $V$ is the volume of bolus ($m^3$) [22].

### *Bolus Radiation Test*

A radiation test for the synthesized bolus was performed in the radiotherapy installation room of Dr. Soetomo Hospital, Surabaya, and East Java, Indonesia. The synthesized bolus with varied thicknesses of 0.5, 1, and 1.5 cm was irradiated by Linac Varian 2300ix, (Varian Medical Systems, and USA) with the photon beam energies of 6 and 10 MV and a dose rate of 100 MU $min^{-1}$.

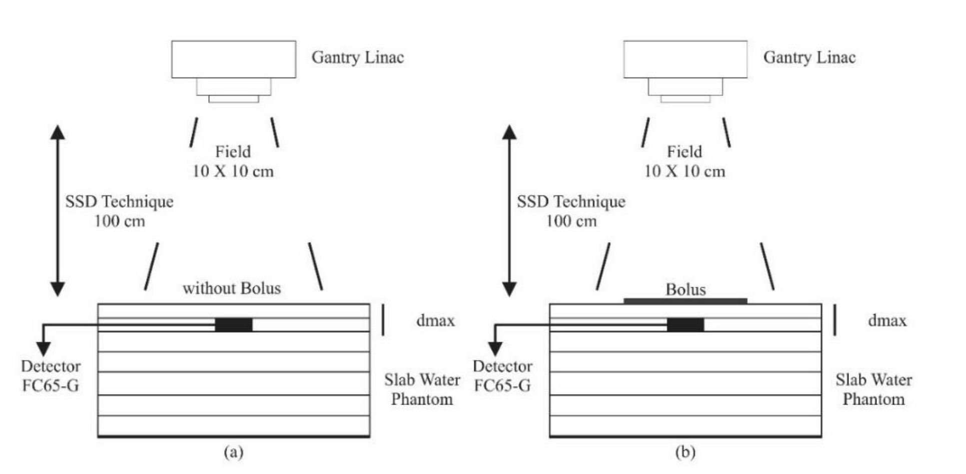


Figure 1. Schematic diagram of this study (a) without bolus and (b) using a bolus

The scheme of the radiation test for the synthesized bolus material is shown in Figure 1. Based on Figure 1(a), the source-surface distance and field size were set at 100 cm and 10×10 $cm^2$, respectively. The measurement of ionized load used a cylindrical detector-farrmer type ionization chamber FC 65 G (Scanditronix Wellhofer Dosimetrie, Germany) and electrometer (Physikalisch-Technische Werkstätten Unidos Series IC 61674, Germany). The detector was placed on the surface of a slab water phantom and positioned in the maximum depths of 1.5 and 2.5 cm to have 6 and 10 MV photons, respectively.

Figure 1(a) illustrates the radiation test of the water slab phantom without the synthesized bolus, whereas Figure 1(b) shows radiation test for the synthesized bolus placed on the top of the water slab phantom [23]. From these measurements, 2 types of charge (nC) were obtained, namely from irradiation without bolus, and using bolus. Afterward, the transmission factor was calculated by comparing the results of the measurements of charge (nC) with bolus and without bolus [24]. The percentage of surface dose calculation is the surface radiation dose of a solid water phantom, divided by the radiation dose at a maximum depth [4].

Furthermore, the effective mass attenuation coefficient was chosen because the Compton effect was the predominant interaction process that occurred when a megavoltage photon beam interacted with a material. The effective mass attenuation coefficient of material by considering the density ($\rho$) value could be calculated using the following equation:

$$\text{In}\ (I/I_0) = -\mu_{\text{meff}} .\ X_b .\ f .\ \rho_b \qquad (2)$$

where $(I/I_0)$ is the transmission factor for the radiation as it traverses through the bolus, and $X_b$ is the thickness of the bolus (cm), $\rho_b$ is the density of bolus (g/$cm^3$), $\mu_{\text{meff}}$ is the effective mass attenuation coefficient ($cm^2$/g) and $f$ is a correction factor obtained from the bolus function of its thickness [2, 25].

