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The Impact of In-House Bolus Thickness on The Percentage of Surface Dose for 10 and 12 MeV Electron Beams

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Abstract: The surface dose on electron irradiation which is received by the skin does not reach 100%, so a bolus is needed as a compensator material in order to reach or approach 100%. This study aims to create, test, and describe the effect of different thicknesses of boluses that are made of 3D printed TPU, silicone sealant and resin on equivalence with tissue and the percentage of surface dose produced. A bolus with a size of 15x15 cm^2 and with variations in thickness of 0.3 cm, 0.5 cm, and 1 cm was imaged by a CT-Scan to analyze the CT-Number value and relative electron density using imageJ software. After that, the bolus was irradiated by a Linac with an energy of 10 MeV and 12 MeV to measure the surface dose using an advances marcus detector. The result of this study showed that 3D printed TPU, silicone sealant and resin are similar to some soft tissues. Silicone sealant has the highest flexibility of the two boluses. In addition, silicone sealant also produces the highest increase in the percentage of surface dose in phantom.

Keywords: Bolus; Density; CT-Number; Surface Dose

Introduction

Radiotherapy is a cancer treatment method which uses ionizing radiation to damage and kill cancer tissue (Delwiche, 2013). One of the modalities that are commonly used in radiotherapy is the Linear Accelerator (Linac) (Rancangkapti et al., 2019). The radiation beam that is produced by the Linac is in the form of high-energy electrons and photons which are useful for cancer therapy in a variety of positions (Hariyanto et al., 2020). Electron beam radiation is commonly used to treat skin cancer, tumors or lymph nodes that are close to the surface of the body (superficial) because the electrons have a low energy level and do not penetrate deep into the body (Su et al., 2014). However, the percentage of the electron dose that hits the skin surface has not yet reached 100%, and only at a certain depth the maximum dose can be obtained (Robertson et al., 2021). Therefore, it is necessary to have a method/effort so that the cancer tissue near the skin surface gets the maximum dose while the normal tissue around it gets the minimum dose (Khan, 2003; Mayles et al., 2007).

The bolus as a compensating agent is placed on the skin surface so that the patient can easily move the built-up region so that the maximum dose is near the patient's skin (Ricotti et al., 2017). The most important characteristic of the bolus material is that it is equivalent to body tissue (Sekartaji et al., 2020). In addition, the bolus must be elastic enough to conform to the shape of the patient's body surface, durable and cost-effective (Tino et al., 2020). Nevertheless, there are always uncertainties and assumptions in the preparation and utilization of boluses. Every medical physicist is faced with unique and different problems. Therefore, medical physicists commonly manufacture “in-house boluses” or artificial boluses that are designed according to the patient's needs and are derived from more cost-effective materials (Malaescu et al., 2015). Boluses that are commonly used by medical physicists are generally

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made of superflab, play-doh, paraffin wax, HAPRC (Highly Absorbent Polypropylene and Rayon Cloth), and gelatin (Zhao et al., 2017). Apart from the advantages they have, those bolus materials also have several drawbacks, such as paraffin wax that takes a long time and is less stable at a certain temperature; play-doh that is difficult to form with an even thickness and is less consistent in maintaining its shape; and gelatin that has a problem in the form of the presence of air gaps between the bolus and the skin surface and that is easy to grow fungus (Nagata et al., 2012; Vyas et al., 2013). Therefore, this research intends to manufacture in-house boluses from materials that are elastic, easy to find, cost-effective, and easy to manufacture by medical physicists such as 3D printed TPU, silicone sealant, and resin.

3D printed boluses have been previously made by Ricotti (2017) that are made of PLA and ABS with various infill percentages, namely 20%, 40% and 60% infill. The results show that the higher the infill percentage, the higher the bolus density and the homogeneity so that the dose distribution can be even. PLA bolus has a higher density than ABS bolus at the same percentage of infill (Ricotti et al., 2017). The use of the 3D printed bolus is advantageous because the bolus can be shaped/printed according to the patient's needs so as to minimize the air gap between the skin and the bolus. However, PLA and ABS materials are not very elastic, so this study tries to make a 3d printed bolus that is made of TPU (Thermoplastic Polyurethane) with 100% infill in the hope of obtaining a more elastic and homogeneous texture.

