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Analysis of the Attenuation Coefficient of Composite Silicone Rubber and Gliceryn for Soft Tissue Phantom Applications

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ABSTRACT

Introduction: Phantom is an object that can be used to investigate the accuracy of radiation dose delivered to patients. Phantom is usually produced from the combination of the silicone rubber as a matrix and glycerin as a filler to form a composite for the replacement of the human soft tissue. The composite is imaged using computed tomography (CT) simulator for the determination of the attenuation coefficient.

Material and Methods: The Phantom in the current study has been synthesized from silicone rubber with and without the addition 10% and 20% of glycerin. The type of silicone rubber in this study was Room Temperature Vulcanized (RTV) 52 with blue catalyst by a ratio of 100:5 (wt%). Samples were scanned using CT simulator to obtain the images and then exported to the Eclipse treatment planning system for analysis. The region of interest (ROI) was at the center of an area of 50×50 pixels to determine the CT number.

Results: The ROI results for the sample without and with the addition of glycerin 10% and 20% resulted in the CT values of 287.4, 280.5, and 225.2 HU, respectively, which were within the ROI range of the human soft tissue. The attenuation coefficients of the 3 samples were 0.239, 0.238±0.001, and 0.233±0.001 cm^{-1} for no glycerin, glycerin 10%, and glycerin 20%, respectively. The values of the half-value layer were 2.902±0.001, 2.911±0.001, and 2.980± 0.001 cm for phantom with no glycerin, glycerin 10%, and glycerin 20%, respectively.

Conclusion: Phantoms in the current study were indicative of high potentials as an object of research for radiotherapy and educational purposes. Moreover, the composite with glycerin 20% could be the best surrogate of tissue in order to study human liver.

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Introduction

Phantom is usually used for education and research to find a high-accuracy position of patients for the delivery of radiation [1]. The accuracy of the radiation dose is one of the quality control parameters for minimizing the radiation effect in healthy tissues surrounding the cancer cell [2]. Several studies reported the successful fabrication of phantom by gelatin [3,4], agar, silicone (soft Gel A-341C) [3], liquid silicone rubber [5], and silicone rubber [6-7] as base materials. Agar and gelatin-based phantoms cannot be used for a long time [3-4] since they can easily be decomposed by fungi or bacteria. Moreover, gelatin-based phantoms require a refrigerator in the manufacturing process [4]. As reported, silicone-based phantoms (e.g., silicon rubber) have longer durability [3, 5, 7]. Silicone rubber is commonly used as a protective layer at high-temperature environments due to the presence of methyls and Si-O groups and polydimethylsiloxane [8].

The application of glycerin in composite shows a significant increase in the setting time [9,10]. In this regard, the present study aimed to combine the silicone rubber as a matrix and glycerin as a filler to produce a composite for replacing the human soft tissue for radiotherapy studies and educational purposes. The composites were analyzed using CT simulator for the determination of the CT number. The CT number values are related to the linear X-ray attenuation coefficient determined by the energy (in this study 120 kV) of the X-ray and effective atomic number [11]. Therefore, attenuation property is an important parameter for phantom materials [12].

Materials and Methods

Material

Silicone rubber RTV 52 and catalyst RTV blue produced by local Indonesia company (Megah Abadi Kimia) were mixed with the ratio of 100:5 [6] for the matrix, and glycerin ($C_3H_8O_3$) 10% and 20% as the filler materials. The boiling point of glycerin is 290ºC with the molecular weight of 92 gram/mol, specific gravity of 1.25 g/cm^3, and freezing point of 20ºC [13]. Moreover, a phantom without glycerin was produced as the control in the present study.