## Results

In the present study, boluses were fabricated successfully as a tissue compensation for radiotherapy. The variety of samples is shown in Figure 2. Bolus, which contains PG 34% and 24% had a pellucid and transparent physical appearance. The results were in concordance with those obtained by Adamson et al. [26]. They fabricated the bolus from PG with excellent visibility (it can be proven by reading handwriting under the bolus as depicted in Figure 3b) [26]. The transparent level of the bolus can assist its positioning on the body contour and hinder the air gap circumstance, which has been reported by Vyas et al. [10]. Moreover, the production of bolus using the composition of PG 24 %: SR 8% and the addition of Al resulted in mediocre visibility of bolus (declining quality). The same results were obtained by Nagata et al., who used Play-doh and super flab as raw materials [13].

### *Bolus Density*

Bolus density for all samples is shown in Table 1. It can be seen that bolus with PG 34% and PG 24% had the density value that decreased when the thickness of samples increased. It is due to the density value that has a proportionate relationship with the volume of the bolus. Based on Table 1, the highest density value was obtained as 0.964 g/$cm^3$ for bolus PG 24% with a thickness of 0.5 cm, whereas the lowest one was obtained as 0.864 g/$cm^3$ for PG 24% with a thickness of 1.0 cm. Moreover, synthesized bolus with PG 24% had a better flexibility than bolus with PG 34%, as shown in Figure 3(a). The flexible property assisted the radiation therapy in a particular case, such as the uneven surface of the target as reported by Gunhan et al. [4].

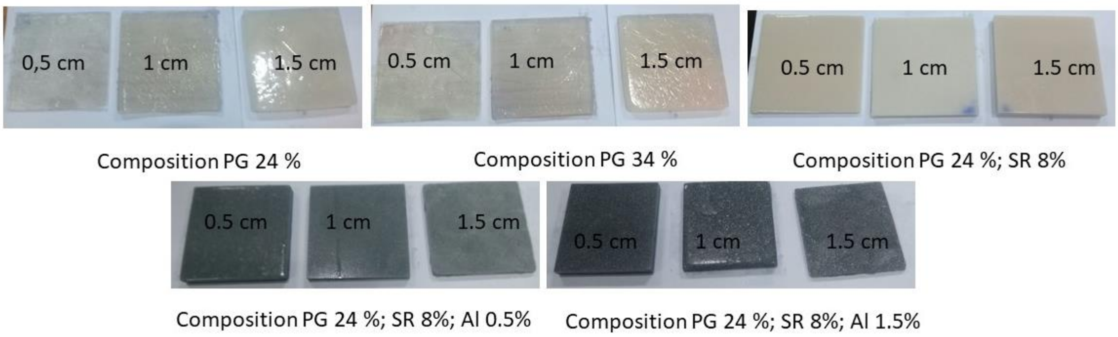
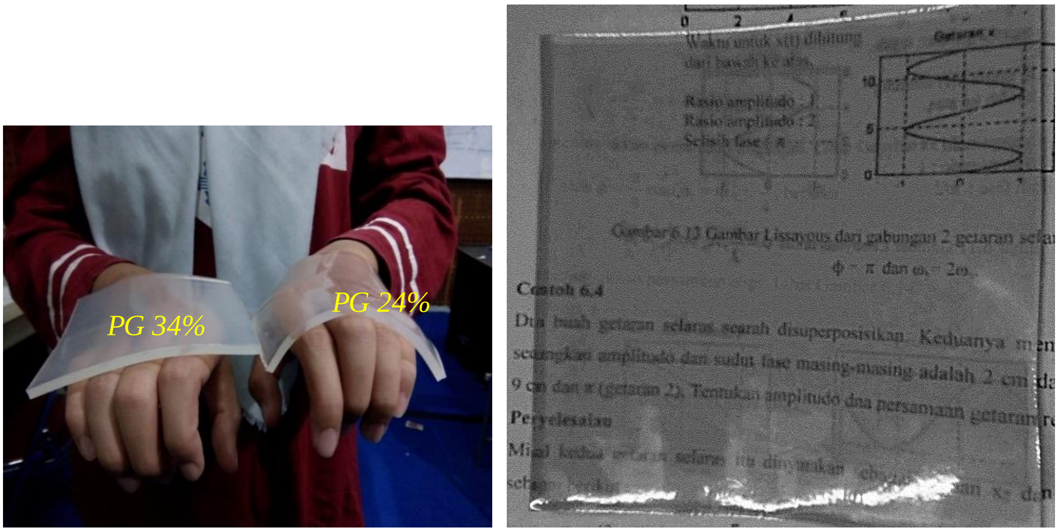


