A Comparative Study of Dosimetric Characterization of Bolus Based on Natural Rubber (*Hevea Brasiliensis*) and Clinical Bolus for Therapy with Megavolt Electron Radiation

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Abstract. The aim of this study is to evaluate the dosimetry properties of the synthesized bolus material from natural rubber compared to clinical boluses (Play-Doh and Paraffin Wax), involving the values of relative electron density (RED), transmission factor value (TF), mass attenuation coefficient (MAC), percentage surface dose (PSD), and curve of percentage depth dose. In this study, all boluses have dimensions of 11\times11\times0.5\ cm^3. Bolus density was measured and analyzed using a CT SCAN and treatment planning system. On the other side, the dosimetry test was performed using Linear Accelerator (LINAC) and detector plan parallel chamber (PPC-40) with an electron beam energy source (6, 9, 12 MeV). Relative electron density for natural rubber bolus, Play-Doh, and paraffin wax were obtained around 0.80, 0.91, and 0.79, respectively. These results indicate that the natural rubber bolus has close to the value of soft tissues such as the lung. Based on the calculation, the transmission factor and the mass attenuation coefficient of natural rubber have the best absorber properties achieved at 12 MeV energy with the results of 99.83\% and 0.0045\ cm^2/g; this also occurred in the clinical boluses. The surface dose experienced an increase in each addition of energy as much as 8.73, 5.35, and 4.79\% for energy sources 6, 9, and 12 MeV, respectively. Therefore it can be concluded that the bolus synthesized by natural rubber can be used as an alternative bolus alongside the clinical bolus in this study (paraffin wax and Play-Doh) in the treatment of superficial cancer using megavolt electron energy.

1. Introduction

LINAC (Linear Accelerator) is often used in the process of radiotherapy for various types of cancer. LINAC is a medical device that can produce multiple energies in the form of photons and electron beams and can be used to treat cancer in various positions [1, 2]. In the present study, the megavolt electron beam will be used due to the provides a distinct advantage from the photon beam in superficial tumor therapy. The depth dose curve for the electron beam shows a high surface dose compared to the megavolt photon beam as well as their maximum dose depth (Z_{max}) [3]. It means that the electron beam is suitable for treating superficial cancer. Even though the electron beam is suitable for superficial cancers, the level of energy electron is still able to cause disruption in healthy tissue outside of the tumor although with low energy [3, 2]. To overcome this problem, bolus or tissue substitute derived from material equivalent to human soft tissue could be added to compensated it with...
the thickness that is adjusted according to the planning target volume [4]. The bolus has a function to control the dose distribution of radiation beams which have a high absorbency dose to the target, and can also be used to form isodose lines to conform to the shape of the tumor [1]. The requirements for a good bolus are that the material is equivalent to human tissue, homogeneous, non-toxic, has no bubbles and does not change its nature after several times of irradiation [3]. The natural rubber will be used as the bolus material due to it has properties as biopolymer material which is certainly environmentally-friendly [5]. The natural rubber has also been reported could be used in the medical world, one of which is as a substitute for corpses in medical science. The natural rubber has a composition that is almost similar to human soft tissue [6, 7]. The main purpose study was to determine the dosimetry properties of bolus materials. The tested material was natural rubber, Play-Doh, and paraffin wax, and then those materials will be compared with each other. Relative electron density, transmission factor, mass attenuation coefficient, percentage depth dose curve, and percentage surface dose will be investigated to determine performance for each bolus in medical application, especially for radiation therapy.

2. Material and Method

2.1 Bolus Fabrication
Bolus from natural rubber: 56 mL of liquid natural rubber was mixed gently until homogenous solution while added ten drops of the catalyst (5 mL of formic acid). Subsequently, the solution poured into an acrylic mold with dimensions 11×11×0.5 cm\(^3\) and then let it dried. Meanwhile, for the fabrication of bolus from Play-Doh, 455 g of Play-Doh placed into an acrylic mold with dimensions 11×11×0.5 cm\(^3\) and then compacted and leveled to fit the sizes. The same procedure was used for the fabrication of bolus from paraffin wax.

