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by Eko Hidayanto

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PAPER

Effect of variation of silicone rubber RTV 52 and bluesil catalyst 60 R composition on bolus material for electron beam radiotherapy application

Eko Hidayanto[1], Heri Sutanto[1], Indras Marhaendrajaya[1], Gede Wiratma Jaya[1], Zaenal Arifin[1], Choirul Anam[1], Lidya Purna Widyastuti Setjadiningrat Kuntjoro[2], Galih Puspa Saraswati[3] and Geoff Dougherty[4]

[1] Department of Physics, Diponegoro University, Tembalang, Semarang-50275, Indonesia
[2] Faculty of Medicine, Diponegoro University, Tembalang, Semarang-50275, Indonesia
[3] Radiotherapy Installation, Ken Saras Hospital, Bergas, Semarang-50552, Indonesia
[4] Radiotherapy Department of Applied Physics and Medical Imaging, California State University Channel Islands, Camarillo, CA 93012, United States of America

E-mail: ekohidayanto@fisika.fsm.undip.ac.id

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Abstract

A bolus is a material equivalent to soft tissue and is directly placed on the skin surface during radiotherapy. It is commonly used to increase the dose on the skin surface in electron beam radiation. A typical material for a bolus is silicone rubber (SR). We made a bolus with dimensions of $17 \times 17 \times 1$ cm^3 by varying silicone rubber (SR) RTV 52 and hardening material (bluesil catalyst 60 R) using a simple molded method. We characterized it using a CT scan to find the relative electron density (RED) and examined it using the electron beam of a linear accelerator (LINAC) at energies of 5 and 7 MeV to investigate the percentage of surface dose (PSD). The PSD value is relative to the dose at maximum doses (d_{max}). The RED value of the bolus was from 1.168 ± 0.021 to 1.176 ± 0.019, higher than the soft tissue (muscle) value of 1.043. The percentage of surface dose (PSD) test at 5 and 7 MeV LINAC energy showed that the highest PSD without using a bolus were $84.79 \pm 0.06\%$ and $86.03 \pm 0.07\%$, respectively. With a bolus, the PSD values were $112.52 \pm 0.16\%$ and $111.14 \pm 0.03\%$, respectively. The results indicate that bolus fabrication using SR RTV 52 and bluesil 60R is very effective for radiotherapy in the treatment of skin cancer due to an increase in surface dose.

1. Introduction

Cancer treatment is generally carried out using external beam radiotherapy. Generally, external beam radiotherapy uses a linear accelerator (LINAC) that can produce radiation beams such as electrons and photons. In general, an electron beam of mega electron volt (MeV) energy is typically used if the location of the cancer is on the skin surface or within a few centimeters deep from the skin surface [1]. During radiotherapy it is likely that some radiation will strike normal tissue, and this may cause new undesirable cancer risk. Initially, the dose of electrons received on the skin is relatively small, then slowly increases with the depth of skin, and rapidly decreases again. The dose to treat cancer located at the skin surface using electron beam needs to be enhanced. This can be achieved with the help of a specific radiotherapy device known as a bolus [2], on the surface of the skin to increase surface dose [3]. In addition, the bolus also reduces damage to skin tissue in the area around the cancer, reduces radiation penetration and provides a uniform dose distribution to an irregular surface [4–6].

A bolus is made of material equivalent to soft tissue [7, 8]. Ethyl methacrylate can absorb and transmit radiation close to tissue [9] and is often used as a bolus with dimensions of $15 \times 7.5 \times 1$ cm^3. A bolus of elastic gel material with a thickness of 0.6 cm can increase the surface dose to 90.1% at 6 MeV [5]. The use of such materials, especially in Indonesia, is very difficult because they must be imported, causing a delay Another issue is a disturbance to the radiotherapy services.

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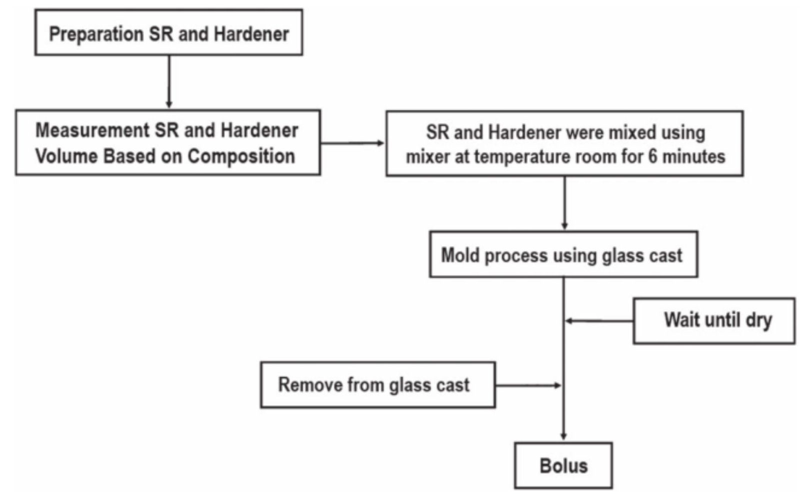