Figure 2. Synthesized boluses with comparison PG 24%, PG 34%, PG 24%: SR 8%, PG 24%: SR 8%: Al 0,5% and PG 24%: SR 8%: Al 1,5%.



(a) (b)

Figure 3. Synthesized bolus; (a) flexibility bolus PG 34% dan PG 24%, (b) transparency of bolus

Table 1. Bolus density for each variation in composition and thickness

| Material | Thickness (cm) | Density (g/cm³) |
|---|---|---|
| PG 34% | 0.5 | 0.889 |
| | 1.0 | 0.947 |
| | 1.5 | 0.917 |
| PG 24% | 0.5 | 0.964 |
| | 1.0 | 0.864 |
| | 1.5 | 0.865 |
| PG 24%: SR 8% | 0.5 | 1.218 |
| | 1.0 | 1.183 |
| | 1.5 | 1.091 |
| PG 24%: SR 8%: Al 0.5% | 0.5 | 1.266 |
| | 1.0 | 1.115 |
| | 1.5 | 1.106 |
| PG 24%: SR 8%: Al 1.5% | 0.5 | 1.273 |
| | 1.0 | 1.202 |
| | 1.5 | 1.031 |

On the other hand, the density value of the bolus synthesized out of PG 24% in addition to SR and Al with a thickness of 0.5 cm revealed a slight enhancement compared to the bolus only made of PG 24%, such as bolus in additon SR 8%: Al 1.5% had an increase of 0.309. Meanwhile, the average bolus density for the thicknesses of 1 and 1.5 cm with the addition of SR and Al had an increase of 0.303 and 0.211 g/cm³.

### Bolus Radiation

Radiation test was carried out by irradiating bolus using Linac Variant 2300ix with the photon beams of 6 and 10 MV. Measurement of the reference value was conducted by measuring the charge without a bolus. The reference value measurements were of two kinds for each energy, using different irradiation times. Therefore, there were two reference values used for calculating the transmission factor value. The measurement of the charge using the synthesized bolus based on Figure 1(b) and measured data are summarised in Table 2.

According to Table 2, the transmission factor of the bolus material could be determined by comparing the measurement of the synthesized bolus with the reference value [24]. The transmission factor of the bolus with a thickness of 0.5 cm had the average transmission factors of 1.0042 and 1.0002 for 6- and 10-MV energies, respectively. This condition explains that a bolus with a thickness of 0.5 cm continues the entire photon beam (non-absorber). Meanwhile, boluses with a thickness of 1 and 1.5 cm had an average transmission factor of < 1.000, as shown in Table 2. For example, a transmission factor of < 1.0000 with a sample thickness of 1.5 cm and composition of PG 24%: SR 8%: Al 1.5% had a transmission factor of 0.978. This fact explains that the photon intensity was declined by 0.022 from the original intensity. Therefore, it can be concluded that as the bolus gets thicker, the transmission factor becomes smaller. The same result was reported by Paliwal et al. [27].

Furthermore, the effective mass attenuation coefficient can be determined using an equation, as mentioned by Khan and Tagoe et al. [2, 25]. Calculation of the mass attenuation coefficient for the synthesized bolus is necessary to consider the material density value, due to the Compton effect, as described by Papanikolaou et al. [28]. The dominant interaction process occurs when a megavoltage ray interacts with the bolus. The calculations of the effective mass attenuation coefficient are summarized in Table 3. The highest effective mass attenuation coefficient for all thicknesses occurred in the boluses with PG 24%: SR 8%: Al 1.5% for both energies of 6 and 10 MV with the values of 0.0144 and 0.0107 cm²/g, respectively.

