Comparison of Dosimetry Characteristics from Some Bolus Materials for 6 and 10 MV Photons Beam Radiation Therapy

G Sekartaji¹, S. Aisyah¹, C.C.C Carina¹, T. Nazara¹, A Nainggolan², and Endarko¹,*

¹Department of Physics, Institut Teknologi Sepuluh Nopember, Kampus ITS Sukolilo, Surabaya 60111, East Java, Indonesia
²Cancer Specialty Hospitals MRCCC Siloam Semanggi, 19230, South Jakarta, Indonesia

Email: endarko@physics.its.ac.id

Abstract. In radiation therapy, bolus material is often used for increased surface dose, compensate for surface irregularities and internal heterogeneities. Bolus has properties equivalent to water and soft tissue. In this study, the mixture of Silicone Rubber (SR) and Bismuth was used for bolus fabrication and then compared to commercial boluses such as Paraffin, Play-Doh, and Paraffin Wax. The study aims to evaluate the comparison of relative electron density (RED), effective mass attenuation coefficient, transmission factor, percentage of surface dose (PSD), and Percentage Depth Dose (PDD) for all boluses. The bolus was made with the size 11 × 11 × 0.5 cm³. Physical density of the synthesized bolus was assessed by computerized tomography (CT) Scanning. The results of the RED analysis for the mixture of Silicone Rubber (SR) and Bismuth, Paraffin, Play-Doh, and Paraffin Wax were 0.954; 0.743; 0.933; and 0.878, respectively. The values of RED for all boluses has a similar to water and soft tissue. These results prove that the bolus is equivalent to soft tissue density such as fat, breast, lungs, and liver. Furthermore, for other dosimetry tests such as transmission factors and attenuation coefficients using Linear Accelerator (LINAC) with photon energy sources 6 and 10 MV. In general, Percentage of surface dose at 6 MV is higher than 10 MV. The highest percentage of the surface dose was achieved by paraffin wax at 6 MV energy by 85%. For effective mass attenuation coefficient result, the highest is the mixture of silicone rubber and bismuth at -0.0030 cm²/g for 6 MV and Play-Doh at -0.0114 cm²/g for 10 MV.

1. Introduction
Radiotherapy or commonly called radiation therapy, radiation oncology, or radiology therapy is one of malignant disease (cancer) treatment besides surgery and chemotherapy [1]. Radiation used in radiotherapy is ionizing radiation because it can forms ion (charged particles) and deposits energy into the tissue cells through which it travels. This energy released can kill cancer cells and cause genetic changes [2]. External radiation generally uses a Linear Accelerator (LINAC) which can produce photon and electron rays [3,4]. Photons irradiation has a maximum dose deeper to tissue when compared to electrons. Besides, it is also the percentage surface dose of photons decreases with energy [5]. In high energy photon therapy, the surface dose can be increased to the level needed as well as reducing the dose to the healthy tissue by using a compensation tissue which comes in contact with the patient’s surface [6]. The main purpose of radiotherapy treatment is to kill cancer cells using high
...doses with minimum side effects [7] to achieve that goal one of them is the use of bolus material for radiotherapy. The use of bolus in external radiation includes (1) Increasing surface dose (2) Compensating un-flat surface of the patient body (3) reduce the penetration of secondary electron beam at healthy tissue [6]. The usage of bolus material must be non-toxic, non-sticky, easy to produce, has attenuation and scattering properties such as water or muscle tissue, flexible, and durable[1, 8]. Bolus material commercially available is superlab, aquaplast (Qfix, Orfit), paraffin, elasto-gel pad, thermoplastic sheet, dental wax and Play-Doh [9–12]. In this study, Silicone Rubber and Bismuth was used as the primary materials for fabrication bolus. The materials will be evaluated compared to commercial boluses such as Paraffin, Play-Doh and Paraffin Wax.

2. Material and Methods

2.1 Fabrication Bolus with Silicone Rubber and Bismuth
Bolus was produced using Silicone Rubber (SR) type RTV-CC with the catalyst, which has clear and transparent properties. The synthesized Bolus was fabricated with a mixture of SR, catalyst, and Bismuth with the amount of 670 mL, 14 mL, and 1 g, respectively. The first stirring sequence is to mix SR and Bismuth for 10 min, then proceed with the addition of a catalyst with a stirring time of 3 min. Furthermore, the mixture is poured in an acrylic mold with dimensions 11 × 11 × 0.5 cm³. Place at room temperature until it becomes a desired bolus.

