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Heri Sutanto <herisutanto@fisika.undip.ac.id>

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An artifact-free thyroid shield in CT examination: a phantom study

Heri Sutanto[1,*], Yulia Irdawati[1], Choirul Anam[1], Toshioh Fujibuchi[2], Geoff Dougherty[3], Eko Hidayanto[1], Zaenal Arifin[1], Johny Wahyuadi Soedarsono[4], Bahrudin[5]

[1] Department of Physics, Faculty of Sciences and Mathematics, Diponegoro University, Jl. Prof. Soedarto SH, Tembalang, Semarang 50275, Central Java, Indonesia

[2] Department of Health Sciences, Faculty of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-Ku, Fukuoka 812-8582, Japan

[3] Department of Applied Physics and Medical Imaging, California State University Channel Islands, Camarillo, CA 93012, USA

[4] Department of Metallurgical and Materials Engineering, University of Indonesia, Depok 16424, Indonesia

[5] Department of Chemical Engineering, University of Riau, Pekanbaru 28293, Indonesia

Corresponding author: herisutanto@live.undip.ac.id

Abstract

This study was to evaluate dose reduction and resulting image quality of a new synthetic thyroid shield based on silicon rubber (SR)–lead (Pb) composites and compare to tungsten paper (WP) and a Radibabarrier thyroid shields in CT examination of the neck. The synthetic SR-Pb thyroid shield had a Pb percentage from 0 to 5 wt% and a thickness of 0.6 cm. Scanning on the neck of an anthropomorphic phantom was performed with and without the SR-Pb, WP, and Radibarrier thyroid shields. The thyroid shields were placed directly on the neck surface. The thyroid dose was measured using radiophoto-luminescence (RPL) detectors. Image quality was characterized by consistency of the Hounsfield unit (HU) on the areas of anterior, posterior and lateral of the neck phantom. Detailed evaluation of the image quality was employed by image subtraction. It was found that the thyroid dose at the surface decreased with an increase of Pb percentage in the SR-Pb shield. The thyroid dose reduction was 34% for a Pb percentage of 5 wt%. The reduction of the dose using WP and Radibarrier were 36% and 67%, respectively. The dose reduction when using the WP and Radibarrier was higher than when using the SR-Pb 5 wt% thyroid shield. However the existence of artifact in the WP and the Radibarrier reduced the image quality, indicated by a significant change of HU, i.e. the increases of HU in the posterior area were 77% for the WP and 553% for the Radibarrier. The SR-Pb shield produced only a very small artifact, resulting in an increase of HU in the posterior area of only 9%. The SR-Pb shield is suitable in the daily clinical setting for thyroid dose reduction in CT examinations while maintaining image quality.

Introduction

Computed tomography (CT) provides excellent images for diagnosing patient abnormalities [1], however the dose received by radiosensitive organs, specifically to the superficial organs such as the thyroid, gonads, eye lens and breast, is a significant concern [2-12]. These organs are composed of radiosensitive cells and have a greater risk of developing cancer in the future [4, 6, 10, 11, 13-17]. Among the most frequent CT examinations are head, thorax, cervical spine and neck. In these CT examinations, the thyroid glands is often exposed to the primary beam and receives high dose [6-8,17,18]. The International Commission on Radiological Protection (ICRP) reported that the thyroid has a tissue weighting factor (W_T) of 0.04, meaning that the risk is very high [19, 20]. Therefore, it is crucial to reduce the dose received by the thyroid as much as possible while maintaining image quality [19, 20]. Dose optimization should be kept in mind because of the inverse relationship between good image quality and low radiation doses [4, 21-23].

A straightforward method to optimize thyroid dose and image quality in the CT examination is using a thyroid shield which is commercially available and is based on bismuth-latex [24]. Gbelcova et al. [25] reported that the reduction of dose by a thyroid shield is in the range from 23% to 35%. This agrees with other studies reporting thyroid dose reductions from 25 to 40% [18, 26, 27]. However, the main limitation of the bismuth shield is that it causes artifact in the image, especially in areas close to the thyroid shield, due to the x-ray transmissions that are supposed to contribute to the image which are absorbed by the material of the thyroid shield itself [10, 24, 28].

