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Evaluation of Elasticity, Dose Reduction, and Image Quality on Sr-Pb Shield for Thoracic CT Examination

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ABSTRACT

The performance of chest computed tomography (CT) always involved the scanning of breast since it was positioned within the scan range. It makes this organ always receives an amount of radiation that potentially harms the biological system. Many attempts have been performed to reduce the radiation doses objected to breast, including the utilization of radio-protective shield. This study aims to develop the radio-protector shield silicon rubber (SR) - Lead (Pb) based for the breast. The shield was developed with a thickness of 0.6 mm and SR:Pb ratios of 100:0, 98:2, 96:4, 94:6, and 92:8. After that, the shield was placed over an anthropomorphic phantom. The shield's reliability was tested in terms of elasticity, radiation dose, and image quality. The elasticity level of a material was indicated by Young's modulus yielded. Our results showed that the Young's modulus decreased as the percentage of Pb increased. Breast surface dose was measured using a Radcal ion chamber on the surface of the breast phantom. The measured dose was reduced as Pb increased, the dose using shielding at the highest percentage of 92:8 wt% is 8.71 mGy. The measured SNR without using shielding is 18.38, while the measured SNR using shield SR-Pb. SR-Pb shielding has a Young's modulus less than 0.035 GPa and can cover the chest of phantom well. SR-Pb shield was able to reduce the breast dose by 26% while the image quality in all variations of the SR:Pb ratio was above the rose criterion value with an insignificant decrease.

Keywords: Dose Reduction, Image Quality, Elasticity, SR-Pb Shielding

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I. INTRODUCTION

Computed Tomography (CT) examinations are performed 400 million times every year, worldwide. CT examinations produce 2560 man-Sv, which is approximately 62% of the total collective effective dose among other examinations [1]. The effective dose in thoracic CT examinations is 5-7 mSv, higher than conventional radiography ranging from 0.1-0.2 mSv [2]. Effective dose is a measure of the radiation dose received by the body organ, taking into account radiation hazards and patient-related factors [3]. Relatively high radiation doses in CT examinations can increase the risk of cancer in sensitive organs [4]. Sensitive organs to radiation in thoracic CT examinations include the lungs, heart, and breasts [5]. The breasts are highly sensitive to radiation because they consist of fatty tissue and glandular tissue. The glandular tissue in the breasts contains rapidly developing lobular cells (proliferation), making it more susceptible to radiation and increasing the risk of breast cancer [6]. In thoracic CT examinations, although the breasts are exposed to primary radiation, they might not be included as a focused organ. Therefore, it is important to optimize the radiation dose received by the breasts without compromising the image quality.

Efforts have been made to reduce radiation doses in the thoracic CT, such as by lowering the tube current [7-9]. This procedure can reduce the dose down to 10- 30% [7]. However, it should be noted that lowering tube currents can produce noisy images and it might disturb the diagnosis' performance [10]. Another effort to reduce organ dose is by applying the radiation shield [11, 12]. One of the preferred materials that often be used as a radiation shield is silicone rubber (SR) [11].

In previous study, Gede et al. [12] developed a SR based shield with a size of $10 \times 10 \times 0.5$ cm^3. SR is a type of polymer derived from polydimethylsiloxane (PDMS) and has characteristics such as radiation resistance, elasticity, and resistance to high temperatures [12]. A further study of SR shielding was conducted by Irdawati et al. [13]. The SR was added by the lead (Pb) to produce the SR-Pb shielding for protecting the eye during head CT examination. The results showed that the SR-Pb shield has an excellent capability to protect the eyes by reducing the radiation dose down to 50% and did not produce severe artifacts within the image even though it was placed directly on the organ's surface [13].

The implementation of SR-Pb for breasts has been studied in 2023 by Lestari et al. [14]. SR-Pb shields with various thicknesses were successfully developed to protect the breast in thoracic CT examinations. The results showed that the use of SR-Pb shielding effectively reduces the dose without showing a significant decrease in image quality. The limitation of that study [14], it only investigated the dose reduction for SR-Pb with single ration of 95%-SR and 5%-Pb. Effect of Pb percentage as a doping to SR on the breast dose and image quality has not been investigated. A further study is needed to observe the response of breast dose and image quality in various ratios of SR-Pb. This study aims to develop the SR-Pb shield with various ratios and evaluate its response against the breast dose and image quality.

II. METHODS AND MATERIAL

SR-Pb shields and breast phantoms were developed. The SR-Pb shields were tested on the in-house breast phantom positioned above the anthropomorphic phantom. Dose and image quality with and without SR-Pb shields were measured. Furthermore, the SR-Pb shields were evaluated for its elasticity by mechanical test.