2.2 Fabrication of Bolus Play-Doh
Next is to prepare one pack of Play-Doh. Play-doh was removed from the pack and then shaped and printed using acrylic molds with dimensions 11 × 11 × 0.5 cm³. Once formed, the Play-Doh bolus is ready to use.

2.3 Fabrication of Bolus Paraffin Wax
This bolus is the same as Play-Doh. The first is to prepare a Paraffin Wax that has characteristic that is dark red color. Paraffin Wax is shaped and molded into acrylic molds with dimensions 11 × 11 × 0.5 cm³. Paraffin Wax is a bolus that is used daily by MRCCC Siloam Hospital Semanggi for treatment cancer in Radiotherapy.

2.4 Fabrication of Bolus Paraffin
Paraffin has characteristics that are white color and hard. The first thing to do is put paraffin into a measuring cup and then heating paraffin using magnetic heat stirrer until it melted. After everything is melted and homogeneous, the liquid was poured into an acrylic mold with dimensions 11 × 11 × 0.5 cm³.

2.5 Density Test
All the synthesized boluses were put on CT Scan in MRCCC Siloam Semanggi Hospital for 2 min. After that, the tomographic image can be seen in the Treatment Planning System (TPS). Region of Interest (ROI) is chosen so that it forms a square to be seen on average from the CT Number. After gained CT-Number value for each bolus, the value is substituted into the equation as follows [13]:

\[ \rho = 1,052 + 0,00048 \, N_{CT}, \, N_{CT} > 100 \]  
\[ \rho = 1,000 + 0,001 \, N_{CT}, \, N_{CT} < 100 \]  

With \( \rho \) is RED value and \( N_{CT} \) is the CT-Number value.

2.6 Dosimetry Test
Dosimetry test for all the synthesized boluses was performed using LINAC Varian 2300CD at Radiotherapy Installation of MRCCC Siloam Semanggi Hospital with photon beam energies of 6 and 10 MV and dose rate of 400 MU/min. Figure 1a shows the measurement setup for dosimetry test. The measurement was done using source to surface distance (SSD) of 100 cm and field area irradiation is
10 × 10 cm². Furthermore, bolus transmission factor measurements were measured using a Farmer ionization chamber of 0.65 cc (Type FC655). For each radiation, the ionization chamber is placed at maximum depth depends on the energy level, for 6 MV at 1.5 cm and 10 MV at 2.3 cm, respectively. The bolus is then placed on the surface of phantom and bolus irradiated with predetermined energy.

### Table 1. Relative Electron Density (RED) Value of Tissue [14]

| Electron density plug material | Relative Electron Density |
|-------------------------------|--------------------------|
| Syringe H₂O                  | 1.00                     |
| Lung (Inhale)                | 0.19                     |
| Lung (Exhale)                | 0.489                    |
| Adipose                      | 0.949                    |
| Breast (50/50)               | 0.976                    |
| Muscle                       | 1.043                    |
| Liver                        | 1.052                    |
| Bone (200 mg/cc)             | 1.117                    |
| Dense Bone (800 mg/cc)       | 1.57                     |

Besides measuring bolus transmission factor, the percentage of surface dose is also determined (PSD). ECLIPSE software was used to determine the percentage of surface dose on the Treatment Planning System (TPS) as presented in Figure 1c.

### Figure 1. Schematic diagram of the study using LINAC (a) without Bolus and (b) with Bolus [15] (c) using ECLIPSE Software.

#### 3. Result and Discussion

The synthesized boluses have been successfully fabricated using a mixture of Silicone Rubber and Bismuth as shown in Figure 2. Adamson et al. reported that a good bolus must have transparent and clear characteristics. They examined boluses from polymers gel, the boluses can be produced good visibility by looking at the appearance of reading text under the bolus with normal condition of
lighting [16]. In this study the mixture of Silicone Rubber and Bismuth bolus has the most transparent visibility among the other boluses which is shown in Figure 2. It has a yellowish clear color and followed by paraffin bolus. While the Play-Doh and Paraffin Wax have poor transparent visibility. This is precisely the same as found by Nagata et al. [12]

Figure 2. Bolus synthesis result (a) The mixture of SR and Bismuth, (b) Play-Doh, (c) Paraffin, (d) Paraffin Wax

3.1 Density Bolus

Based on the results obtained from the CT Scan, all sample showed that HU values are below 100 so that RED value is calculated using Eq. (2) RED and Physical density can be seen in Figure 3.