2.2 Density Test
All density boluses were scanned using CT SCAN (Radiotherapy department, MRCCC Siloam Hospitals Semanggi) that has been regulated by regulating tube current, tube voltage, and slice thickness with values 285 mA, 120 kV, and 5 mm, respectively, through the control room. The results of the scanned bolus then processed in the treatment system planning room to obtain relative electron density parameters using ECLIPS software.

2.3 Dosimetry Test
All dosimetry test of boluses were carried out by medical physicists at the Radiotherapy Installation of MRCCC Siloam Hospitals Semanggi using the VARIAN CLINAC iX 2300. The test was conducted with or without bolus as shown in figure 1. Dosimetry test was carried out using electron with energies of 6, 9 and 12 MeV with reference points was at 1.3, 2 and 2.9 cm, respectively. All measurements were done three times with a detector of parallel plate chamber (PPC-40), then calculated with the TRS 398 standard to obtain the value of the absorbed dose. The obtained of the absorbed dose will be used to calculate the transmission factor and mass attenuation coefficient parameters using equations 2.1 [8] and 2.2 [9] as follows:

\[
Transmission_{\text{sample}}(\%) = 100 \times \left( \frac{dose_{\text{sample}}}{dose_{\text{open field}}} \right)
\]  (2.1)

\[
Mass\;Attenuation\;Coefficient \mu = \frac{1}{\rho x} \ln \left( \frac{D_0}{D} \right)
\]  (2.2)
3. Result and Discussion

3.1 Density Test

The relative electron density (RED) obtained from natural rubber bolus, paraffin wax and Play-Doh in figure 2 are 0.81, 0.91 and 0.79, respectively.

![Fabricated bolus material using](a) natural rubber (b) paraffin wax (c) Play-Doh.

The value of RED can be used to identify whether bolus material that has been fabricated is meet to standard or not. Figure 3 shows relative electron density as a function of the thickness of fabricated boluses. It can be seen that all boluses have a similar value to RED lung soft tissue. It means one of the requirements for a bolus has been fulfilled from this parameter. The same study was also carried out by (Supratman et al., 2018) which discusses the density of natural rubber with the obtained value at 0.893 and the same study was also carried out by (Vyas et al., 2013) on paraffin wax boluses with a density value of around 0.9, which means there is a match between the results of this study [4, 5]. Moreover, the results showed that all boluses have not been able to reach the RED value of other human soft tissue besides the lung. It is probably because those of bolus materials that have been used have a low material atomic number. The solution is to add the thickness of the bolus so that the density increases and the RED value increases too.

3.2 Dosimetry Test

3.2.1 Transmission Factor (TF)

The value of the transmission factor (TF) that has been calculated using equation (2.1) for all boluses can be summarized in table 1. The value of the transmission factor is a parameter used to see the material’s ability to pass on the intensity of electron energy [8]. Based on table 1, it can be seen that the three boluses have TF results that are almost similar to each other with differences that are not too significant between all boluses. This TF value is in accordance with the RED results; if the relative electron density is small, then the ability of the material to transmit the radiation is enormous.
Furthermore, the results of TF without adding a bolus at all energies were 1% whereas values of TF with adding fabricated bolus from natural rubber, paraffin wax, and Play-Doh bolus are tended to change. For all boluses with energies of 6 and 9 MeV have the TF values increase above 1%, whereas all boluses irradiated with energy 12 MeV have the TF values decrease below 1%. These facts indicate all energies of at 6 and 9 MeV that have irradiated for all boluses could be transmitted all of their energy through the boluses whereas the application of 12 MeV energy to all boluses showed the boluses are able to absorb some of the energy so that the surface dose rises. The statement is contradictory to the theory that the higher the energy supplied, the greater the penetrating power so that the transmission factor is also high as explained by (Khan, 2003) [10]. The difference between the results and the theory is probably due to the lack of homogeneity of the three boluses.