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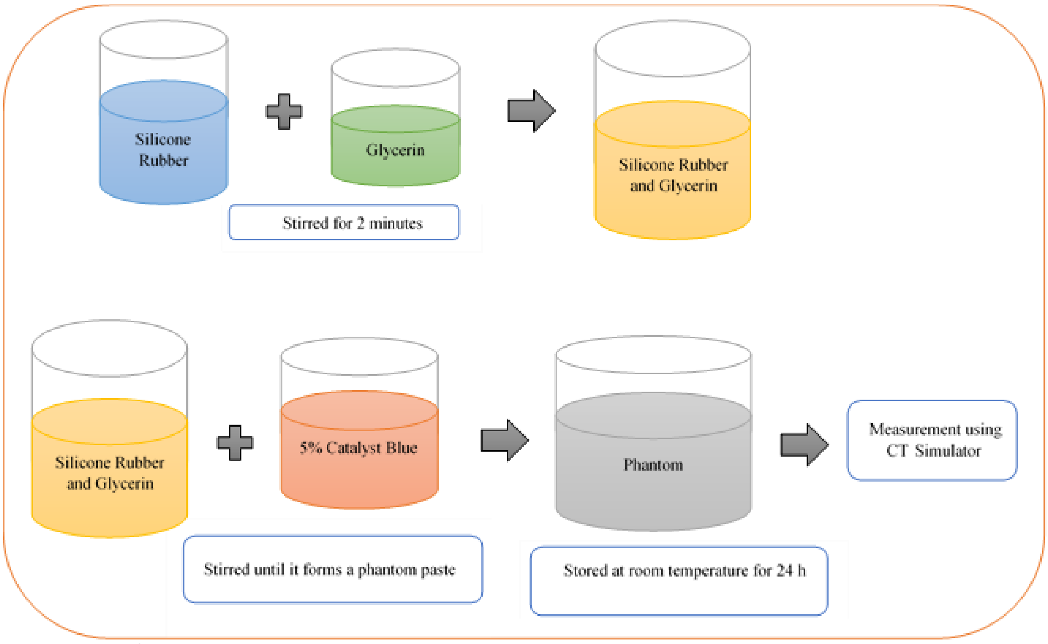


Figure 1. Synthesis process of phantom samples

Synthesis

In this step, silicone rubber and glycerin were mixed by a magnetic stirrer for 2 min [7]. Subsequently, 5% catalyst was added to the composite silicone rubber-glycerin and then stirred until the mixture was homogeneous (5 min). As can be seen in Figure 1, the final mixture was poured into the mold and stored at room temperature for 24 h [7]. The samples were tested using CT simulator with the diameter and height of 2.5 cm and of 1.5 cm, respectively.

Characterization

Samples were first scanned using CT simulator (see Figure 2 for the position of the samples in CT simulator) to obtain images and then exported to the Eclipse treatment planning system application for analysis. The region of interest (ROI) was at the center of an area of 50×50 pixels and then CT number value was determined.

Secondly, the CT number of the phantom in the present study was compared with the CT number of human soft tissue. Regarding the CT number, the attenuation coefficient was calculated using *Equation 1*:

$$CT\ Number\ (HU) = \frac{\mu_j - \mu_a}{\mu_a}\ x\ 1000 \qquad (1)$$

Where, μ_j refers to attenuation coefficient of tissue (cm^{-1}), μ_a denotes the attenuation coefficient of water (cm^{-1}), and 1000 is the scaling factor (contrast factor) [12, 14]. The relation between CT number value and the attenuation coefficients from *Equation 1* is as follows:

$$\mu_j = \left[\frac{CT\ Number\ x\ \mu_a}{1000}\right] + \mu_a \qquad (2)$$

Where μ_a is 0.21 cm^{-1} [15].

In addition, the half value layer (HVL) value of the sample was also calculated in the present study. The HVL is the thickness of the material needed to reduce the intensity of X-rays to one-half of its original value from the initial intensity determined by the *Equation (3)* as follows:

$$HVL = \frac{0,693}{\mu} \qquad (3)$$

Where μ is tissue attenuation coefficient (cm^{-1}) [16].

Results

Phantom samples without and with additional of glycerin 10% and 20% have been characterized by using CT Simulator. The results of the sample image can be seen in Figure 3.