Currently, a common strategy to optimize the thyroid dose by automatic tube current modulation (ATCM) [29]. Hoang et al. [18] reported that by using ATCM, thyroid dose decreased by up to 29.5% and there was no significant degradation of image quality. The similar results were also reported elsewhere [18, 26, 27]. A combination of ATCM and thyroid shield will further increase a dose reduction. Inkoom et al. [28] reported that combination of both can increase the reduction of thyroid dose from 22.5% to 78%. However, many studied reported that a combination of both causes unpredictable dose result when thyroid shield is located before scanning of scout [20, 22]. The dose reduction is difficult to evaluate, because ATCM depends on the region scanned and patient body habitus and is affected by thyroid shield [21, 30-32]. Nowadays, the ATCM is commonly used in the most modern CT, however, it should be noted that not all CT scans are equipped with ATCM feature.

Correspondingly, based on these available strategies, thyroid shield remains the choice for CT scan that is not featured with ATCM or to be used as combination with ATCM. Most thyroid shields are made from Bismuth-latex, because of its high atomic number (Z = 83) and consequent high ability to absorb radiation [33]. To minimize the artifact of the resulting image caused by the thyroid shield, many studies recommend a spacer from 1 to 3 cm between the thyroid shield and the neck [6, 18, 34]. By adding distance, it was reported there is no significant change in HU values with and without thyroid shield. However, an addition of a spacer may be time-consuming and prolong examination time in the clinical practice. Therefore, efforts to develop a new thyroid shield that can effectively reduce doses while minimizing or even removing the artifacts need to be considered.

Recently Irdawati et al. [35] proposed a new material for superficial organ shield based on silicon rubber (SR) and lead (Pb). It was reported that the SR-Pb has a good ability as an eye shield with a dose reduction up to 50% without any artifact appearing in the image even though it is placed directly on the organ surface [35]. Although SR-Pb is a promising material as a superficial organ shield, it has not applied to any other organ other than the eye lens. The aim of this study, therefore, was to investigate the ability of a SR-Pb shield, placed directly on the neck surface, to reduce the dose to the thyroid during CT neck examination. We compared it to other thyroid shields such as Tungsten Paper (WP) and Radibarrier.

Materials and methods

Synthesis procedure of SR-Pb shield

The thyroid shield was synthesized from silicon rubber (SR-RTV52) and lead type lead (II) acetate trihydrate (Pb(CH3COO)2-3H2). There were many steps to synthesis the SR-Pb shield (Figure 1). The first step was pouring SR and Pb to beaker glass with different percentage of Pb from 0 to 5 wt%. Afterwards, it was then mixed for 30 minutes. To increase homogeneity of SR-Pb, sonication was carried out with an ultrasonic bath. The next step was the vulcanization process to accelerate the drying process of the thyroid shield. After the thyroid shield dries, it was ready to print the shield according to the shape of the neck.