Figure 1. Diagram of bolus preparation for varied composition.

One alternative material that can be used is silicone rubber (SR), which has similar elastic properties to soft tissue [10]. SR has several advantages. It has an excellent level of elasticity at very low temperatures, excellent properties against heat, and resistance to ultraviolet light [11, 12]. It has been used to make biomaterials of artificial prostate organs for brachytherapy applications [10]. Soft tissue phantom-based vulcanization system [13], bolus using SR and bismuth [14]. However, determining the appropriate composition, and thickness, and testing its effectiveness have not been carried out yet.

Based on the potential of SR, the bolus was made by varying the composition of SR and hardener. The variation in composition will change the relative electron density (RED) and percentage of surface dose (PSD) using electron beam radiation.

2. Materials and methods

2.1. Bolus synthesis

Bolus was made by a simple molded method using a mixture of SR and hardener., The SR material used was Silicone Rubber (SR) RTV 52 (Indrasari Chemical Store, Semarang, Indonesia) and the hardener material used was Bluesil Catalyst 60 R (Indrasari Chemical Store, Semarang, Indonesia). The various compositions between SR and hardener used different volume ratios in the glass cast. The dimension of the glass cast is (17 × 17 × 1) cm^3 and volume ratios used (SR: hardener) were 25:1, 37:1, 49:1, 61:1, and 73:1, respectively. SR and hardener materials were mixed by a mixer machine (Type Maspion) for 6 min. The mixer machine has speed 100 RPM. Surface bubbles were removed by exploding the air bubbles using a spatula. The stages in the preparation of the bolus are shown in figure 1.

2.2. Relative electron density (RED) measurement

Relative electron density (RED) measurement begins by taking a bolus tomographic image using CT-Scan (Toshiba). Tomography image was taken using axial scanning with (tube) voltage and tube current of 120 kVp and 160 mA. The obtained tomography image was inputted into the treatment planning system (TPS) program using Monaco software. From this TPS, the CT-Number was then observed by creating ten regions of interest (ROI) on the tomographic image in the axial direction. The RED value was obtained from the following equation:

$$\rho_e = 1.052 + 0.00048 N_{CT} \cdot N_{CT} > 100 \quad (1)$$

$$\rho_e = 1.000 + 0.001 N_{CT} \cdot N_{CT} < 100 \quad (2)$$

with ρ_e is the RED value and N_{CT} is the CT-Number [9].

2.3. Percentage of surface dose (PSD) measurement

The bolus was radiated using LINAC (Siemens Primus M5633, Erlangen, Germany) with an electron beam. The energies of the electron beam used were 5 MeV and 7 MeV. The applicator field was 10 × 10 cm^2. The source to surface distance (SSD) was set at 100 cm from the solid phantom (SP34 Ser. No. 9043, IBA Dosimetry GmbH, Schwarzenbruck, Germany). For radiation measurement, plane-parallel chamber detectors (PPC50 Ser. No. 977, IBA, Germany) were placed on the surface and at the depth of dose maximum (z_{max}) on a solid phantom. Z_{max} is 1.1 cm and 1.5 cm at 5 MeV and 7 MeV respectively. The process is shown schematically in figure 2. The PSD value can be calculated using the following equation:

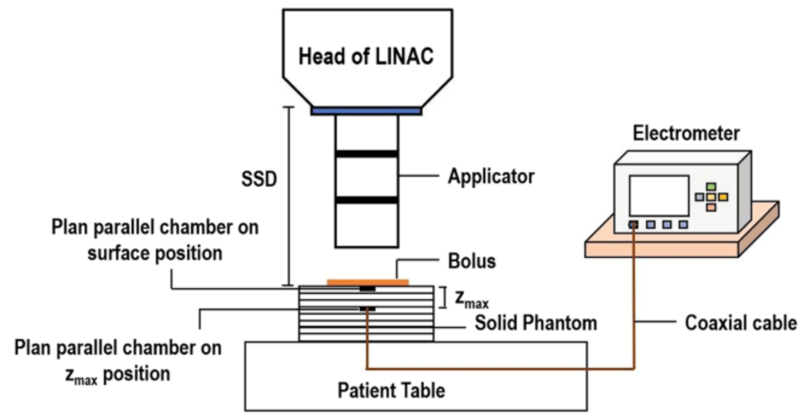

Figure 2. Schematic view using an electron beam to measure the percentage of surface dose (PSD) of a bolus.