A. Shield Synthesis

SR-Pb shield was fabricated using SR base material (RTV 52) mixed with Pb powder. The synthesis procedure is presented by Figure 1. The process was begun by putting 20 mL of distilled water and 30 g of Polyethylene Glycol powder into a measuring cup. After that, the mixture was stirred for 30 minutes until it was homogeneous. Pb powder was added to the mixture with variations of 0, 2, 4, 6, and 8% of the total weight. The PEG-Pb solution yielded was then mixed with SR until homogeneous for 30 minutes. The SR-Pb mixture was poured into a mold that had been smeared with silicone oil beforehand. The radiation shield produced has an area of 40 cm × 30 cm and a thickness of 0.6 cm. Finally, the blues catalyst as a hardener was added to the mixture and then mixed for approximately 3 minutes.

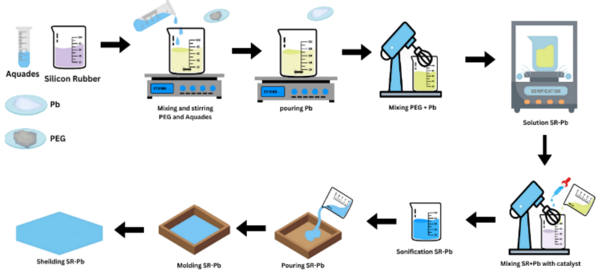

Figure 1. The synthesis procedure of SR-Pb shielding

B. Breast Phantom Fabrication

Breast phantoms were synthesized using the SR mixed with the *blues catalyst* at 2% of the total volume. The SR was used as the breast phantom material because SR has a density similar to the soft tissue [15]. The breast model has a medium size referred on the volume of bras commonly sale in the market (i.e. a size 42 bra), with a volume of 798 cc. The mold for making the SR-Pb shield was made from iron. The iron mold was chosen to provide the support of the necessary structure for the synthesized sample. The detailed steps can be seen on Figure 2.

C. Elasticity Test of SR-Pb *Shield*

Testing the elasticity of polymeric materials aims to assess their suitability for clinical use that must have sufficient flexibility to fit the irregular anatomical shape of the human body. The elasticity level of a material can be measured using the Young's modulus. Young's modulus is the ratio between the stress applied to the material and the strain produced due to the stress. The lower Young's modulus value means, that the material is more elastic and it will be better to be used as a shield [15, 16]. Young's modulus can be calculated using Hooke's law expressed in equation (1) [17, 18].

$$E = \frac{\sigma}{\varepsilon} \qquad (1)$$

Where E is Young's modulus (GPa), σ is stress (GPa), and ε is strain. Young's modulus properties were measured using a Universal Testing Machine (UTM) with a force loading of 50 kN by ASTM D 3039 standard. Figure 3 presents the sample model for elasticity testing.

D. Dose Measurement

The dose was measured using a 10 cm pencil-shaped ion chamber (model 10 x 6-3CT, Radcal, Radcal Corporation, Monrovia, California, USA) on a Siemens Somatom 128 slice CT scanner. The Radcal dosimeter was used to record the surface dose of the breast. The Radcal is chosen because its practical use since the measured dose can be directly observed on the electrometer connected to the detector [19].

For dose measurements, a breast phantom and anthropomorphic phantom were used. The anthropomorphic phantom was used since its contours highly represent the real patient's body, enhancing a more realistic examination. Measurements were performed by placing the ion chamber detector at the surface of the breast (at the 12 o'clock position), under the SR-Pb shield. The CT examination was performed using the scanning parameters tabulated in Table 1.

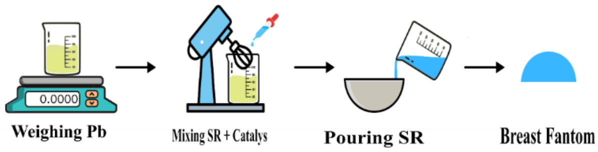

Figure 2. Breast phantom synthesis procedure.

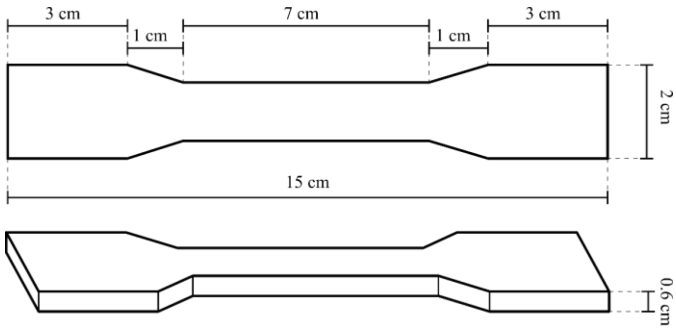

Figure 3. Specimen model for elasticity test on polymer gel material.