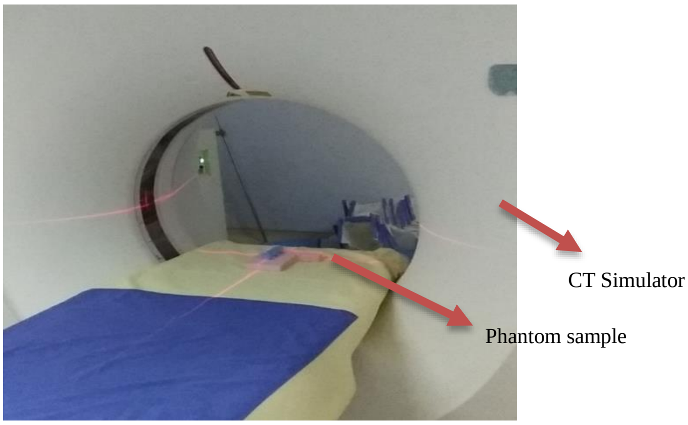
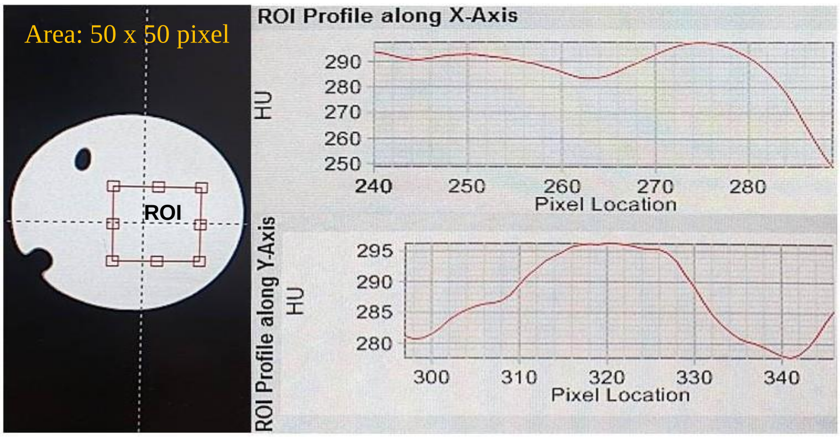
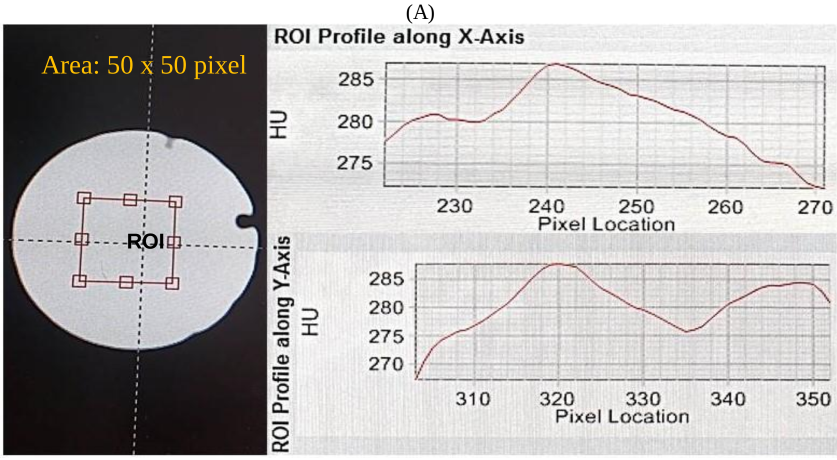