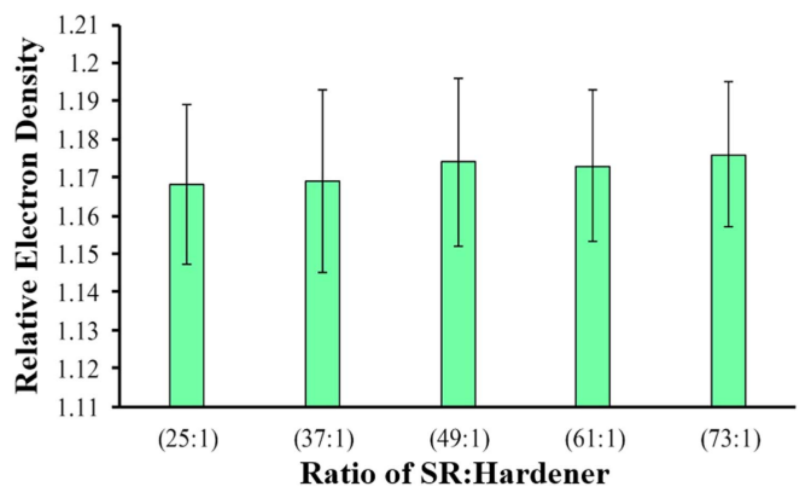

Figure 3. Relative electron density (RED) for each volume ratio.

$$\% \ Percentage\ Surface\ Dose = \frac{D_S}{D_{max}} \times 100\ \% \quad (3)$$

with D_S is the dose radiation measurement at the surface of a solid phantom and D_{max} is the dose radiation measurement at z_{max} within the solid phantom [5]. Therefore, PSD value is relative to the dose at maximum doses (d_{max}).

Table 1. relative electron density of each tissue [6].

Tissue	Electron density (relative to H_2O)
Muscle	1.043
Breast	0.976
Dense Bone	1.512

3. Results and discussion

3.1. Relative electron density (RED)

The RED value for each sample is shown in figure 3. The highest RED value of 1.176 ± 0.019 was produced in samples of 73:1 ratio, and the lowest RED value of 1.168 ± 0.021 was produced in samples of 25:1 ratio. The RED value of each bolus has an important role in the calculation of the dose distribution when providing electron beam radiation to tissue [9, 15]. The RED values of different types of tissue are listed in table 1.

Our boluses had a higher RED value than soft tissues such as muscle and breast. This is because of the different compositions. Soft tissue consists of hydrogen (H), oxygen (O), nitrogen (N), and chlorine (Cl),

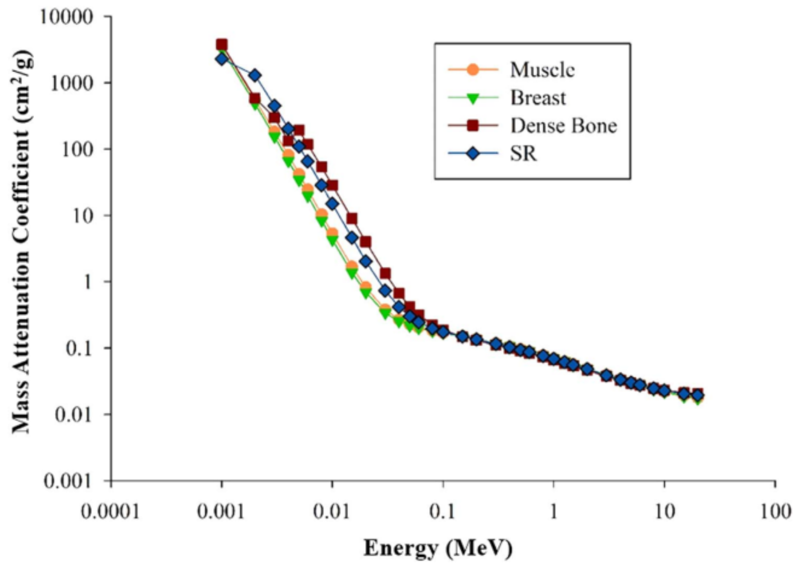

Figure 4. Mass attenuation coefficient (MAC) for bolus and tissue.