Some of the in-house boluses which have been made are from silicon rubber. Silicon rubber boluses proved to be elastic and able to increase the dose on the phantom surface. This research tries to make a bolus from another silicone material, namely silicone sealant which is cheaper. This research also tries to make a bolus made of resin which is transparent and elastic enough so that it is easily positioned on the surface of the patient's skin. In this research, boluses were printed in 3 sizes with different thicknesses, namely 15x15x1 cm^3, 15x15x0.5 cm^3, and 15x15x0.3 cm^3. Each of these materials would be tested for the value of Relative Electron Density (RED) using a CT scan and be observed for the effect of bolus thickness on the percentage of dose on the phantom surface with electron radiation of 10 MeV and 12 MeV.

Method

In-house Bolus Fabrication

The bolus samples in this study were 3D printed TPU, silicone sealant, and resin. The making of 3D printed TPU used ender 3, modified foron 3d printer. The TPU filament used was 1.75 mm in diameter. Bolus was printed with 100% infill with a printing temperature of 210 ºC. Furthermore, the silicone sealant bolus was made manually without the help of a machine by mixing tapioca flour and silicone sealant with a tapioca percentage of 43% of the weight of the silicone sealant. The bolus resin was also made manually by mixing the lycal resin and the catalyst at a mixing ratio of 2:1. After mixed, the samples were printed with a size of 15 cm x 15 cm with variations in thickness of 0.3 cm, 0.5 cm, and 1 cm.

Relative Electron Density Test

The Relative Electron Density test was carried out at The Radiology Department at Lavalette Hospital, Malang. All bolus samples were scanned using a Toshiba Alexion 16 slice CT-scanner. The bolus was placed on the couch of the CT-Scan plane, and the settings on the CT-scan plane were done by setting the tube voltage and current of 120 kV and 60 mA. After the setting stage, the CT-scan was activated to start scanning on the bolus. The scan result was a bolus image which was then processed using imageJ software to get the CT-number value. The CT-number bolus value can be obtained by averaging the CT-number value of the 5 ROI in the center of the image and pointing it at 3,6,9, and 12 o'clock (Nowik et al., 2015). After obtaining the CT-number values for each bolus, these values were entered into the following equations (Guswantoro et al., 2020):

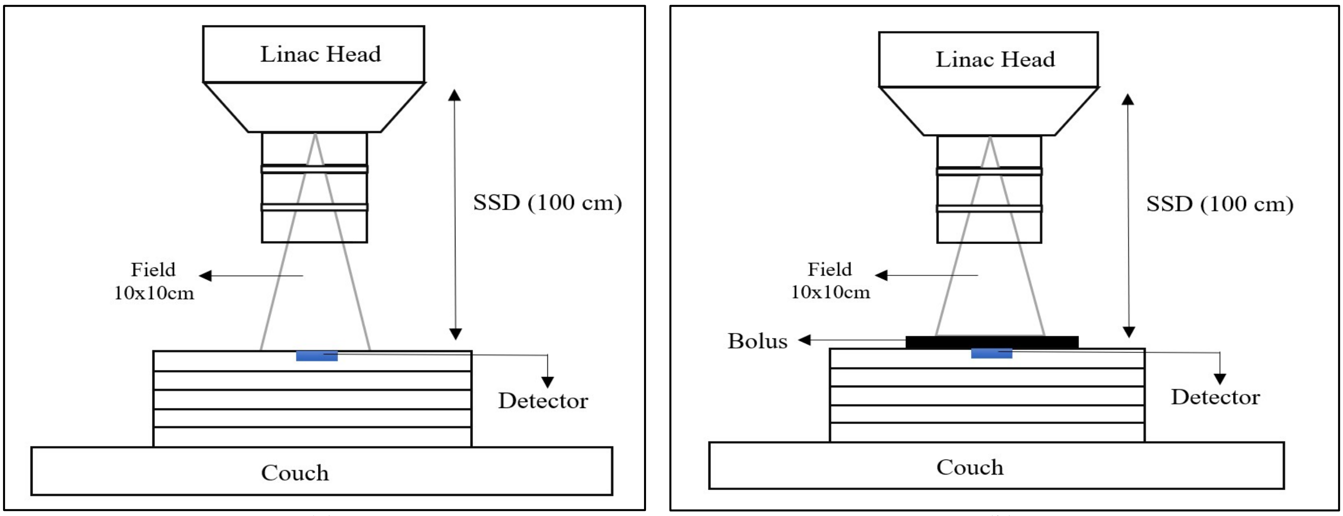
$$\rho_a = 1.052 + 0.00048N_{CT}\ , N_{CT} > 100 \quad (1)$$