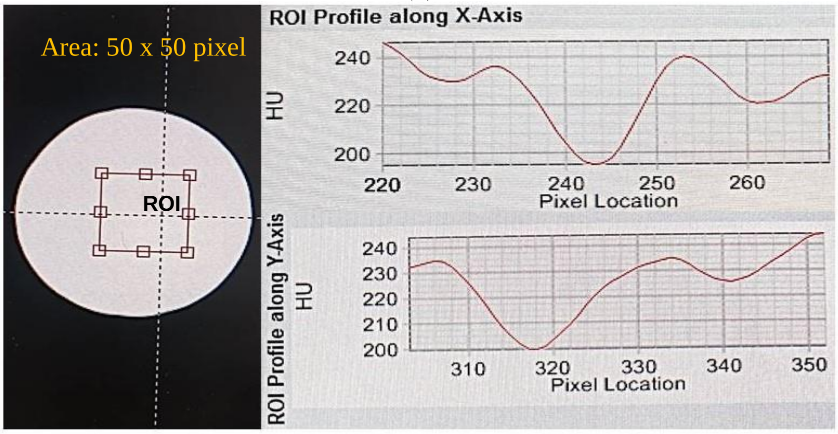
Figure 2. Phantom sample testing



(A)



(B)



(C)

Figure 3. Images of the sample of the addition (A) Without Glycerin , (B) 10% Glycerin and (C) 20% Glycerin

In Figure 3, the ROI locations for the 3 samples were at the center of 50×50 pixels area. The ROI for the sample without and with the addition of glycerin 10% and 20% resulted in the mean values of CT as 287.4, 280.5, and 225.2 HU, respectively (Table 1 and Figure 4). Some parameters of CT simulator output included slice thickness, exposure factor, and window width. The exposure parameters were tube voltage (kV) and tube current (mA)[14]. In the present study, the values related to the slice thickness of all samples, tube voltage, tube current were 1 mm, 120 kV, 50 mA, respectively.

Figure 5 shows the attenuation coefficient of the phantom and HVL value for the three samples. The attenuation coefficient values for no glycerin, glycerin 10%, and glycerin 20% were 0.239±0.001, 0.238±0.001, and 0.233 ± 0.001 cm^{-1}, respectively. The HVL values for no glycerin, glycerin 10%, and glycerin 20% were reported as 2.902±0.001, 2.911±0.001, and 2.980±0.001 cm, respectively.