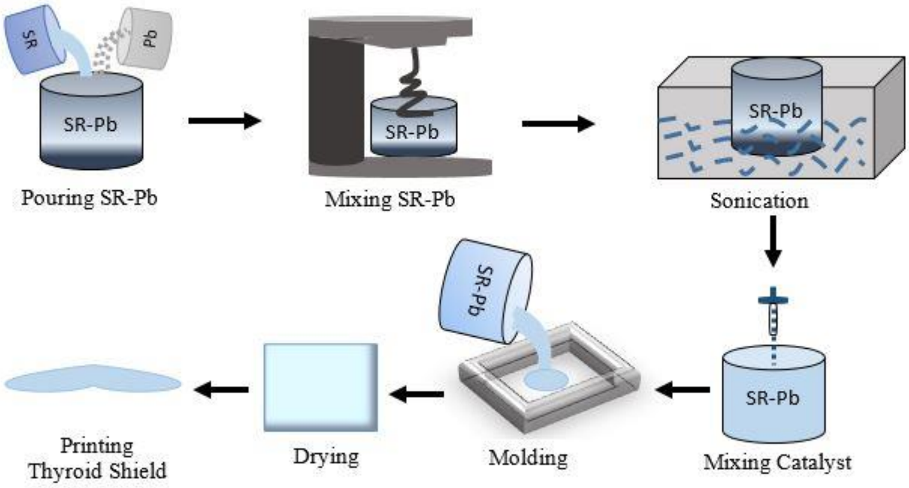

Figure 1. Synthesis procedure of SR-Pb thyroid shield.

Characterization of the SR-Pb shield

There are at least two important parameters of SR-Pb as an organ shield need to be characterized. Two characteristics of SR-Pb are effective atomic number (Z_{eff}) and elasticity. The Z_{eff} is most important parameters for tissue equivalence, radiation scattering, radiation absorption, and shielding effectiveness for X-ray radiation. The Z_{eff} of SR-Pb with different percentage of Pb from 0 to 5 wt% were calculated using Auto-Z_{eff} software version 1.7 [36]. The elasticity of the SR-Pb is also important due to its placement in irregular shape of the neck surface. For quantitative analysis, the elasticity of SR-Pb thyroid shield was measured by the value of the Young modulus and strain. The Young modulus is a measure of the stiffness of an elastic material, and the strain is the degree of change in the length of material for a given force.

Dose measurement

The dose received by thyroid with and without the SR-Pb thyroid shield was measured using Radiophoto-luminescence (RPL) glass detectors type GD-352M (Chiyoda Technol Corporation, Japan). The RPL detectors had a sensitivity range from 10 μGy to 10 Gy. Three RPLs were placed on the surface of the neck anthropomorphic phantom, as shown in Figure 2(a). The SR-Pb was shown in Figure 2(b). The SR-Pb shield was compared with Tungsten Paper (WP) (Toppan Printing and Kyoto University, Japan) (Figures 2(c)) and Radibarrier (Shin Etsu Chemical, Japan) (Figures 2(d)). The WP and Radibarrier have a thickness of 10 mm.

There were many steps in dose measurement using RPLs. After annealing at a temperature of 400^{o} C to remove the previous dose stored, the initial dose value before irradiation is read to determine the background dose. Following the irradiation process, the RPLs were pre-heated at 80^{o} C and read using the reader of Dose Ace type FDG-1000 (Chiyoda Technol Corporation, Japan). The scanning parameters were tabulated in Table 1. Each examination was repeated three times to verify the effect of the shield in reducing organ dose.

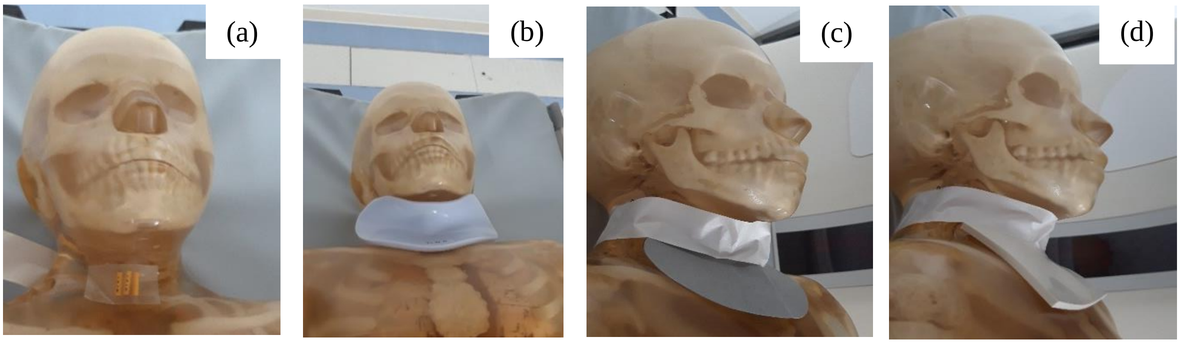

Figure 2. Placement of RPLs and thyroid shields. (a) 3 RPLs were placed on the surface of the neck phantom to measure doses received by the thyroid, (b) phantom with the SR-Pb thyroid shield, (c) phantom with Tungsten Paper (WP) sheet, and (d) phantom with the Radibarrier.