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

The value of ρ is the RED value and N_{CT} is the CT-number value. If the bolus CT-number was more than 100, then to obtain the RED value equation (1) was used. However, if the CT-number value was less than 100, then equation (2) was used.

Percentage of Surface Dose (PSD) Measurement

The percentage of surface dose (PSD) measurement was carried out at the Radiotherapy Installation of Lavalette Hospital using the Linac Elekta Synergy Platform with electron beam energies of 10 MeV and 12 MeV and a dose rate of 200 MU min^{-1}. Initially, the phantom surface dose was administered without the use of a bolus. The phantom was placed on the couch of a linac and was set up like an SSD with a size of 100 cm and a radiation field area of 10x10 cm^2. The advanced markus detector was placed on the surface of the phantom as shown in the figure 1 (a).



(a) (b)

Figure 1. The Set Up of Surface Dose Measurement (a) without bolus (b) with bolus

After all the set ups were appropriate, the linac was activated to irradiate the solid phantom whose absorbed dose on its surface would be measured. Before obtaining the PSD, the absorbed dose was calculated on the phantom surface. The calculation of the absorbed dose was done using equation (3) as follows (Andreo et al., 2000):

$$D_{W,Q} = M_Q N_{D,W,Q_0} k_{Q,Q_0} \quad (3)$$

Where:

$D_{W,Q}$ = The absorbed dose read at the measurement point

M_Q = Dosimeter system reading at the measurement point

N_{D,W,Q_0} = Calibration factor in term of the absorbed dose to water for the dosimeter at the reference quality Q_0

k_{Q,Q_0} = Correction's factor for detector irradiation quality

The value of k_{Q,Q_0} was obtained using an interpolation approach of beam quality R_{50} at a depth of 39.12 mm for 10 MeV and 45.79 mm for 12 MeV. N_{D,W,Q_0} depends on the type of detector, and for the advanced Markus detector used in this study the calibration factor was 1.482 Gy/nC. Meanwhile, the value of M_Q which is the reading of the dosimeter system at the measurement point was influenced by temperature and pressure, electrometer calibration correction factor, polarity correction factor, and ion recombination correction factor. The M_Q value could be obtained using equation (4) as follows (Andreo et al., 2000):

$$M_Q = M_1 h_{pl} k_{TP} k_{elec} k_{pol} k_s \quad (4)$$

Where:

M_1 = Dosimeter reading

h_{pl} = Fluence scaling factor

k_{TP} = Temperature and pressure correction factor

k_{elec} = Electrometer calibration correction factor

k_{pol} = Polarity correction factor

k_s = Ion recombination correction factor

After obtaining the value of $D_{w,Q}$, the percentage value of the surface dose on the phantom could be obtained by comparing the value of $D_{w,Q}$ with the maximum electron dose at a certain depth (Dmax) as shown in equation (5) as follows (Günhan et al., 2003):

$$PSD = \frac{D_s}{D_{max}} \times 100\% \quad (5)$$

For energies of 10 MeV and 12 MeV, the maximum dose (D_{max}) of electrons was at a depth of 2.1 cm and 2.4 cm, respectively. After that, the same method was carried out for the measurement of the phantom surface dose using various types and thicknesses of in-house boluses as shown in the figure 1(b).

