International urnal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 49 No. 1 February 2025, pp. 458-463

Innovative Silicone Rubber Bolus for Optimized Dose Modulation in X-Ray Applications

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Abstract— This research develops a bolus made of silicone rubber combined with tantalum nanoparticles to enhance dose modulation in X-ray applications. Silicone rubber was chosen for its flexibility and biocompatibility, while tantalum, with its high X-ray attenuation capability, improves dose accuracy. The bolus was tested using Digital Radiography, and its absorbed dose was measured with an X-ray multimeter. The results indicate that this combination has the potential to optimize dose distribution and improve the effectiveness of radiography, although further research is needed for more in-depth analysis.

Keywords—Bolus, Silicone Rubber, Tantalum, MultimeterX-ray.

I. Introduction

The use of bolus in radiotherapy and Radiodiagnostic plays an important role in ensuring the proper distribution of radiation dose on the surface or in uneven areas around it. A bolus acts as an additional absorption medium commonly placed on patient`s skin to determine the penetration of radiation, ensuring that the dose received by the target tissue matches the required dose. The use of bolus also presents excessive dose to surrounding tissues (1). The bolus resembles human soft tissue, helping reduce imaging artifacts and modulating the radiation dose to achieve more accurate diagnostic results (2). However, conventional bolus materials often have limitations, such as inflexible mechanical properties, inability to adapt to various patient anatomies, and low efficiency in absorbing and scattering radiation.

Silicone rubber has long been used as a bolus material due to its flexibility, biocompatibility, and ability to adapt to the patient`s body. Additionally, silicone rubber can be manufactured at room temperature and maintains its physical properties after irradiation, making it a reliable choice for medical applications, especially as a bolus (3). Adding tantalum nanoparticles to silicone rubber holds the potential to improve radiation dose modulation. Tantalum, with its high atomic number, has superior X-ray attenuation abilities, that can improve imaging contrast and accuracy, which is benefical for radiation therapy (4). A study by Hariyanto et al. created a bolus using propylene glycol, silicone rubber, and aluminum, which was found to enhance the surface dose percentage (5).

An innovative method for designing bolus is combining silicone rubber with tantalum nanoparticles, which can improve dose regulation in X-ray applications. The effectiveness of radiation therapy can be enhanced with this composite material's improved compatibility with the patients anatomy, increased X-ray attenuation, and optimal dose distribution. To accurately evaluate the clinical potential of this composite bolus, further investigation into its dosimetric and physical characteristics is required. This study creates a bolus using silicone rubber and tantalum nanoparticles, which will be tested using digital radiography machine, with absorbed doses measured using an X-ray multimeter.

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II. Experimental procedure

A. *Materials*

Silicone Rubber RTV 52, Tantalum Nanoparticle (Ta NPs) with 99% purity synthesized with Nd-YAG Laser device, Catalyst bluesil, Silicone oil, Mold, and X-ray Multimeter.

B. *Method to synthesis of bolus*

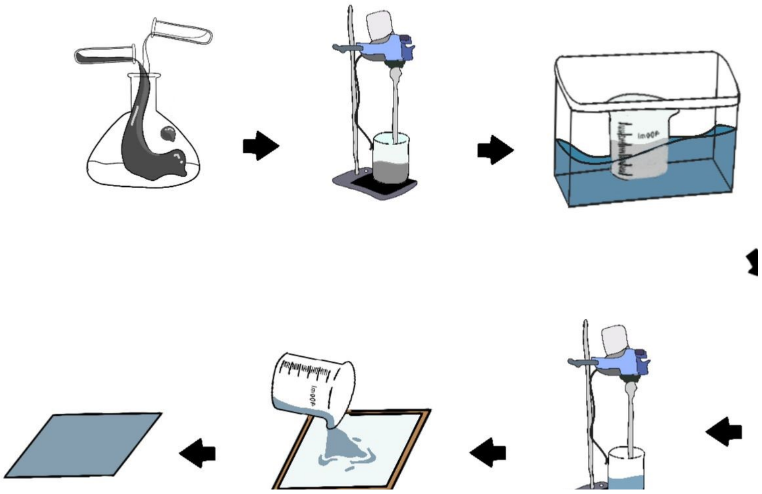

Figure 1. The bolus synthesis process

The bolus was synthesized from silicone rubber(SR) mixed with tantalum nanoparticle. The synthesis process is illustrated in Figure 1. A total of 160 ml of silicone rubber was mixed with 10 ml of tantalum nanoparticles, with varying exposure times of 20 minutes, 40 minutes, and 60 minutes. This was followed by a sonication process to ensure the homogeneity of the Sr-Ta mixture. After adding a catalyst equivalent to 2% of the total mixture of silicone rubber and tantalum nanoparticles, the Sr-Ta mixture was remixed and then poured into a mold with dimensions of 17x17x0.5 cm^3.

C. *Dose measurement*

The bolus dose was measured using digital radiography (Siemens Healthineers) with the assistance of an X-ray multimeter (Raysafe X2) to determine the bolus dose. The multimeter was placed at a premarked point, and the bolus was positioned on the detector, as shown in Figure 2.

Figure 2. Dose measurement set-up

The measurements performed on each bolus were identical, with a tube voltage of 85 kV, a current of 2 mAs, and a time of 6.5 seconds for each measurement.

III. Result and Discussion

Figure 3 shows the bolus synthesized using tantalum nanoparticles and silicone rubber. Figure 3a displays the bolus with a 60-minute exposure variation, Figure 3b shows the bolus with a 40-minute exposure variation, Figure 3c presents the bolus with a 20-minute exposure variation, and Figure 3d depicts the bolus without the nanoparticle mixture.