According to Figure 4, the surface percentage dose value of bolus had less value than those without bolus for a thickness of 0.5 cm, using both photon energies of 6 and 10 MV. This phenomenon was possible as a result of coherent scattering and was more dominant than Compton scattering. Coherent scattering can be referred to as classical scattering, wherein the electromagnetic waves that pass through material only make electrons oscillate. This electron oscillation radiates energy at the same frequency as that of the first electromagnetic wave. It is shown that no energy is changed or absorbed in this incident [2].

Table 2. Transmission factor for boluses with radiation area of 10×10 cm$^2$

| Material | Thickness (cm) | Charge without bolus (nC) | | Charge with bolus (nC) | | Transmission Factor | |
|---|---|---|---|---|---|---|---|
| | | 6 MV | 10 MV | 6 MV | 10 MV | 6 MV | 10 MV |
| PG 34% | 0.5 | 18.255 | 18.37 | 18.37 | 18.38 | 1.006 | 1.001 |
| | 1 | 18.255 | 18.37 | 18.26 | 18.31 | 1.000 | 0.997 |
| | 1.5 | 18.255 | 18.37 | 18.04 | 18.17 | 0.988 | 0.989 |
| PG 24% | 0.5 | 18.255 | 18.37 | 18.39 | 18.40 | 1.007 | 1.002 |
| | 1 | 18.255 | 18.37 | 18.22 | 18.31 | 0.998 | 0.997 |
| | 1.5 | 18.255 | 18.37 | 18.06 | 18.16 | 0.989 | 0.989 |
| PG 24%: SR 8% | 0.5 | 18.310 | 18.29 | 18.38 | 18.27 | 1.004 | 0.999 |
| | 1 | 18.310 | 18.29 | 18.17 | 18.19 | 0.992 | 0.995 |
| | 1.5 | 18.310 | 18.29 | 17.97 | 17.99 | 0.981 | 0.984 |
| PG 24%: SR 8%: Al 0.5% | 0.5 | 18.310 | 18.29 | 18.36 | 18.28 | 1.003 | 0.999 |
| | 1 | 18.310 | 18.29 | 18.23 | 18.20 | 0.996 | 0.995 |
| | 1.5 | 18.310 | 18.29 | 17.96 | 17.99 | 0.981 | 0.984 |
| PG 24%: SR 8%: Al 1.5% | 0.5 | 18.310 | 18.29 | 18.33 | 18.29 | 1.001 | 1.000 |
| | 1 | 18.310 | 18.29 | 18.14 | 18.15 | 0.991 | 0.992 |
| | 1.5 | 18.310 | 18.29 | 17.91 | 17.99 | 0.978 | 0.984 |

Table 3. Effective mass attenuation coefficient for boluses with 6- and 10-MV energies and radiation size of 10×10 cm$^2$

| Material | Thickness (cm) | Density (g/cm³) | Effective mass attenuation coefficient ($\mu_{meff}$) cm²/g | |
|---|---|---|---|---|
| | | | 6 MV | 10 MV |
| PG 34% | 0.5 | 0.889 | -0.0146 | -0.0013 |
| | 1 | 0.947 | 0.0000 | 0.0037 |
| | 1.5 | 0.917 | 0.0095 | 0.0086 |
| PG 24% | 0.5 | 0.964 | -0.0147 | -0.0035 |
| | 1 | 0.864 | 0.0025 | 0.0039 |
| | 1.5 | 0.865 | 0.0085 | 0.0092 |
| PG 24%: SR 8% | 0.5 | 1.218 | -0.0063 | 0.0020 |
| | 1 | 1.183 | 0.0065 | 0.0052 |
| | 1.5 | 1.091 | 0.0115 | 0.0114 |
| PG 24%: SR 8%: Al 0.5% | 0.5 | 1.266 | -0.0047 | 0.0010 |
| | 1 | 1.115 | 0.0043 | 0.0051 |
| | 1.5 | 1.106 | 0.0127 | 0.0114 |
| PG 24%: SR 8%: Al 1.5% | 0.5 | 1.273 | -0.0017 | 0.0000 |
| | 1 | 1.202 | 0.0078 | 0.0064 |
| | 1.5 | 1.031 | 0.0144 | 0.0107 |