Result and Discussion

In this present research, a bolus has been successfully made as a tissue compensator for radiotherapy. Various kinds of samples can be seen in the figure 2. The elasticity of three boluses will decrease when the thickness of the boluses increases. A bolus made of resin looks the most transparent and translucent. This makes the resin easier to get positioned and makes it easier for the verification on whether or not there is an air gap between the skin and the bolus. This verification will be more difficult to do if the bolus is opaque or not translucent (Adamson et al., 2017). Resin is superior in terms of transparency, but in terms of elasticity, milky white silicone sealant tends to be more elastic. This elasticity is one of the important characteristics of the bolus so that it is easily positioned on the uneven human body. If sorted in terms of elasticity, silicone sealant is the most elastic, followed by resin and 3D printed TPU respectively.

Although 3D printed TPU tends to be less elastic, it is more homogeneous than the other two materials. This is because in its manufacturing process, it uses machines and 100% infill. This fact is supported by the research conducted by (Malone et al., 2021; Ricotti et al., 2017) who made bolus with 3d Printed Technique. This lack of elasticity can also be compensated with another advantage as 3d printed TPU can be shaped according to the needs.

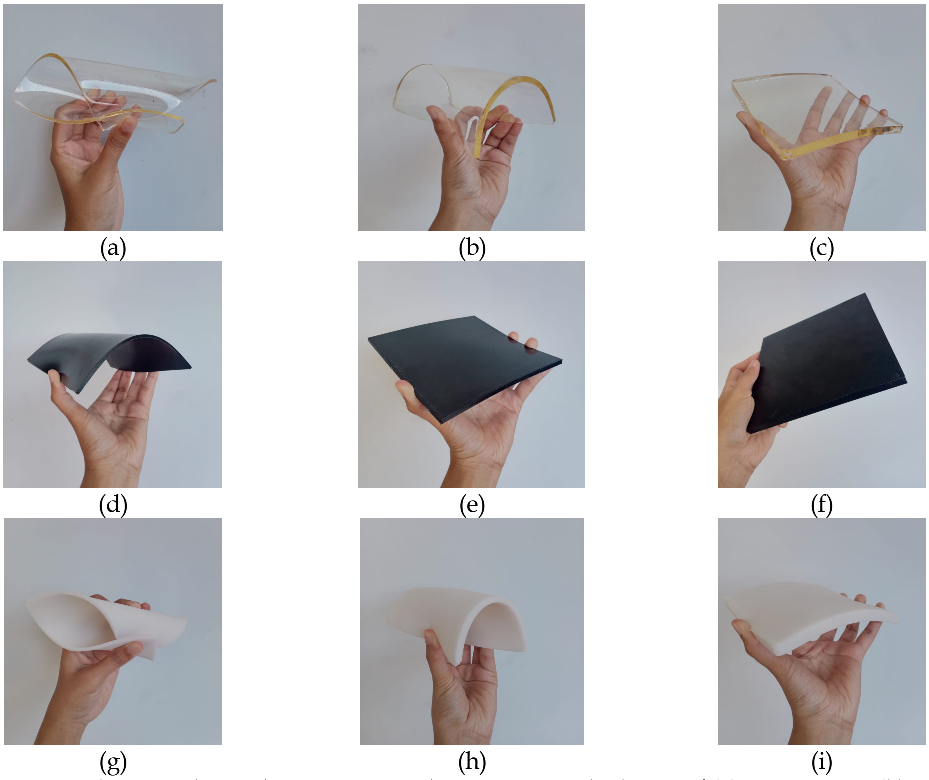


Figure 2. Some In-House Bolus samples with 15x15 cm^2 and variations in thickness of (a) 0.3 cm resin (b) 0.5 cm resin (c) 1 cm resin (d) 0.3 cm 3D printed TPU (e) 0.5 3D printed TPU (f) 1 cm 3D printed TPU (g) 0.3 cm silicon sealant (h) 0.5 cm silicon sealant (i) 1 cm silicon sealant.

