Characteristic of natural rubber as bolus material for radiotherapy

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Characteristic of natural rubber as bolus material for radiotherapy

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Abstract

Bolus is material similar to tissue and is placed directly on skin surface during radiotherapy with electron beam. This research has successfully developed bolus using Natural Rubber (NR) organic polymer. The bolus produced has a dimension of $11 \times 11 \times 0.5$ cm^3. This bolus has also undergone characteristics testing using CT-Scan to measured relative electron density (RED). The mass attenuation coefficients (MAC) testing was calculated using software XCOM Version 3.1 and effective atomic number (EAN) testing was calculated using Auto Zeff Version 1.7. Bolus was exposured to electron beam radiation with energy 8 and 10 MeV using Linear Accelerator (LINAC) to measure the percentage of surface dose (PSD) value. Results show that the bolus has RED value of 0.893, which is nearly the same as that of soft tissues such as Lung, Fat, and Liver. For MAC calculation result is similar with water and soft tissue (lung), and for EAN calculation result is under water and soft tissue. The Percentage of Surface Dose (PSD) values while using bolus were 94.63% and 95.31% for 8 and 10 MeV energies, respectively. These values mean that there has been an increase in PSD with the use of bolus, even though it is not yet 100%. Hence, NR is an alternative material for bolus as it is similar to soft tissue and helps to increase the dose on skin surface.

1. Introduction

Radiotherapy is a medication method using ionizing radiation to treat cancer [1]. The most commonly applied radiation therapy for patient is external radiation using a Linear Accelerator (LINAC) [2]. LINAC produces two radiation beams, photon (x-ray) in megavolt (MV) and electron in mega electron volt (MeV) [1]. Electron beam from LINAC is very useful for tumor therapy on superficial (surface) areas down to 7 cm depth, whereas photon beam is effective for depths more than the skin surface [3]. In photon beam, surface dose depends on the energy and surface area. When the dose is lower than compared to the maximum dose, it is known as the skin sparing effect [1]. Skin sparing effect for electron beam is very insignificant, or barely exists, that electron beam is the most proper method to treat cancer on the skin surface, despite the fact that the surface dose may not reach 100% [4]. The surface dose on the skin surface can be increased with the use of bolus.

Bolus is a material similar to that of tissue and is directly applied on the skin surface during radiotherapy [1]. Bolus is used in order to compensate for the uneven skin contour, get rid of skin sparing effect, provide extra attenuation, increase surface dose, make up for missing tissue, and improve dose absorbance during radiotherapy [1, 2, 5]. Bolus must not slide during treatment [2]. Therefore, bolus comes with the properties of similar dosimetry with tissue, is homogeneous, tough, has good plasticity, very easy to shape, non-poisonous, does not undergo energy change, does not come with bubbles, and has certain thickness [1, 2, 5, 6].

Bolus is mostly made of commercially available synthetic materials such as paraffin wax, polystyrene, Lucite, elastic-gel, super flab, thermoplastic sheets, dental wax, polypropylene, and rayon cloth [5, 7–9]. In 2003, Günhan *et al* [10] carried out a study on bolus made of elastic-gel material and found that an energy of 6 MeV at 0.6 cm thickness increase surface dose by up to 90.1%. Meanwhile, Hsu *et al* in 2008 [11] revealed that bolus

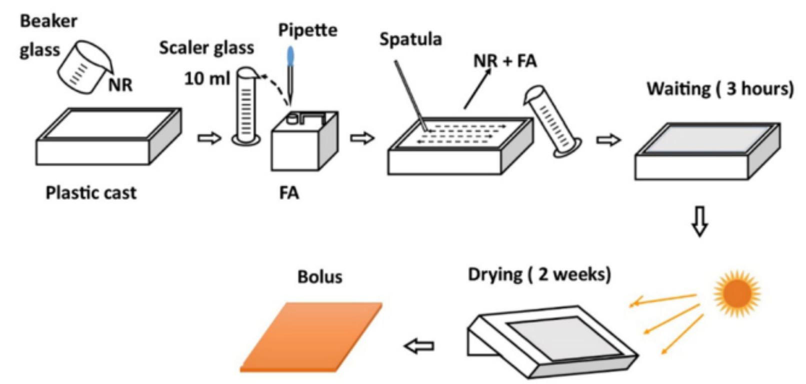

Figure 1. Scheme of bolus fabrication.

made from aquaplast solid material with 2 mm thickness raises surface dose to 92.7%. Other than those two materials, there are many alternatives that are environmentally friendly, affordable, renewable, and are widely available in nature. One of them is Natural Rubber (NR).