Furthermore, based on Figure 5 showing a bolus with a thickness of 0.1 cm shown, the bolus resulted in an increase of percentage surface dose for all photon energies. The highest percentage surface dose was observed in the bolus with a composition of PG 24%: SR 8%: Al 1.5% with a value of 60.274% and 38.768% for the energies of 6 and 10 MV, respectively. Meanwhile, based on Figure 6, a bolus with a thickness of 1.5 cm also led to an increase in percentage surface dose for all photon energies. In this regard, a bolus with the composition of PG 24%: SR 8%?: Al 1.5% produced the highest percentage surface dose with the values of 61.863% and 39.393% for energies of 6 and 10 MV, respectively. On the other hand, the percentage surface dose difference between bolus and bolus-free irradiation is shown in Tables 4 and 5.

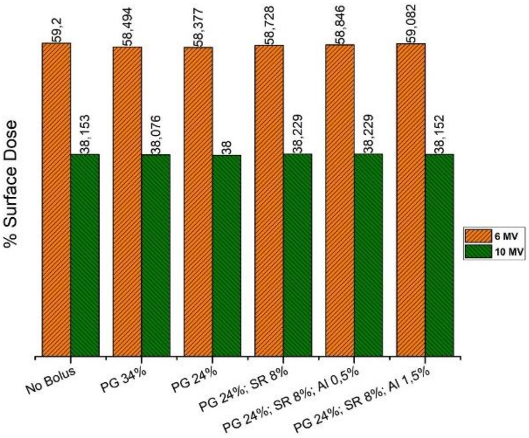


Figure 4. Percentage of surface dose for various boluses with a thickness of 0.5 cm for 6-MV energy with a maximum depth of 1.5 cm and for 10-MV energy with a maximum depth of 2.5 cm, with an irradiation area of 10×10 cm$^2$

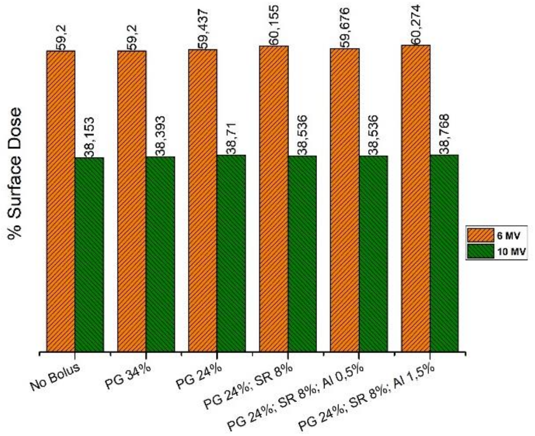


Figure 5. Percentage of surface dose for various boluses with a thickness of 1.0 cm for 6-MV energy with a maximum depth of 1.5 cm and for 10-MV energy with a maximum depth of 2.5 cm, with an irradiation area of 10×10 cm$^2$

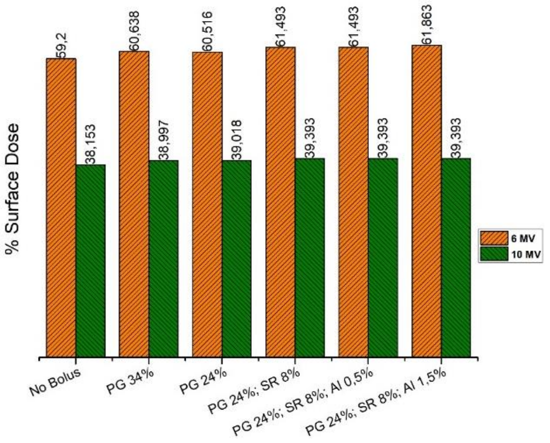


Figure 6. Percentage of surface dose for various boluses with a thickness of 1.5 cm for 6-MV energy with a maximum depth of 1.5 cm and for 10-MV energy with a maximum depth of 2.5 cm, with an irradiation area of 10×10 cm$^2$