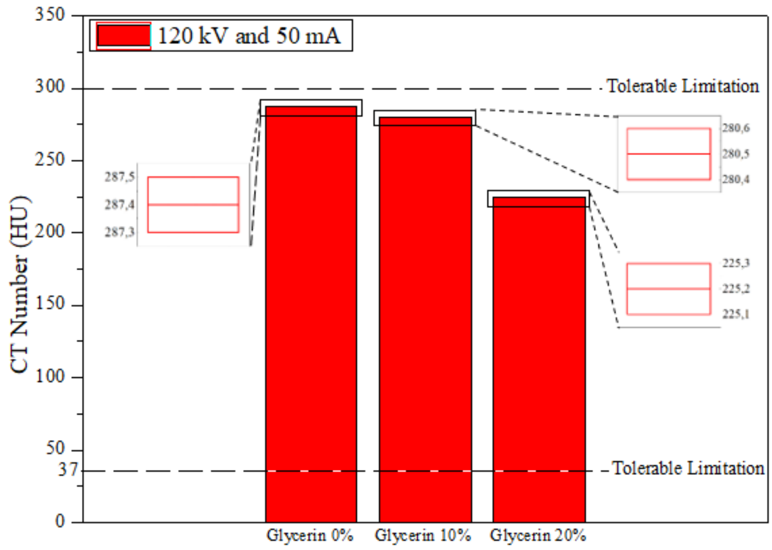


Figure 4. CT Number of mean for phantom samples

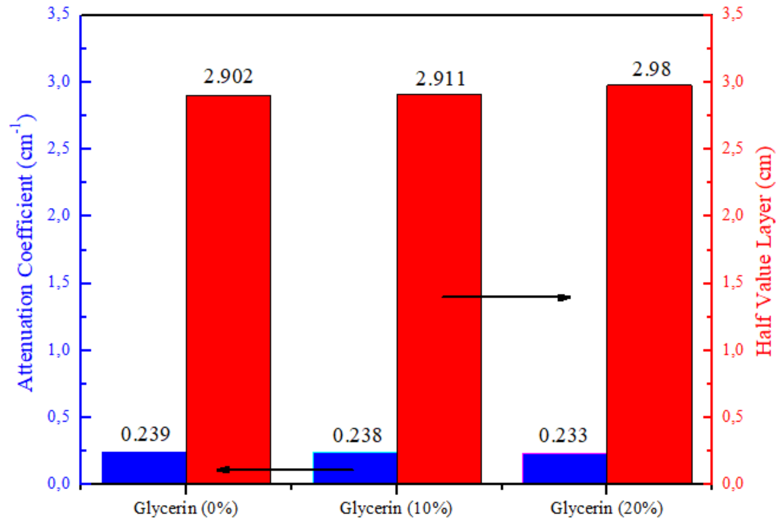


Figure 5. Calculation results of phantom attenuation coefficient and HVL values

Table 1. CT Number values for all samples

Samples	CT Number (HU)			Area (pixel)
	Min	Max	Mean	
Glycerin (0%)	211	311	287.4 ± 0.1	
Glycerin (10%)	189	303	280.5 ± 0.1	50 x 50
Glycerin (20%)	78	270	225.2 ± 0.1	

Discussion

Phantom is as a tissue surrogate used to measure radiation doses for radiotherapy studies and educational purposes since the patient's body cannot be used as an object of research. The basic material used in the current study was silicone rubber. Silicon is a polymeric material consisting of a chain of polysiloxane in the form of poly-dimethylsiloxane [17].

The type of silicone rubber and blue catalyst was RTV 52. The process of stirring RTV 52 (silicone rubber+catalyst) showed the presence of air bubbles [18] caused the pore as can be seen in the sample image Figure 3 (a). The sample without the glycerin revealed empty space (indicated by the hole and defect at the edge of the circle). Therefore, the addition of glycerin in the sample is expected to fill the air bubbles. In Figure 3 (b), the addition of glycerin 10% le to visible empty space in the sample (defect at the edge of the circle). As seen in Figure 3 (c), the phantom with glycerin 20% indicated that the defect space was covered suggesting this phantom as the best composition of the phantom. Regarding the CT number, the obtained values of phantoms with glycerin 10% and 20% were within the value range of the human's soft tissue (i.e., 37-300 HU) [14]. Figure 4 shows that the CT number decreased with the increase of glycerin in phantoms. On the other hand, the obtained values of CT number for the three samples were within the tolerance range.

The attenuation coefficient for the sample with glycerin 20% was estimated at 0.233±0.001 cm^{-1}, which was reported by King's et al as a suitable surrogated for the human liver (2011) [19]. Several studies also reported the attenuation coefficients of human liver as 0.203 cm^{-1} [12] and 0.199 cm^{-1} [20]. The attenuation coefficient was used as the input parameter in the calculation of the HVL by using Equation (2). The HVL values of the attenuation coefficient and HVL value in the current study are shown in Figure 5. The HVL is used to identify how deep the penetrating power of the X-rays inside the material is for the accuracy of the radiation dose received by the patient [21, 22]. As shown in Figure 5, the HVL value of the phantom with glycerin 20% confirmed the suitability of this sample as the replacement of the human liver in measuring radiation doses for radiotherapy studies and educational purposes.

Conclusion

Phantoms that have been synthesized from silicone rubber RTV 52 with the addition of glycerin 10% and 20% are suitable surrogates of the human liver in measuring radiation doses for radiotherapy studies and educational purposes. The CT number values measured in the sample without and with the addition of glycerin 10% and 20% were 287.4, 280.5, and 225.2 HU, respectively. The attenuation coefficient for the phantom with glycerin 20% was 0.233±0.001 cm^{-1} and the HVL value was 2.980±0.001 cm indicating it can be a good surrogate for the human liver. The investigated phantoms in the current study showed high potentials for replacing the human soft tissue in radiotherapy studies and educational purposes.

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