3.2.2 Mass attenuation coefficient (MAC)
Table 2 presents the mass attenuation coefficient (MAC) was calculated using equation (2.2). The MAC value is used as parameters to reflect the ability of a material to absorb radiation, the greater the MAC, the greater the attenuation value. MAC is the calculation of the linear attenuation coefficient divided by the density of the material [11]. Based on the theory, the MAC value is the opposite of the TF value which means that the MAC results will be related to the TF results. Based on table 2 it is found that the greatest MAC value is at 12 MeV energy which means that at this energy; natural rubber, Play-Doh, and paraffin wax could function as a bolus as it should because it has the ability to absorb radiation. Meanwhile, for all energies of 6 and 9 MeV, could not function as a bolus as they should because all the energy intensity is passed on.

3.2.3 Percentage depth dose (PDD) curve
In this section, the depth dose percentage curve obtained is shown in figure 4. This PDD curve was obtained from simulation measurements using ECLIPS software by adjusting sample thickness,
phantom thickness, applicator size, and energy variations according to actual measurements. The black line shows the maximum peak of the curve before using bolus and the orange line shows the maximum peak after using bolus. If observed from figure 4 (a) - (c) it is found that from the point from the surface to the maximum point is called the accumulation area, in this area the maximum interaction occurs between the source electron and the electron atom of the medium, but after passing through the maximum point the energy decreases rapidly with respect to depth [10]. For the electron energy it generally produces a PDD curve like figure 4. After observing the addition of natural rubber, paraffin wax, and Play-Doh boluses for all the energy, the builds up results are shifted towards the surface, which means that these three boluses meet the requirements of the bolus itself (shifting the radiation dose towards the surface of the skin) [12]. However, if it is related to the previous parameters, the build-up area that is formed at 12 MeV energy should be small because the greater the energy, the ability of the bolus to absorb radiation is also large which causes the radiation dose to shift to the surface. In fact, the PDD curve at 6 and 9 MeV energy forms smaller build up area than the builds up area at 12 MeV energy.

Table 2. Mass attenuation coefficient value of natural rubber and clinical bolus (Play-Doh & paraffin wax) at a thickness of 0.5 cm.

| Material          | Energy (MeV) | Mass attenuation coefficient (cm$^2$/g) |
|-------------------|--------------|----------------------------------------|
| Natural rubber    | 6            | -0.1318                                |
|                   | 9            | -0.0579                                |
|                   | 12           | 0.0040                                 |
| Play-Doh          | 6            | -0.0682                                |
|                   | 9            | -0.0238                                |
|                   | 12           | 0.0268                                 |
| Paraffin wax      | 6            | -0.0709                                |
|                   | 9            | -0.0546                                |
|                   | 12           | 0.0057                                 |

Figure 4. Percentage depth dose curve of energy 6, 9 and 12 MeV.
The bar diagram of the percentage of the surface dose (PSD) in figure 5 is obtained from the percentage depth dose curve. Based on figure 5 it is known that the percentage of surface doses at 6, 9 and 12 MeV energy before the use of bolus is 82.66%, 83.39%, and 87.45%, respectively. However, after the use of bolus the percentage surface dose value increases by almost 100%. This means that the addition of boluses during the radiation process has a good effect because it can produce increased doses to the surface. This surface dose has an important role so that cancer in the superficial area can get the maximum dose and outside the target volume get the minimum dose. Based on the PSD results, it means that one of the bolus requirements has been fulfilled which is to increase the dose to the surface [13]. When the natural rubber bolus, paraffin wax bolus, and Play-Doh bolus compared with each other there was no significant difference in PSD values because these three bolus materials have the same ability in terms of absorbing radiation.