Table 4. The difference of percentage surface dose between bolus and bolus-free irradiation at a thickness of 1.0

| Material | Percentage surface dose | |
|---|---|---|
| | 6 MV | 10 MV |
| PG 34% | 0.000 | 0.240 |
| PG 24% | 0.237 | 0.557 |
| PG 24%: SR 8% | 0.955 | 0.383 |
| PG 24%: SR 8%: Al 0.5% | 0.476 | 0.383 |
| PG 24%: SR 8%: Al 1.5% | 1.074 | 0.615 |

Table 5. The difference of percentage ionization between bolus and bolus-free irradiation at a thickness of 1.5

| Material | Percentage surface dose | |
|---|---|---|
| | 6 MV | 10 MV |
| PG 34% | 1.438 | 0.844 |
| PG 24% | 1.316 | 0.866 |
| PG 24%: SR 8% | 2.293 | 1.240 |
| PG 24%: SR 8%: Al 0.5% | 2.293 | 1.240 |
| PG 24%: SR 8%: Al 1.5% | 2.663 | 1.240 |

## Discussion

Based on the density value obtained from Table 1, all the synthesized boluses had densities comparable to those of water/muscle, fat, and air [29]. Water and muscle have an electron density of 3.36×1026 elec/kg, whereas this value is 3.34×1026 elec/kg in fat, as reported by Hendee and Ritenour [30]. Those values affect the bolus interaction with charged particles, which could occur in the process of attenuation or Compton scattering. The density value obtained in this study is in line with that reported by Mayer et al. [31]. They reported that glass beads and waxes with petroleum formula could result in an equivalent density to water or tissue at 6-MV photon irradiation. Vyas et al. also showed the same thing in 2013 by summarizing several boluses for megavoltage photons and electrons in radiation therapy [10]. For instance, they reported the densities of 1.20, 0.9, and 1.02 g/cm³ for Elasto-Gel bolus (made of water, glycerin, and acrylic polymer), paraffin wax, and Superflab bolus (made of vinyl latex elements), respectively [10].

According to Table 2, bolus with the thicknesses of 1 and 1.5 cm had a transmission factor that was closest to soft tissue characteristics (range: 0.96-0.98). The present study tended to have similar results with a study conducted by Montaseri et al. [24]. The transmission factor of ethyl methacrylate as the bolus radiotherapy had a similar value to soft tissue, which has been measured at the same thickness level. On the other hand, the bolus transmission factor with the addition of SR and Al powder appeared to have decreased transmission. This result is consistent with those obtained by Malescu et al. They stated that bolus material from SR and the mixture of SR and Al had a smaller transmission factor than thermoplastic materials [21].

In addition, bolus with the addition of SR and Al could increase the attenuation of an absorber. In the present study, a lower effective mass attenuation coefficient was obtained, compared to the value reported by Malaescu et al. [21] who made bolus from SR with the addition of Al, in which electron was used as the irradiation source. On the other hand, boluses with a thickness of 0.5 cm had a negative value for an effective mass attenuation coefficient. It could be caused by the loss of contribution from Compton scattering, due to the thickness of the bolus as revealed in the study by Dubois et al. [32]. This fact is supported by the research conducted by Nagata et al. [13] who measured the attenuation coefficient value of Superflab material and plastic water and suggested using a bolus thickness of 1.1-2.5 cm.

Based on Tables 4 and 5, the obtained percentage surface dose had a slight difference with the results of the research performed by Supratman et al. [33]. They reported a surface dose increase of 4% and produced a bolus that was equivalent to the tissue with an irradiation electron beam. However, in this study, the surface dose could be improved, using a PG-based bolus.