NR is an elastic organic polymeric material (elastomer) derived from the sap of *Havea brasiliensis* trees through a tapping process [12]. NR contains water, protein, lipid, phospholipid, carbohydrate, and the other organic and inorganic compounds [12, 13]. NR is advantageous in that it has proper elasticity, tensile strength, and is tearing-prove, compared to the other synthetic rubbers [13]. NR has been widely used in industry and research sectors such as memory shapes, vibrio-acoustic insulation, sensor applications, antimicrobials, and asphalt modification [14–18]. Some researchers have used NR in the biomedical field. Recently Murniati *et al* [19] have used NR that is mixed with nano composites as human tissue for cadaveric substitutes in medical surgical practice. Then Watthanakaroon *et al* [20] has succeeded in using latex NR as a wound dressing by combining biopolymers to exudate absorption, drug release, antimicrobial activity, and cellular proliferation that prevents microbial inductive invasion of cell, and stimulates target cell response to improve wound healing. In this study, bolus with NR material has been subjected to several testing processes such as electron density test and percentage of surface dose (PSD) using electron beam.

2. Materials and methods

2.1. Material

The bolus in this research was made from NR with additional 90% formic acid (CV. Indrasari, Semarang, Indonesia). Formic Acid (FA) (CV. Indrasari, Semarang, Indonesia) serves as coagulant, as bolus production starts with coagulation. In this process, a 196 ml NR was poured, before 5 ml of formic acid was added, and the mixture was stirred for 20 s. The solution (NR + formic acid) was aged for 3 h, after which the fluid is cleaned. That solution was dried under the Sun for 2 weeks to get rid of fluids. The dried NR changes in color from white to brown and shrinks from an initial dimension of $(14 \times 14 \times 1)\ \mathrm{cm}^3$ to $(11 \times 11 \times 0.5)\ \mathrm{cm}^3$. A scheme of bolus production is shown in figure 1, and the resulting bolus is given in figure 2.

2.2. Relative electron density (RED)

Measurement of relative electron density (RED) on bolus was performed by scanning process using CT-Scan (Toshiba), image of scan process sent to computer to determine CT-Number Hounsfield Units (HU). To calculate the relative electron density of the CT-Number data the following equation was used:

$$\rho_e = (HU + 1000)/1000 \qquad -1000 \leqslant \mathrm{HU} \leqslant 47 \tag{1}$$

$$\rho_e = HU/1827.15 + 1.0213 \quad \mathrm{HU} > 47 \tag{2}$$

with ρ_e is RED value and HU is Hounsfield Units for the different tissue equivalent materials. If HU $\leqslant$ 47 then we use equation (1) and if HU $\geqslant$ 47 then we use equation (2) [21].

2.3. Percentage surface dose (PSD)

The measurement of surface dose percentage (PSD) in bolus has been done by giving electron beam radiation from a Linear Accelerator (LINAC) device (Electa). The energy used is 8 MeV and 10 MeV with the applicator

Figure 2. Resulting natural rubber bolus.