Table 1. Parameters of CT examination.

Parameter	Input
Imaging mode	CT *helical*
Projections	Anterior-Posterior (AP)
Tube voltage	120 kV
Tube current	110 mA
Slice thickness	5 mm
Pitch	1.2
Field of view (FOV)	347

E. Image Quality Test

Image quality was evaluated using a signal-to-noise ratio (SNR). SNR is measured by creating a region of interest (ROI) on the breast phantom image. The signal and noise were obtained in Hounsfield units (HU). Signal is the mean CT number within the ROI, while noise is the standard deviation of the CT number in the ROI. A higher SNR indicates a better image quality compared to the lower one. The SNR is calculated by Equation 2.

$$SNR = \frac{signal}{noise} \qquad (2)$$

III.RESULTS AND DISCUSSION

A. Elasticity

Young's modulus results for SR-Pb shielding with various Pb percentages can be seen in Figure 4. It shows that Young's modulus decreases as the Pb percentage increases, and the strain increases as the Pb percentage increases. The higher Pb percentage, it will become increasingly inelastic. The elasticity value increases from 0.14 N/mm^2 to 0.26 N/mm^2 as the percentage of Pb increases from 0% to 8%.

Young's modulus indicates the degree of stiffness of a material and strain percentage indicates the amount of deformation or shape change experienced by a material due to an applied force [20]. Our results show a similar trend to some previous studies [15, 19, 21]. The results of the current study indicate that the addition of Pb into SR has a significant effect on mechanical behavior, while the elongation at the break of the composite (strain) is slightly reduced by the addition of Pb percentage.

This phenomenon occurs due to the cross-linking interaction between Pb and SR as a matrix that limits the movement of polymer chains [22, 23]. The current study also produced shield characteristics with ideal polymer materials, indicated by young modulus values ranging from 0.035 to 0.050 GPa [16]. However, the result of shield synthesis using SR-Pb is 0.26 N/mm^2 or equivalent to 0.0026 GPa, which is below this criterion. This means that the synthesized shielding has a lower young modulus [20]. This indicates that the lower elasticity so, it can adapt better to the irregular contours of the patient. Therefore, the fabricated SR-Pb shields with various young modulus characteristics are suitable for use in clinical examinations.

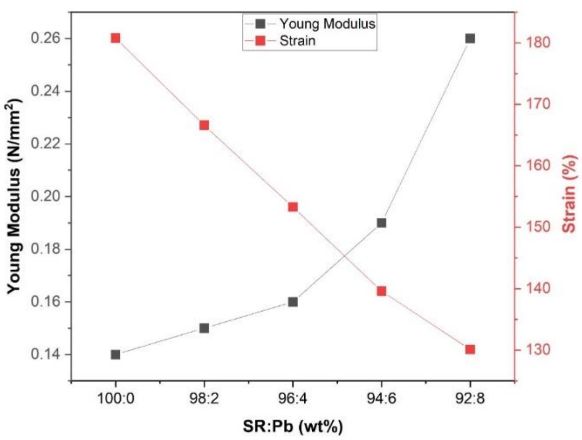

Figure 4. Young's modulus of SR-Pb shields at various percentages of Pb doping

B. Radiation Dose

Figure 5 shows the radiation dose without and with SR-Pb shields with various percentages of 100:0; 98:2, 96:4; 94:6, and 92:8 wt%. The radiation dose on the breast using an ion chamber showes a decrease along the increase of Pb percentage. The dose decreases with the increases of Pb percentage. Compared to without any shield, the highest dose reduction achieved from the highest Pb percentage 8%, which is 26.1%.