Table 1. The scanning parameters

Tube voltage	120 kVp
Tube current	150 mA
Time rotation	0.75 sec/rot
Slice thickness	5 mm
Field of view (FOV)	320 mm
Scan type	Helical
Pitch	1.375

Image quality evaluation

The image quality with and without thyroid shield was evaluated and compared. Image quality evaluation is based on the consistency of HU values. Larger HU values compared with the image without the thyroid shield were indicative of the presence of artifact in the image. For quantitative analysis, artifact in the image was evaluated with four circular region of interests (ROIs) at areas of the anterior (i.e. at the area of the thyroid), lateral soft tissue (i.e. right and left side) and at the posterior of the neck. The size of each ROI was 112.14 mm^2. Locations of the ROIs in the image are shown in Figure 3. For a detailed evaluation of image quality, image subtraction between images using a thyroid shield and without it was performed.

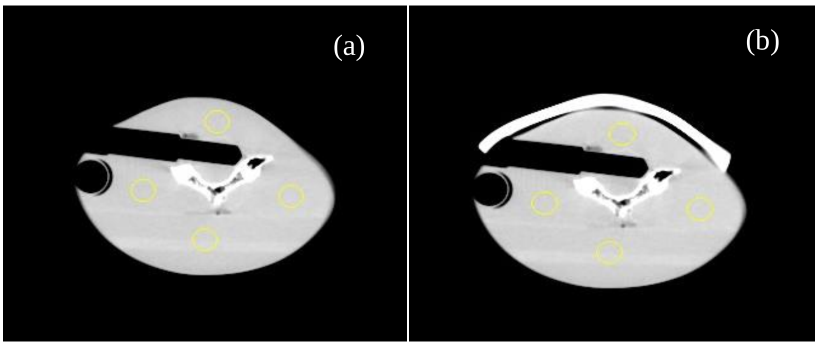

Figure 3. Locations of the ROIs to calculate HU values. (a) Without thyroid shield, and (b) With SR-Pb thyroid shield.

Results

Characteristics of the SR-Pb shield

Figure 4 shows the Z_{eff} of the SR-Pb as a function of photon energy for various Pb percentage from 0 up to 5 wt%. The Z_{eff} values were constant in the intermedium energy region (0.5-5 MeV) and in the very high energy (>100 MeV). A variation was observed in the lower energy (0.01-0.1 MeV) and in the

the high energy regions (5-100 MeV). It is found that the Z_{eff} values increased with an increase in Pb content in the SR-Pb as predicted.