Relative Electron Density Test

The CT-number value represents the relative electron density value of each bolus material used. If the CT-number of the material is known, it can be estimated that the density of the material will be equivalent to a certain tissue. RED some body tissues can be seen in Table 2. The results of the bolus sample test in terms of CT-number and RED can be seen in Table 1.

Table 1. Relative Electron Density (RED) of In-house boluses

Bolus	Thickness (cm)	CT-Number	Density	RED
3D Printed TPU	0.3	5.614	0.338	1.006
	0.5	41.589	0.573	1.042
	1	133.687	1.120	1.116
Resin	0.3	4.689	0.298	1.005
	0.5	41.449	0.507	1.041
	1	47.481	1.022	1.048
Silicone Sealant	0.3	27.507	0.378	1.028
	0.5	16.041	0.551	1.016
	1	124.579	0.982	1.112

From Table 1 it can be seen that although the bolus is made of the same material, each thickness has a different RED value. 3D printed TPU with a thickness of 0.3 has the RED that is close to the water value, while 3D printed TPU with a thickness of 0.5 cm has the RED similar to soft tissues such as kidneys and lungs, and for 3D printed TPU with a thickness of 1 cm the RED is similar to trabecular bone. Similar to 3D printed TPU, 0.3 cm resin and 0.5 resin also have the RED close to water and kidneys. Meanwhile, for the resin with a thickness of 1 cm, the RED is similar to liver. Silicone sealant with a thickness of 0.3 cm and 0.5 cm has the RED that resembles soft tissues such as brain and breast. Lastly, the RED from silicone sealant with a thickness of 1 cm is similar to trabecular bone.

Table 2. Relative Electron Density (RED) Value of Some Tissues (Yohannes et al., 2012)(Marzi et,al., 2013)

Tissue	RED Value
Water	1.000
Trabecular Bone	1.117
Lung	1.041
Breast	1.014
Kidney	1.041
Brain	1.035
Liver	1.050

Percentage of Surface Dose (PSD)

Initially the percentage of surface dose of phantom without bolus when irradiated with 10 MeV was 90.2%. When given various in-house boluses on the phantom surface, the percentage of the surface dose increased. This is because the bolus as a compensator can shift the build-up region of the electron beam. The highest increase in the percentage of the surface dose occurred when silicone sealant bolus was added, accounting for 95.9% at 0.3 cm thickness, 96.4% at 0.5 cm thickness, and 99.1% for 1 cm thickness. It can be seen in figure 3 that the silicone sealant bolus with a thickness of 1 cm could increase the PSD to almost 100%. Furthermore, the resin bolus with a thickness of 0.3 cm, 0.5 cm, and 1 cm could increase the PSD to reach 94.5%, 95.2%, and 97% respectively. Furthermore, 3D printed TPU could also increase PSD; 3D printed TPU with a thickness of 0.3 cm could increase the PSD up to 94.4%, a thickness of 0.5 cm could increase the PSD up to 95.3%, and a thickness of 1 cm could increase the PSD up to 97.4%. From the figure 3, it can be concluded that silicone sealant gave the highest increase in PSD of the other two materials. In addition, from the data above, it can also be observed that the thicker the bolus size, the higher the increase in PSD that can be obtained. This happens because the thicker the bolus, the greater the shift in the build-up region. Bolus with 1 cm thickness made the penetration of electron particles lower due to the reduced kinetic energy of the electrons resulting in a larger percentage of surface dose (Tampubolon et al., 2019).

The percentage of Surface dose for sample bolus for 12 MeV can be seen in figure 4. Not much different from 10 MeV irradiation, 12 MeV silicone sealant irradiation gave the highest PSD increase compared to other bolus samples. Silicone sealant bolus could increase the surface dose from 92.4% (without bolus) to 97.8% for 0.3 cm bolus, 98.2% for 0.5 cm bolus, and 99.8% for 1 cm bolus. Meanwhile, the second largest increase was obtained by the presence of 3D printed TPU bolus. This 0.3 cm bolus could increase the PSD up to 96.7%, 0.5 cm bolus could increase the PSD up to 97.2%, and 1 cm bolus could increase the PSD up to 98.5%. Lastly, resin bolus with a thickness of 0.3 cm could increase the PSD up to 96.1%, a thickness of 0.5 cm could increase the PSD to 97.1%, and a thickness of 1 cm could increase the PSD to 98.3%.