and organic polymers composed of a C–C bond [16, 17]. On the other hand, our boluses comprise an inorganic polymer bond composed of polysiloxane (Si–O) bonds and methyl (CH_3) bonds [18]. A dense bone consists of a mineral phase, hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), an organic phase, and water [19]. Therefore, dense bone has a higher material density, and consequently a higher RED value, than bolus or soft tissue.

The mass attenuation coefficient (MAC) and effective atomic number (EAN) of the tissues in table 1 were calculated to check conformity with the RED values. The calculation of MAC for the boluses used XCOM software by inputting the chemical formula for the SR material [20]. The calculation of EAN for the boluses and tissues was done using Auto Zeff Version 1.7 [21]. The results of MAC and EAN calculations can be seen in figures 4 and 5, respectively.

MAC and EAN calculations are used to determine the type of bolus including soft or dense tissue. MAC shows the ability of the material to absorb radiation, if the incoming radiation energy is large, the MAC will decrease. Figure 4 shows that the ability to absorb radiation of the SR bolus material is between dense bone and muscle (soft tissue) in the energy range of 0.001 MeV to 0.1 MeV.

3.2. Percentage of surface dose (PSD)

The PSD values for each sample are shown in figure 6. PSD values before the use of bolus are (84.79 $\pm$ 0.06)% and (86.03 $\pm$ 0.07)% for 5 MeV and 7 MeV energies, respectively. When using bolus, the PSD values of each sample are above 100%. The samples with the maximum and minimum PSD values at 5 MeV energy are 25:1 and 73:1 with values of (112.52 $\pm$ 0.16)% and (108.54 $\pm$ 0.12)% respectively. For 7 MeV energy, the highest and lowest PSD values are produced by samples of 37:1 and 25:1 ratio, at (111.14 $\pm$ 0.03)% and (110.37 $\pm$ 0.14)%, respectively. The PSD value without bolus increased with the increase of electron beam energy. The increase in PSD values was occurred due to the more scattering when electrons passed through the medium. At low energy, the electrons become more easily scattered when interacting with the medium, resulting in the fluence of the electron beam being further increased at larger scattering angles (θ) [7, 22]. The PSD values are increased with a bolus of 1 cm thickness [23]. The value of PSD value in this study yields a value above 100%.

The value of PSD in a solid phantom for 5 MeV LINAC energy generally decreases with an increasing ratio of SR to hardener. Higher RED values result in lower PSD values. Physically this may occur as a result of the many different scatterings, where at the time an electron passes through the bolus with higher RED more scattering occurs. The PSD values in a solid phantom with 7 MeV energy resulted in different PSD values for each sample. When compared with the PSD value at 5 MeV, some samples increase, and others decrease the PSD value. For samples of 25:1, 37:1, and 61:1 the PSD value was decreased overall, whereas for samples of 49:1 and 73:1 the PSD value was increased overall.

Increasing radiation energy increases the PSD value [5, 7], which is appropriate to sample with ratios 49:1 and 73:1. The increase in PSD values for both

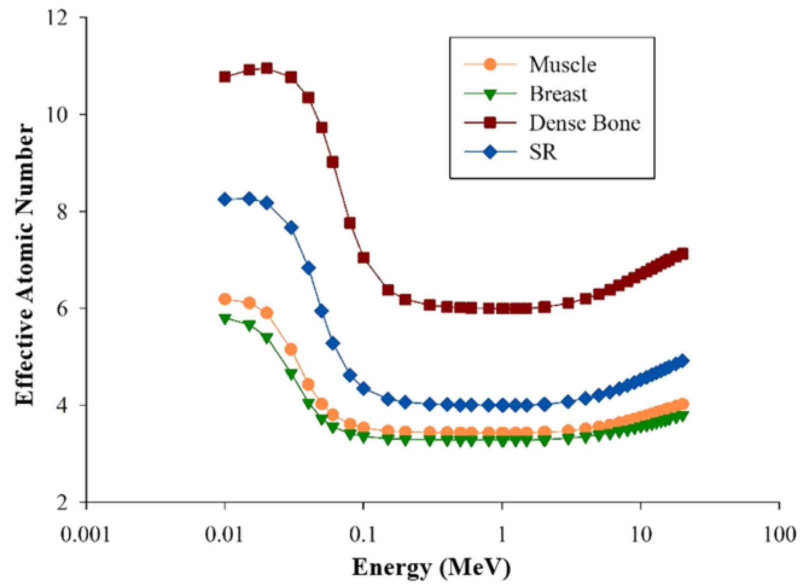

Figure 5. The effective atomic number (EAN) for bolus and tissue.