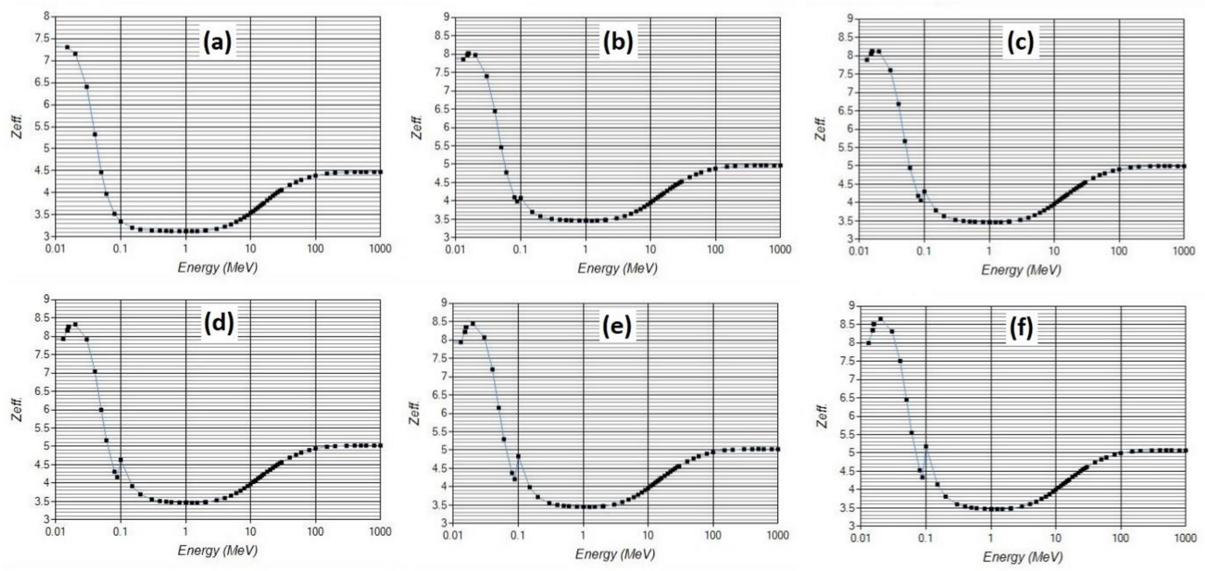

Figure 4. The Z_{eff} of the SR-Pb as a function of photon energy for various Pb percentage. (a) SR-Pb 0 wt%, (b) SR-Pb 1 wt%, (c) SR-Pb 2 wt%, (d) SR-Pb 3 wt%, (e) SR-Pb 4 wt%, and (f) SR-Pb 5 wt%

Figure 5 shows that the addition of Pb percentage caused an increase of Young modulus and a decrease of strain value. This happens because the level of deformation of the chain of SR molecules is limited by Pb and leads to increased stiffness and decreased change in the length of a material [37-39]. The thyroid shield with Pb 5 wt% has a value of the Young modulus and strain of 55.96 Pa and 62%, respectively. These values indicate that it still has sufficient elasticity to cover a non-flat organ such as the neck surface. Figure 2(b) shows visually the elasticity of the SR-Pb thyroid shields so that its placement in the throid area is very easy. This differs from Tungsten paper (WP) (Figures 2(c)) and the Radibarrier (Figures 2(d)), which do not have good elasticity and require tape to locate them in position on the thyroid area.

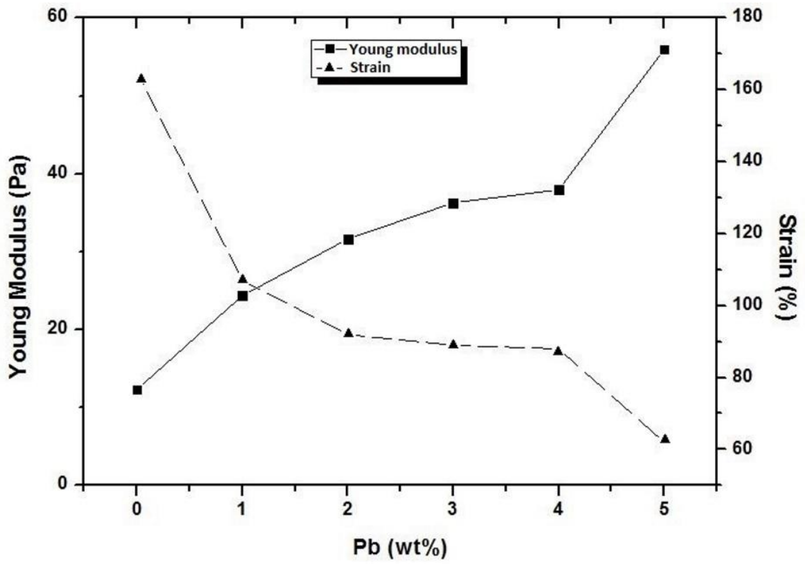

Figure 5. Yong modulus and strain of the SR-Pb thyroid shield for various Pb percentage from 0 up to 5 wt%.