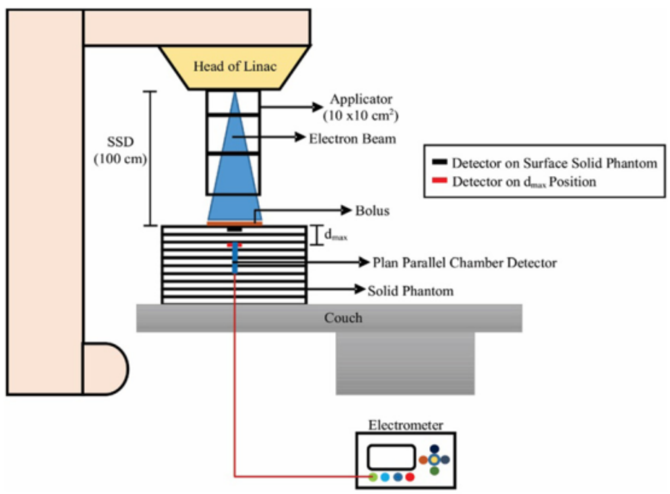

Figure 3. Scheme to measure the percentage of surface dose (PSD).

field size 10 × 10 cm^2, and the source distance to surface dose (SSD) is set in a 100 cm position. The plan parallel chamber detector (PTW-Freiburg, Germany) was used to measure electron beam radiation both on the surface and maximum dose depth (D_{max}) positions. D_{max} position for 8 and 10 MeV energies are 1.7 and 2.2 cm, respectively. A scheme of PSD measurement is depicted in figure 3, while PSD calculation uses the following formula:

$$\%PSD = \frac{D_S}{D_{max}} \times 100\% \tag{3}$$

with D_S is the radiation dose measured on the surface of the solid water phantom and D_{max} is the dose radiation measured at the solid water phantom position [10].

3. Results and discussion

3.1. Relative electron density (RED)

The value of CT-Number for NR bolus was obtained for −107 HU. By using equation (1) the relative electron density (RED) is 0.893. For RED values of several tissues can be seen in table 1 below:

Table 1. Relative electron density of tissue [22, 23].

Tissue	Typical HU	Relative electron density
Liquid water	0	1.000
Lung (inhale)	−772.76	0.190
Fat	−50	0.950
Humerus	700	1.390
Cranium	1.5	1.510
Rib	600	1.340
Liver	50	1.052

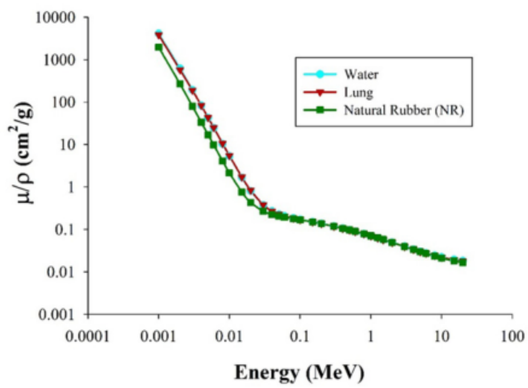

Figure 4. Mass attenuation coefficients for water, lung, and NR.

According to table 1, the RED value generated by bolus is above the RED value of lung and under the Fat and Liver. These results indicate that the NR material has a coefficient of attenuation less than water or an HU value < 47 so that the CT-Number of NR material is lower than the CT-Number of water. This is caused by the different composition of NR and water. Water is consists of H_2O bonds, whereas NR is composed of C_5H_8 bonds [12, 13]. Moreover, NR contains all kinds of materials including hydrocarbon, protein, carbohydrate, lipid, and some other organic compounds, mineral, and water [12, 13]. This also means that the RED value of NR is similar to that of soft tissue and hence, theoretically, NR is a suitable material for bolus. In addition to the RED data, the value of mass attenuation coefficients (MAC) was obtained using software XCOM Version 3.1 [24]. In the NR (C_5H_8) and Water (H_2O) materials, the value was taken the total attenuation with coherent scattering value using XCOM software [24]. While on the lung tissue obtained by viewing table x-ray MAC [25]. The MAC calculation results on bolus NR can be seen in figure 4. From figure 4, shows that the bolus NR value is close to water and soft tissue (lung).

In addition to RED and MAC values, an effective atomic number (EAN) bolus NR calculation was performed using software Auto Zeff Version 1.7 [26]. The results obtained can be seen in figure 5. Based on the graph that the EAN value is under water and soft tissue (lung). This result is obtained accordance to the value of RED, where the value of RED bolus NR under water and soft tissue (lung).