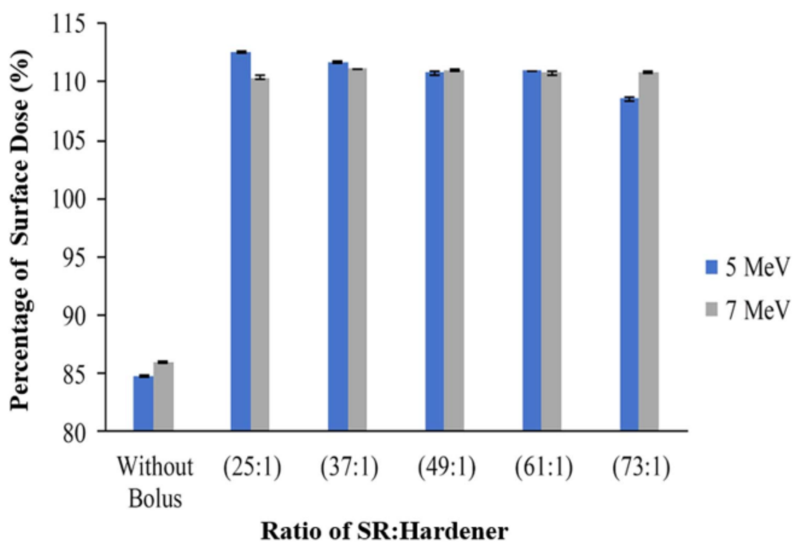

Figure 6. Percentage of surface dose bar chart for non-bolus and each composition materials.

these samples occurs because of the possibility of less scattering. For the other three samples, there may be further penetration of electron particles leading to a larger z-max value in the solid phantom because there is still a considerable amount of kinetic energy. Overall, the PSD value in this study was higher than Gu nham *et al* [5]. Clinically the maximum surface dose should be 100%, but in this study values above 100% were recorded, so that it is necessary to reduce the bolus thickness below 1 cm so that the surface dose reaches 100% and no more.

Typically, the electron beam central axis percentage depth dose (PDD) curve shows that surface dose is relatively high (85%–100%). The maximum dose happened at a certain depth as known as the depth of dose maximum (z_{max}). After z_{max}, the dose will drop rapidly at a low-level dose called the Bremsstrahlung tail. To get a complete picture of the dose pattern along the depth, a PDD curve is needed. However, the measurement of PDD on a bolus has not been carried out in this study.

4. Conclusion

Bolus synthesis using silicone rubber has been successfully performed using a simple molded method with various material compositions. The RED results show that samples that produce maximum values (1.176) are of 73:1 ratio, while samples that produce the minimum values (1.168) are of 25:1 ratio. For MAC and EAN, the calculation shows the same result with the RED value where the bolus is between soft tissue and hard tissue. The highest and lowest PSD values for 5 MeV energies, 112.52 $\pm$ 0.16% and 108.54 $\pm$ 0.12%, are produced by samples of 25:1 and 73:1 ratio respectively. For 7 MeV energies, the highest and lowest PSD values, 111.14 $\pm$ 0.03% and 110.37 $\pm$ 0.14%, are produced by samples of 37:1 and 25:1 ratio respectively. This means that each sample produced a surface dose percentage of more than 100%. Theoretically, the highest surface dose percentage without using bolus is only 80%, whereas the use of bolus can increase it up to 100%. Therefore, the radiation dose received by cancerous tissue at the surface of the skin becomes higher. These results indicate that silicone rubber can be used as an alternative material to make a bolus.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

ORCID iDs

Eko Hidayanto https://orcid.org/0000-0002-3438-0369
Heri Sutanto https://orcid.org/0000-0001-7119-9633
Gede Wiratma Jaya https://orcid.org/0000-0001-7279-6923
Zaenal Arifin https://orcid.org/0000-0003-0396-4553
Choirul Anam https://orcid.org/0000-0003-0156-6797
Geoff Dougherty https://orcid.org/0000-0003-3187-3595

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