Figure 3. (a) RED and (b) Physical Density value

In Fig. 3 The mixture of Silicone Rubber and Bismuth Bolus has the highest RED value amounted to 0.954 while for Paraffin, Play-Doh, and Paraffin Wax has RED value amounted to 0.743, 0.933, and 0.878, respectively and Play-Doh has the highest Physical Density value amounted 0.915 while for The mixture of Silicone Rubber and Bismuth, Paraffin, Paraffin Wax has physical density value amounted to 0.8872 g/cm\(^3\), 0.747 g/cm\(^3\), and 0.793 g/cm\(^3\). In general the bolus has a density value range of 0.743-0.954. RED and physical density value for all boluses is equivalent to soft tissue such as fat, breast, lungs, and liver.

3.2 Dosimetry Test Using LINAC

After density test, then dosimetry test using LINAC iX2300 with photon energy of 6 and 10 MV. The reference value that is read on the detector is 20.47 nC for energy 6 MV and 18.63 nC for 10 MV. Then proceed with photon irradiation using a bolus that the reading results can be seen in Table 2. From the load reading, data can be obtained the value of the transmission factor refers to [15].

Table 2 shows comparative results of the transmission factors of fabrication bolus (SR + Bismuth) and commercial bolus with photons beam 6 MV and 10 MV. Transmission factor data table obtained by calculation based on comparison of load readings using bolus and without bolus. The transmission factor itself shows that the ability of material to continue photon intensity after being irradiated. It
means that a 0.5 cm bolus transmits all bolus energy but an amplification occurs due to scattering. When a photon passes through the media, three things occur, namely inverse square law, attenuation, and scattering. Based on the data it can be concluded that the greater the energy used, the transmission factor of the bolus will be even more significant. This result is same as research conducted by [17].

| Table 2. Transmission factors of boluses for photon energy with radiation field area 10 × 10 cm² |
|---------------------------------------------------------------|
| Materials          | Charged Without Bolus | Charge (nC) | Transmission Factor |
|                   | 6 MV | 10 MV | 6 MV | 10 MV | 6 MV | 10 MV |
| SR + Bismuth       | 20.50 | 18.74 | 1.001 | 1.006 |
| Play-Doh           | 20.47 nC | 18.63 nC | 20.59 | 18.74 | 1.005 | 1.006 |
| Paraffin           | 20.51 | 18.73 | 1.001 | 1.005 |
| Paraffin Wax       | 20.51 | 18.74 | 1.001 | 1.006 |

| Table 3. Effective mass attenuation coefficient for boluses with 6 and 10 MV photon energies with radiation field size 10 × 10 cm² |
|---------------------------------------------------------------|
| Materials          | Thickness (cm) | Density (g/cm³) | Effective mass attenuation coefficient (μm eff) cm²/g |
|                   | 6 MV | 10 MV | 6 MV | 10 MV |
| SR + Bismuth       | 0.5 | 0.954 | -0.003 | -0.0123 |
| Paraffin           | 0.5 | 0.743 | -0.0152 | -0.0158 |
| Play-Doh           | 0.5 | 0.933 | -0.0034 | -0.0114 |
| Paraffin Wax       | 0.5 | 0.878 | -0.004 | -0.0134 |

The effective mass attenuation coefficient is defined as a measure of the ability of a material to absorb or spread electromagnetic radiation in any form per unit of mass. Photons that produce interactions will transfer some of their energy to matter and produce some or all of the energy absorbed. This calculation is done because in the energy range the interaction that occurs is Compton scattering [5]. Based on table 3. It can be seen that the bolus with a thickness of 0.5 cm with all material variations in photon energy 6 and 10 MV shows negative value. It means the bolus does not function as an absorber or bolus can not absorb radiation properly. It is undoubtedly very continuous with the value of the transmission factor where has a value of 1 so that all photon radiation is forwarded. The negative attenuation coefficient value is due to Rayleigh scattering where the intensity of the incoming photon will be the same as the photon after collision. In the table the highest value of effective mass attenuation coefficient for 6 MV is the mixture of Silicone rubber and bismuth. SR has an inorganic polymer bond which is a siloxane bond consisting of silicon (Si) and oxygen (O) atoms and methyl bonds consisting of carbon (C) and hydrogen (H) atoms [18]. Bismuth is a heavy metal that has a high atomic number (Z) of 83. The mass attenuation coefficient will increase with the increase in the atomic number of the medium and decrease with increase in the energy [19]. In this interaction the vibrating electrons remain bound by the nucleus in the atom. Elastic scattering increase in electrons with high binding energy, which means electron electrons with high number of atoms and relatively low energy photons. Furthermore, the highest effective mass attenuation coefficient value for 10 MV energy is obtained by Play-Doh bolus which has composition such as water, boric acid, flour, salt and mineral oil. This is the same as found by Nagata et al, that Play-Doh is more attenuating compared to water under the electron beam especially for lower energies [12].