4. Conclusions
In this study, it was demonstrated the dosimetry properties of the bolus used clinically (Play-Doh & paraffin wax) had a similarity to the synthesized bolus from natural rubber. All boluses had a value of the relative electron density similar to human soft tissue, namely the lung. Moreover, all boluses could absorb radiation at energy 12 MeV or the value of the mass attenuation coefficient was much higher than at 6 and 9 MeV whereas from the PDD curve and PSD, it was revealed that all boluses could shift the builds up area towards the surface, which means the surface dose would get the maximum dose and outside the target, the volume would get the minimum dose. Therefore, the synthesized bolus from natural rubber had a potential application for radiation therapy alongside the clinical bolus (paraffin wax and Play-Doh) in the treatment of superficial cancer using Megavolt electron energy.

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References
[1] D. Darmawati, S. Suharni, “Implementation of Linear Accelerator in the Treatment of Cancer Cases,” Proceedings of Meeting and Scientific Presentation of Accelerator Technology and Its Application14, 36 – 47, 2012.
[2] D. Newton, “European Patent Office Patlib 2008, Warsaw, Poland, 28–30 May 2008,” World Pat. Inf., vol. 30, no. 4, pp. 348–349, Dec. 2008.
[3] W. J. Strydom, W. Parker, M. Olivares, *Electron Beams: Physical and Clinical Aspects*. 2005.

[4] V. Vyas, L. Palmer, R. Mudge, R. Jiang, A. Fleck, B. Schaly, E. Osei, P. Charland, “On Bolus for Megavoltage Photon and Electron Radiation Therapy,” *Med. Dosim.*, vol. 38, no. 3, pp. 268–273, Sep. 2013.

[5] E. B. K. Aditya, H. M. Djakaria, T. Amalia and D. Arianzy, “Characteristic and Profile Electron Beam Therap,” *Journal of the Indonesian Radiation Oncology Society* no. 3. 55–64. 2012.

[6] F. A. Lothfy, I. S. Mustafa, Z. S. Yahya, S. A. Ishak and N. M. Daud, “To Study The Durian Seed as A New Substrate for Bolus In Radiotherapy,” *Proc. of 16th The IIER Int. Conf. 14th*, pp.110–3. 2015.

[7] A. S. Supratman, H. Susanto, E. Hidayanto, G. W. Jaya, S. Y. Astuti, T. Budiono, and M. A. Firmansyah, “Characteristic of Natural Rubber as Bolus Material for Radiotherapy,” *Mater. Res. Express*, vol. 5, no. 9, p. 095302, Aug. 2018.

[8] I. Malaescu, C. N. Marin, and M. Spunei, “Comparative Study on the Surface Dose of Some Bolus Materials,” *Int. J. Med. Phys. Clin. Eng. Radiat. Oncol.*, vol. 04, p. 348, 2015.

[9] S. N. A. Tagoe, S. Y. Mensah, J. J. Fletcher, and E. Sasu, “Telecobalt Machine Beam Intensity Modulation with Aluminium Compensating Filter Using Missing Tissue Approach,” *Iran. J. Med. Phys.*, vol. 15, no. 1, pp. 48–61, Jan. 2018.

[10] F. M. Khan, Electron Beam Therapy. In: Khan FM, editor. *The Physics of Radiation Therapy*. 3 ed. Philadelphia: Lippincott Williams & Wilkins; 2003. pp. 297-354.

[11] V. P. Singh, N. M. Badiger, “Photon Interaction Properties of Some Semiconductor Detectors,” *Nuclear Reactor Technology*. 2016; 27: 72.

[12] D. Lambert, N. D. Richmond, R. H. Kermode, D. J. T. Porter, “The Use of High Density Metal Foils to Increase Surface Dose in Low-Energy Clinical Electron Beams,” *Journal of Radiotherapy and Oncology* no. 53, 161-166. 1999.

[13] S. Izeki, K. Hatakeyama, F. Ebihara, and Y. Koga, “Bolus for radiotherapy,” US6231858B1, 15-May-2001.