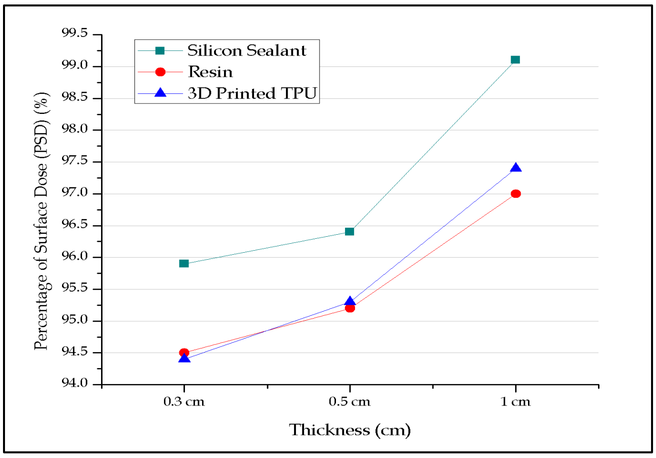


Figure 3. Percentage of Surface Dose (PSD) for Some Thickness for Each Sample Bolus on 10 MeV

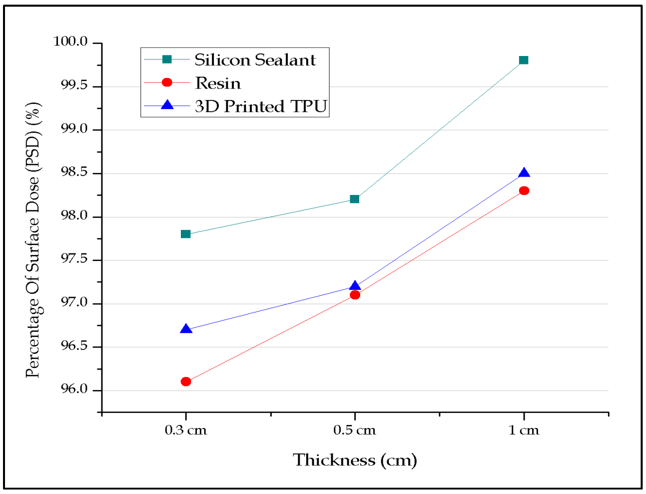


Figure 4. Percentage of Surface Dose (PSD) for Some Thickness for Each Sample Bolus on 12 MeV

If it is observed from the figure 3 and figure 4 of the PSD measurements without bolus, it can be seen that the greater the energy used, the greater the PSD produced. This can be seen from the PSD generated by 12 MeV which was higher than that generated by 10 MeV. This can happen because electrons with lower energy will be scattered more easily when interacting with the medium. This causes the electron beam fluence to increase due to the larger scattering angle (Podgorsak, 2005). This affects the build-up region that occurs not too deep after passing through the solid surface of the phantom, so that the ratio of the surface dose to the maximum dose becomes smaller at the use of low energy electrons (Astuti et al., 2018).

Conclusion

In this research, a bolus made of silicone sealant, resin and 3D printed TPU was successfully made with a size of 15 x 15 with various thicknesses, namely 0.3 cm, 0.5 cm, and 1 cm. The RED of each bolus is similar to that of various soft tissues. 3D printed TPU has the highest RED equivalent to trabecular bone, and resin has the smallest RED equivalent to brain tissue. Boluses have been shown to increase the surface dose on the phantom surface. In the same material, the thickness of the bolus is directly proportional to the increase in PSD. Among the three bolus materials in this research, silicone sealant with a thickness of 1 cm has the highest increase in the surface dose up to 99.8%.

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