3.3 Dosimetry Test Using TPS

This dosimetry test produces a percentage depth dose (PDD) and percentage surface dose (PSD). As can be observed in Fig. 4a the position of Dmax point when using no bolus is located at 1.5 cm for 6MV energy and 2.3 cm for 10 MV. Moreover, when using the bolus Dmax point will shift closer to the surface. The 6 MV photon Dmax result of 1 cm but only paraffin bolus has a different result of 1.23 cm. This result certainly has more in-depth than other boluses. While in Fig 4 b, for 10 MV photons...
have stable results with a value of 1.98 cm from the surface for all boluses. This proves that the use of bolus can shift $D_{\text{max}}$ position. Moreover, it proves that the higher the photon energy emitted, the position of the $D_{\text{max}}$ will increase. It is due to the interaction between photon and bolus material, where for photon energy is higher than the energy transferred to electrons in the bolus is also getting more prominent, as a result the secondary electrons will have a longer path.

Figure 4. Percentage Depth Dose (PDD) in energy (a) 6MV (b) 10 MV

It is consistent with research conducted by Malaescu et al. which that by adding Al and Cu metal material to RTV-350 silicon rubber, the maximum dose ($D_{\text{max}}$) point shift as well as commercial bolus such as thermoplastic [8]. Also, according to research Sroka et al. that depth of $D_{\text{max}}$ shift to a higher depth in phantom because the range of secondary electrons in the air is almost three times for a 15 MV photon beam compared to 6 MV [20].

Figure 5. Percentage Surface Dose (PSD) bolus in energy 6MV and 10 MV

The value of percentage surface dose (PSD) can be seen in Fig. 5. The value of PSD when using without bolus in energy 6 MV and 10 MV are 51.80% and 48.43%, respectively. It explains that photons have a very low surface dose value called skin-sparing effect. This study shows that PSD values increase when using bolus material. In 6 MV energy the PSD value was obtained by Paraffin Wax by 85% and at 10 MV obtained by Play-Doh by 74.85%. When photon energy increase, skin-sparing effect, and build-up region increase. Due to high photon energy, secondary electrons resulting from interactions tend to move forward, so the amount of ionization will increase and maximum when it reaches a depth equal to the electron range.

4. Conclusion
The present study has been successfully demonstrated comparative study between the synthesized bolus from a mixture of SR and bismuth and commercial bolus which is the results showed that both boluses had a similar property to muscle, fat, lung, breast and liver. The value of transmission factor of
all bolus is more than 1 because there is an amplification when photons through medium there are 3 things inverse square law, attenuation, and scattering. Moreover, the effective mass attenuation coefficient had greater values when it was using high energy photon. PDD shows the shift of Dmax point approaching the surface when using bolus material. In 6 MV energy the PSD value was obtained by Paraffin Wax by 85% and at 10 MV obtained by Play-Doh by 74.85%. The use of bolus material can increase percentage surface dose (PSD) and reduced skin-sparing effect.

**Acknowledgement**

Special thanks to Mr. Andreas Nainggolan as Medical Physicist who has guided during the process of collecting data at Radiotherapy installation in Cancer Specialty Hospitals MRCCC Siloam Semanggi.