Effect of thyroid shields on the dose reduction

The superficial dose at the thyroid during CT examination of the neck using SR-Pb thyroid shields with a Pb content from 0 to 5 wt%, and its comparison with the WP and the Radibarrier thyroid shields, can be seen in Figure 6. The dose without thyroid shield 69.855 ± 0.8 mGy, and the dose reductions with the SR-Pb thyroid shields with variation of Pb percentage of 0, 1, 2, 3, 4 and 5 wt% are 12%, 18%, 19%, 20%, 22% and 34%, respectively. It also shows that the Radibarrier has the greatest ability to reduce the dose to the thyroid, compared with SR-Pb and WP thyroid shields.

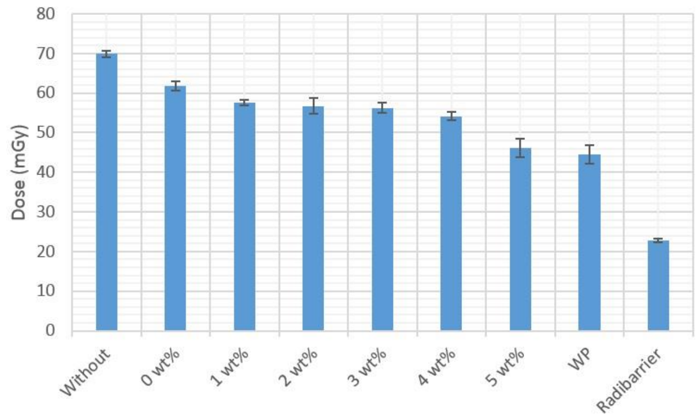

Figure 6. Thyroid dose in the CT examination of the neck, with and without thyroid shields.

Effect of thyroid shield on the image quality

Neck images with and without thyroid shields are shown in Figure 7. The resulting images using the SR-Pb thyroid shield do not reveal any artifacts in the thyroid (anterior area), lateral areas and posterior area, while the WP shield causes significant artifact in the anterior area, and minor artifact in the lateral and posterior areas. The Radibarrier provides severe artifact in all areas of the image (anterior, posterior and lateral).

The artifacts in the resulting image can be identified by increased HU values and its standard deviations in the anterior, lateral and posterior regions, tabulated in Table 2. The HU values of the SR-Pb increased slightly compared to those without the thyroid shield (8.8%), while the HU values in the anterior (thyroid area) of the WP and the Radibarrier increase significantly by up to 77.0% and 552.7%, respectively. Image quality using the SR-Pb shield was maintained, as evidenced by the SD values being similar to without the thyroid shield. WP and Radibarrier have higher difference SD values when compared with the image without a shield.