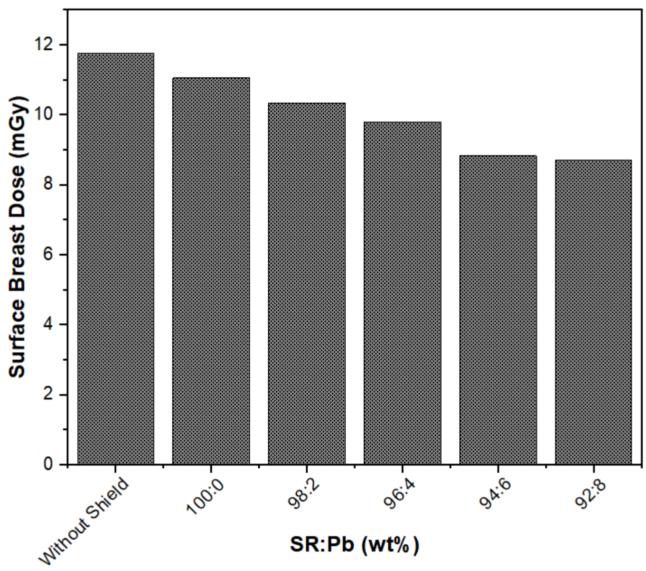

Figure 5. Breast surface dose at various percentages of Pb doping

The surface dose of breast was reduced as the Pb percentage increases. This is due to their high atomic number of Pb, Z = 82 [24], hence it has a large number of electrons in the atoms and lead the increase of density. This enhances a lack of space between atoms and molecules in the SR-Pb shield and leads an increase of X-rays interaction with the electrons, increasing the radiation uptake [25].

C. Image Quality

Figure 6 shows the SNR values in the breast region without and with SR-Pb shields with various percentages of 100:0; 98:2, 96:4; 94:6, and 92:8 wt%. The SNR tends to decrease as the percentage of Pb increases. The higher the SNR of an image, the better image quality is yielded. The use of SR-Pb shield can lead to a decrease of SNR value because Pb absorbs X-ray intensity and increases the image noise. However, the absorbed X-ray can reduce the radiation dose received by the patient. Therefore, it is important to ensure that the images have a good quality to diagnose the abnormalities of patients accurately.

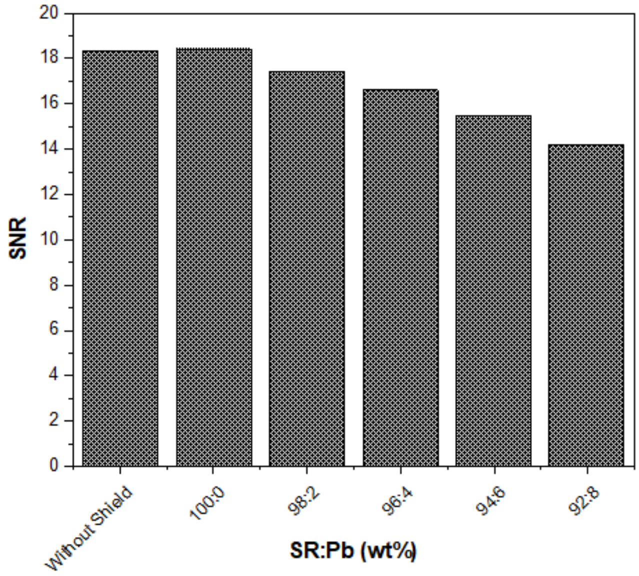

Figure 6. SNR against the variation of Pb percentage in SR-Pb shield

The highest SNR is found in the image without shield which is 18.38. While the smallest SNR is found in the image using SR-Pb shields with a percentage of 92:8 wt%. The decrease of SNR along the increasing percentage of Pb is highly correlated to the dose radiation received by the phantom. If the dose received by the phantom is reduce, then the image quality (SNR) will also inevitably decrease.

Although the graph shows a decrease of SNR, the difference of SNR between the shielded and unshielded phantom for all percentages of Pb was has a small difference of only 6%. The difference between the highest SNR shielding SR:Pb 100:0 and the lowest SR:Pb was 4.24. Therefore, it can be said that the use of SR-Pb shielding still produced a good image that can be used in CT examinations.

However, the effective as an effect of Pb doping on shielding cannot be observed yet. This is because the SNR at a percentage of 98:2 wt% was still high (SNR = 14) and exceeded the Rose criterion. Rose criterion states that a minimum SNR of 5 is required to detect a clinical image clearly [26]. Further study is needed by increasing the percentage of Pb to determine the optimal ratio between SR and Pb.

IV. CONCLUSION

SR-Pb shields with various Pb percentages have been successfully synthesized and investigated for breast dose reduction in the thoracic CT examnations. The SR-Pb shield percentage 8% has an elasticity level less than 0.035 GPa and provide a well coverage to chest surface of patient. The employment of SR-Pb shield percentage 8% is effective to reduce the radiation dose received by the breast up to 26%. The SNR of the images scanned with and without the SR-Pb shields with maximum percentage of 8% is 18.47 to 14.23. The study also noticed that the SNR with and without presented a small difference of only 6% decrease.

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