## Conclusion

In the current study, a PG-based bolus was successfully fabricated and revealed to have the capability of functioning as tissue compensation with a density range of 0.864-1.273 g/cm³. The density of synthesized boluses was close to the density of fat and water or muscle. The transmission factor value of bolus decreased with the increasing bolus thickness and was inversely proportional to the attenuation coefficient of the effective mass for both energies of 6 and 10 MV. Meanwhile, the percentage surface dose of the bolus with a thickness of 0.5 cm showed a decreased value, compared to the value obtained without bolus. On the contrary, the boluses with the thicknesses of 1 and 1.5 cm revealed an increase in the percentage surface dose, compared to the value estimated without bolus. Moreover, it was found that boluses with a thickness of 0.5 cm could not increase the percentage surface dose compared with the boluses of thickness 1 .0 and 1.5 cm. However, bolus with a thickness of 1.5 cm with the addition of SR and Al had the closest properties to the soft tissue. Overall, the results revealed that the boluses with both thicknesses of 1.0 and 1.5 cm could increase the percentage surface dose, thereby having potential applications in megavoltage photon radiation therapy.

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## References

1. Podgorsak E. Radiation Oncology Physics: A Handbook for Teachers and Students. Austria: International Atomic Energy Agency.2005.
2. Khan FM. The physics of radiation therapy, 3. ed. Philadelphia: Lippincott Williams & Wilkins. 2003.
3. Benoit J, Pruitt AF, Thrall DE. Effect of wetness level on the suitability of wet gauze as a substitute for superflab® as a bolus material for use with 6 MV photons. Veterinary radiology & ultrasound. 2009;50(5):555-9.
4. Günhan B, Kemikler G, Koca A. Determination of surface dose and the effect of bolus to surface dose in electron beams. Medical Dosimetry. 2003;28(3):193-8.
5. Zeidan OA, Chauhan BD, Estabrook WW, Willoughby TR, Manon RR, Meeks SL. Image-guided bolus electron conformal therapy-a case study. Journal of applied clinical medical physics. 2011;12(1):68-75.
6. Cunningham J, Cohen M, Dutreix A. ICRU Report 24: Determination of absorbed dose in a patient irradiated by beams of X-or gamma-rays in radiotherapy procedures. International Commission on Radiation Units and Measurement. Washington. 1976.
7. Kirkpatrick JP, Demehri FR, Johnston SE, Stalnecker AM, Cooney TM, inventors; Kirkpatrick John P, Demehri Farokh R, Johnston Sara E, Stalnecker Andrew M, Cooney Tabitha M, assignee. Bolus materials for radiation therapy and methods of making and using the same. United States patent application US 11/926,829. 2008.
8. Walker M, Cohen N, Menchaca D. Play-doh® and water-soaked gauze sponges as alternative bolus material for cobalt-60 teletherapy. Veterinary Radiology & Ultrasound. 2005;46(2):179-81.
9. Hsu SH, Roberson PL, Chen Y, Marsh RB, Pierce LJ, Moran JM. Assessment of skin dose for breast chest wall radiotherapy as a function of bolus material. Physics in Medicine & Biology. 2008;53(10):2593.
10. Vyas V, Palmer L, Mudge R, Jiang R, Fleck A, Schaly B, et al. On bolus for megavoltage photon and electron radiation therapy. Medical Dosimetry. 2013;38(3):268-73.
11. Gerbi BJ, Antolak JA, Deibel FC, Followill DS, Herman MG, Higgins PD, et al. Recommendations for clinical electron beam dosimetry: supplement to the recommendations of Task Group 25. Medical physics. 2009;36(7):3239-79.
12. Humphries SM, Boyd K, Cornish P, Newman FD. Comparison of Super Stuff and paraffin wax bolus in radiation therapy of irregular surfaces. Medical Dosimetry. 1996;21(3):155-7.
13. Nagata K, Lattimer JC, March JS. The electron beam attenuating properties of s uper f lab, p lay-d oh, and wet gauze, compared to plastic water. Veterinary Radiology & Ultrasound. 2012 ;53(1):96-100.
14. Bedford JL, Childs PJ, Hansen VN, Warrington AP, Mendes RL, Glees JP. Treatment of extensive scalp lesions with segmental intensity-modulated photon therapy. International Journal of Radiation Oncology* Biology* Physics. 2005;62(5):1549-58.
15. Lambert GD, Richmond ND, Kermode RH, Porter DJ. The use of high density metal foils to increase surface dose in low-energy clinical electron beams. Radiotherapy and Oncology. 1999;53(2):161-6.
16. Constantinou C, Harrington JC. Tissue compensators made of solid water or lead for megavoltage X-ray radiotherapy. Medical Dosimetry. 1989;14(1):41-7.
17. Arancini WD, Brackenridge SA. Tin foil modified electron radiation of the skin of the nose. Radiographer. 2008;55(1):7-11.
18. Lim TY, Poole RL, Pageler NM. Propylene glycol toxicity in children. The Journal of Pediatric Pharmacology and Therapeutics. 2014;19(4):277-82.
19. Catanzaro JM, Smith Jr JG. Propylene glycol dermatitis. Journal of the American Academy of Dermatology. 1991;24(1):90-5.
20. Wu L, Wang X, Ning L, Han J, Wan Z, Lu M. Improvement of silicone rubber properties by addition of nano-SiO2 particles. Journal of applied biomaterials & functional materials. 2016 ;14(1):11-4.
21. Malaescu I, Marin CN, Spunei M. Comparative Study on the Surface Dose of Some Bolus Materials. International Journal of Medical Physics, Clinical Engineering and Radiation Oncology. 2015;4(04):348.
22. Young HD,Freedman RA. University Physics with Modern Physics. Pearson Education. 2015.
23. Jaya GW, Sutanto H. Fabrication and characterization of bolus material using polydimethyl-siloxane. Materials Research Express. 2018;5(1):015307.
24. Montaseri A, Alinaghizadeh M, Mahdavi SR. Physical properties of ethyl methacrylate as a bolus in radiotherapy. Iranian Journal of Medical Physics. 2012;9(2):127-34.
25. Tagoe SN, Mensah SY, Fletcher JJ, Sasu E. Telecobalt Machine Beam Intensity Modulation with Aluminium Compensating Filter Using Missing Tissue Approach. Iranian Journal of Medical Physics. 2018;15(1):48-61.
26. Adamson JD, Cooney T, Demehri F, Stalnecker A, Georgas D, Yin FF, et al. Characterization of water-clear polymeric gels for use as radiotherapy bolus.