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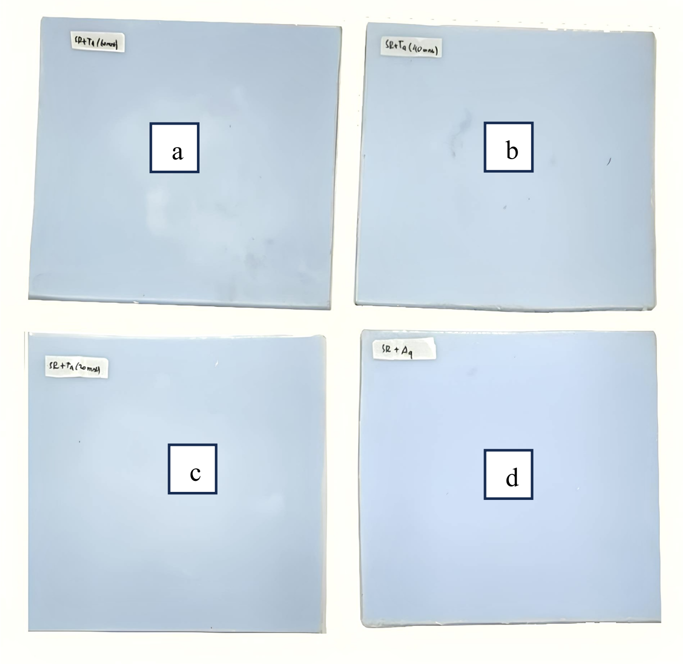

Figure 3. Bolus with variations in Nanotantalum exposure time

Figure 3 shows the synthesized bolus. There are no significant color changes observed in the bolus, but the bolus without the tantalum mixture appears slightly darker compared to the bolus with the nanotantalum mixture. The effect of the exposure time is demonstrated through further testing, specifically X-ray exposure testing. The results obtained can be seen in the table 1.

Table 1. dose measurement

Tube voltage (kV)	Materials	Dose (µGy)
85	SR+Aq	110.3
	SR+Ta 20 min	111.8
	SR+Ta 40 min	113.6
	SR+Ta 60 min	116.7

Table 1 explains that the dose changes in the bolus were measured with the same voltage value of 85 kV, resulting in different doses, with the highest dose being 116.7 µGy and the lowest dose being 110.3 µGy. This is interpreted in the graph below.

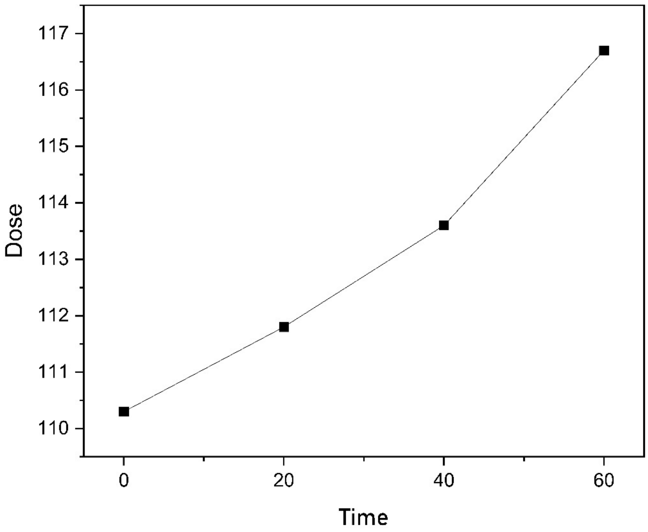

Figure 4. shows the graph of the relationship between synthesis duration and surface dose.

Figure 4 illustrates the graph of the relationship between time and the radiation dose of nanotantalum. The highest dose is 116.7 µGy when nanoparticle exposure lasts for 60 minutes, while the lowest dose is 110.3 µGy in the bolus without the addition of tantalum nanoparticles. The radiation dose increases as the exposure time increases. This dose change is related to the concept of attenuation, which describes the reduction in radiation intensity as it passes through a medium due to absorption and scattering. The addition of tantalum nanoparticles in the silicone rubber bolus enhances the efficiency of radiation dose modulation by increasing X-ray attenuation, absorbing radiation intensity, and reducing uneven dose distribution (6). The exposure time affects the amount of nanotantalum produced, so longer exposure times can spread more radiation, leading to a higher resulting dose. X-ray radiation passing through a material may undergo scattering; therefore, a higher concentration of nanoparticles increases the detected dose due to more scattered radiation being recorded by the detector (7).

The material used in this study is tantalum, which has a high atomic number of 73. This is because the properties and interaction mechanisms between X-rays and materials require a high atomic number and density, as such materials have a higher probability of interaction (8). The duration of radiation exposure can also increase the dose; therefore, the use of metal materials can significantly reduce the dose. Between the target and the source, materials with high density are considered more efficient in attenuating X-ray radiation (9). The tantalum nanoparticles in the bolus function to absorb the dose, ensuring that the measured dose is not too sharp and can be controlled.

IV. CONCLUSIONS

Bolus made from silicone rubber and a mixture of tantalum nanoparticles has been successfully synthesized and tested using an X-ray machine. The results show that the duration of the exposure time affects the absorbed dose. The longer the exposure time to the nanoparticles, the more radiation is absorbed, in accordance with the attenuation concept, where atoms interact more, making it highly effective for diagnostic imaging.

ACKNOWLEDGMENT

The author expresses gratitude to all members of the Laser Advance Nanoparticle(LAN) at Diponegoro University, and smart material research center (SMARC). as well as to Dr. Rini Safitri and Irhamni for her support and guidance, and to the staff of Prince Abdul Nayef Hospital.

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