**References**

[1] E. B. Podgorsak, *Radiation Physics for Medical Physicists*, 2 ed. Berlin Heidelberg: Springer-Verlag, 2010.
[2] R. Baskar, K. A. Lee, R. Yeo, dan K.-W. Yeoh, “Cancer and Radiation Therapy: Current Advances and Future Directions,” *Int. J. Med. Sci.*, vol. 9, no. 3, hlm. 193–199, Feb 2012.
[3] Y. Santi dkk., “Characteristics of Bolus Using Silicone Rubber with Silica Composites for Electron Beam Radiotherapy,” *J. Phys. Its Appl.*, vol. 1, hlm. 24–27, Nov 2018.
[4] J. Coleman, C. Park, J. E. Villarreal-Barajas, P. Petti, dan B. Faddegon, “A comparison of Monte Carlo and Fermi-Eyges–Hogstrom estimates of heart and lung dose from breast electron boost treatment,” *Int. J. Radiat. Oncol. Biol. Phys.*, vol. 61, no. 2, hlm. 621–628, Feb 2005.
[5] F. M. Khan, *Khan’s Lectures: Handbook of the Physics of Radiation Therapy*. Wolters Kluwer/Lippincott Williams & Wilkins Health, 2011.
[6] B. Günhan, G. Kemikler, dan A. Koca, “Determination of surface dose and the effect of bolus to surface dose in electron beams,” *Med. Dosim. Off. J. Am. Assoc. Med. Dosim.*, vol. 28, hlm. 193–8, Sep 2003.
[7] S. Mehta, V. Suhag, M. Semwal, dan N. Sharma, “Radiotherapy: Basic Concepts and Recent Advances,” *Med. J. Armed Forces India*, vol. 66, no. 2, hlm. 158–162, Apr 2010.
[8] I. Malaescu, C. N. Marin, dan M. Spunei, “Comparative Study on the Surface Dose of Some Bolus Materials,” *Int. J. Med. Phys. Clin. Eng. Radiat. Oncol.*, vol. 04, hlm. 348–352, Jan 2015.
[9] F. Chang, P. Chang, K. Benson, dan F. Share, “Study of elasto-gel pads used as surface bolus material in high energy photon and electron therapy,” *Int. J. Radiat. Oncol. Biol. Phys.*, vol. 22, no. 1, hlm. 191–193, 1992.
[10] S. Visscher dan E. Barnett, “Comparison of Bolus Materials to Highly Absorbent Polypropylene and Rayon Cloth,” *J. Med. Imaging Radiat. Sci.*, vol. 48, Okt 2016.
[11] T. Seppälä dkk., “A dosimetric study on the use of bolus materials for treatment of superficial tumors with BNCT,” *Appl. Radiat. Isot. Data Instrum. Methods Use Agric. Ind. Med.*, vol. 61, hlm. 787–91, Des 2004.
[12] V. Vyas dkk., “On bolus for megavoltage photon and electron radiation therapy,” *Med. Dosim. Off. J. Am. Assoc. Med. Dosim.*, vol. 38, no. 3, hlm. 268–273, 2013.
[13] K. Faulkner, “Introduction to Physics in Modern Medicine (Second Edition),” *Br. J. Radiol.*, vol. 83, no. 987, hlm. 271, Mar 2010.
[14] T. Kouno dkk., “Impact of Exposure Dose Reduction of Radiation Treatment Planning CT Using Low Tube Voltage Technique,” *Nihon Hoshusen Gijutsu Gakkai Zasshi*, vol. 71, hlm. 308–15, Apr 2015.
[15] A. Montaseri, M. R. Alinaghizadeh, dan S. Mahdavi, “Physical Properties of Ethyl Methacrylate as a Bolus in Radiotherapy,” *Iran. J. Med. Phys.*, vol. 9, hlm. 127–134, Jul 2012.
[16] J. D. Adamson dkk., “Characterization of Water-Clear Polymeric Gels for Use as Radiotherapy Bolus,” *Technol. Cancer Res. Treat.*, hlm. 1533034617710579, Jan 2017.
[17] P. Kumar, N. M. J. Nigam, S. N. S., dan P. Kumar, “Comparison Of Electron Beam Transmission Of Different Energies With Two Different Block Materials At Different Placement Positions Within The Applicator,” *SRMS J. Med. Sci.*, vol. 1, Nov 2016.
[18] T. Segura dan G. Burillo, “Radiation modification of silicone rubber with glycidylmethacrylate,” *Radiat. Phys. Chem.* 1993, vol. 91, hlm. 101–107, 2013.
[19] C. Orton, *Progress in Medical Radiation Physics*. Springer Science & Business Media, 2013.
[20] M. Sroka, J. Regula, dan W. Lobodziec, “The influence of the bolus-surface distance on the dose distribution in the build-up region,” *Rep. Pract. Oncol. Radiother.* , vol. 15, no. 6, hlm. 161–164, Nov 2010.