3.2. Percentage of surface dose (PSD)

The result of PSD on solid phantom surface can be seen in figure 6. Based on figure 6, the PSD value without using bolus at 8 MeV and 10 MeV are 89.39% and 90.63%, respectively. At the time of using bolus, the value of PSD on solid phantom surface has increased to 94.63% and 95.31%, respectively.

Results (figure 6) show that the use of bolus increases PSD value on solid phantom surface. This is due to shifting in buildup area (the gap between skin surface and D_{max} position) that is close to the solid phantom surface [1, 10]. This is supported by results from Gunham *et al* who used 0.6 mm thick bolus made of elastic-gel material at 9 and 12 MeV and yielded PSD values of 93.0% and 95.6% [10]. A 0.5 mm thick bolus made from NR comes with higher PSD value for 8 MeV energy compared to the use of 9 MeV energy. Meanwhile, at 10 MeV, PSD value from this NR bolus is close to that of bolus made of elastic-gel at 12 MeV. This indicates that lower electron beam energy can still significantly raises PSD with the use of bolus [10, 27].

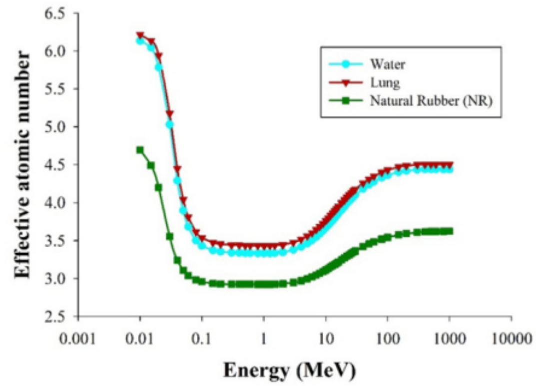

Figure 5. Effective atomic number for water, lung, and NR.

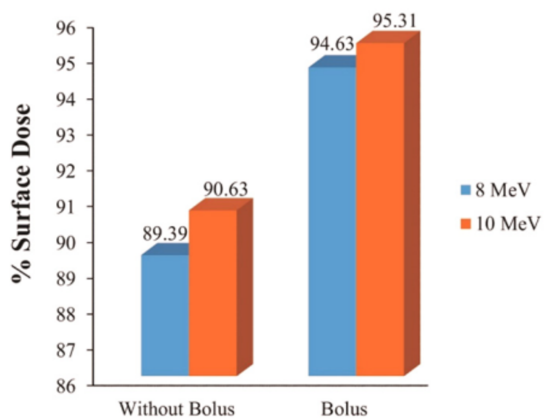

Figure 6. Percentage of Surface Dose (PSD) on solid phantom surface.

On the other hand, Hsu *et al* conducted a research using bolus made of solid aquaplast. It was irradiated with photon energy of 6 MV. The resulting PSD was 92.7% for a bolus thickness of 0.2 cm [11]. This revealed that the use of bolus for photon beam reduces the skin sparing effect. This effect is greater with the use of photon beam, instead of electron. This is why electron beam is more commonly used in therapies for tumor or cancer on skin surface [4]. It can also be concluded that in further research should compare increases in PSD values with the use of boluses made of NR and solid aquaplast at 6 MV energy. Even though the use of NR for bolus has not been able to improve PSD up to 100%, NR is still a good alternative candidate for bolus. Therefore, the next researches should probably probe the use of this type of bolus at different thickness.

4. Conclusion

Based on the results of this research, bolus with natural rubber material has relative electron density value of 0.893. The mass attenuation coefficients (MAC) on bolus NR using software XCOM Version 3.1 is similar to water and soft tissue (lung). For effective atomic number (EAN) calculation results on bolus NR using software Auto Zeff Version 1.7 is under water and soft tissue (lung). The PSD value at 8 MeV and 10 MeV are 94.63% and 95.31%, respectively. These results show improvement in PSD values with the use of bolus, albeit, less than 100%. Overall, the NR material can be used as an alternative bolus material because it is similar to soft tissue in terms of RED value that it should function well in radiotherapy.

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