Technology in cancer research & treatment. 2017;16(6):923-9.

27. Paliwal BR, Rommelfanger S, Das RK. Attenuation characteristics of a new compensator material: Thermo-Shield for high energy electron and photon beams. Medical physics. 1998 ;25(4):484-7.
28. Papanikolaou N, Battista J, Boyer A, Kappas C, Klein E, Mackie T, et al. Tissue inhomogeneity corrections for megavoltage photon beams. AAPM Report No. 85, Task Group No 65 of the Radiation Therapy Committee of the American Association of Physicists in Medicine. 2004.
29. White DR, Booz J, Griffith RV, Spokas JJ, Wilson IJ. 4. The Composition of Body Tissues. Reports of the International Commission on Radiation Units and Measurements. 1989;1:20-3.
30. Hendee WR, Ritenour ER. Medical Imaging Physics. New York, USA: John Wiley & Sons Inc.2002.
31. Mayer MN, Yoshikawa H, Moriarity LE, Sidhu N. Use of a petroleum-based bolus for photon radiation therapy of distal extremities in dogs. Veterinary radiology & ultrasound. 2009 ;50(2):235-8.
32. Dubois D, Bice W, Bradford B, Schneid T, Engelmeier R. Moldable tissue equivalent bolus for high-energy photon and electron therapy. Medical physics. 1996;23(9):1547-9.
33. Supratman AS, Sutanto H, Hidayanto E, Jaya GW, Astuti SY, Budiono T, et al. Characteristic of natural rubber as bolus material for radiotherapy. Materials Research Express. 2018 ;5(9):095302.