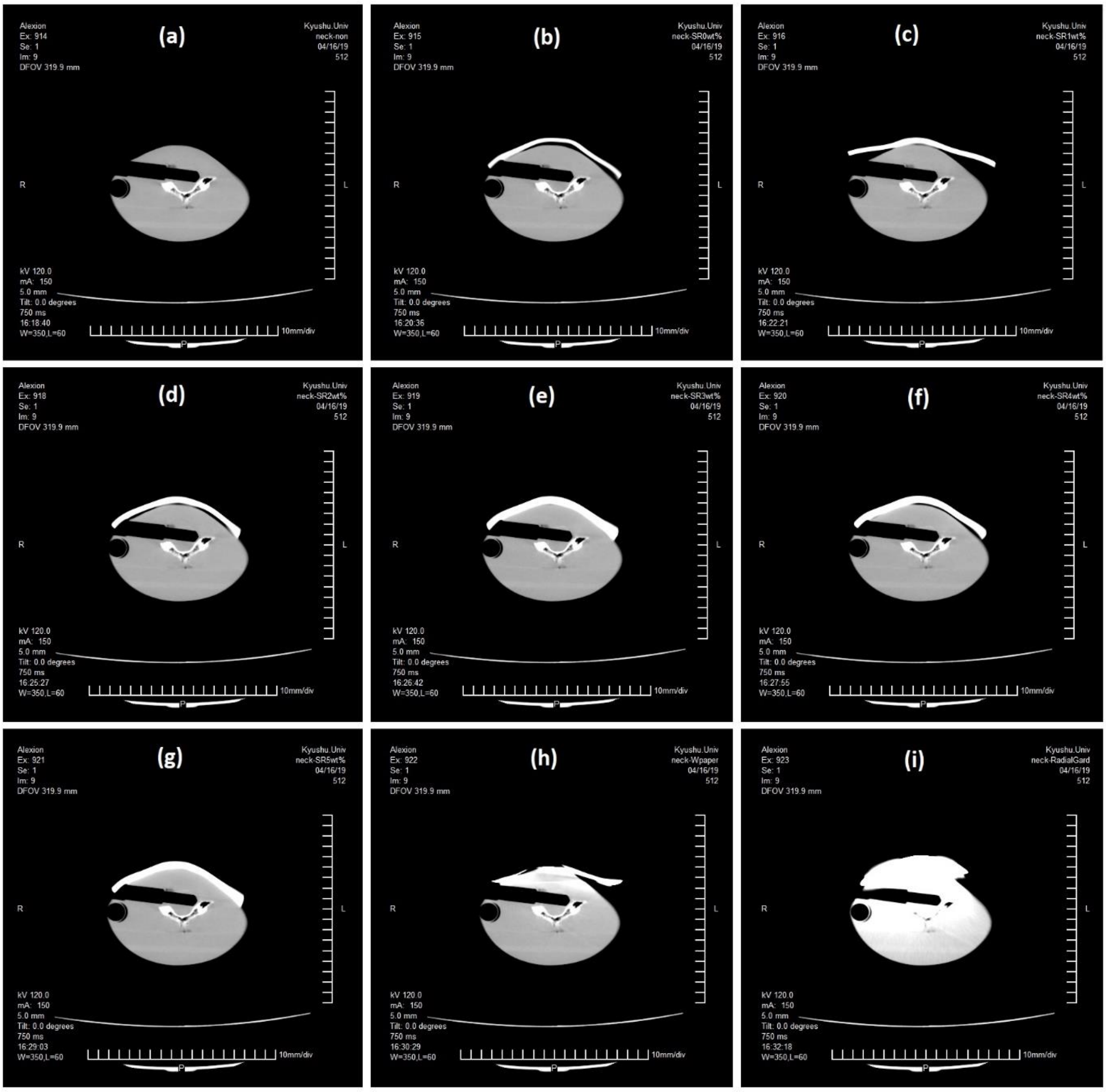

Figure 7. The resulting image of neck on the phantom with and without thyroid shield. (a) Without thyroid shield, (b) SR-Pb 0 wt%, (c) SR-Pb 1 wt%, (d) SR-Pb 2 wt%, (e) SR-Pb 3 wt%, (f) SR-Pb 4 wt%, (g) SR-Pb 5 wt%, (h) WP, and (i) Radibarrier. Window-width (W) is 350 and window-level (L) is 60.

Table 2. HU values and standard deviation of various thyroid shields in four ROI locations.

Thyroid shield	**Area (mm^2)**	**Anterior**		**Lateral**				**Posterior**	
				Right side		**Left side**			
		HU	**SD**	**HU**	**SD**	**HU**	**SD**	**HU**	**SD**
Without	112.14	119.25	2.41	125.30	2.19	125.30	2.29	126.39	3.62
SR-Pb 0 wt%	112.14	120.04	2.60	126.26	1.88	119.16	2.59	126.51	4.03
SR-Pb 1 wt%	112.14	125.37	2.83	121.21	2.27	123.74	2.37	126.73	4.35
SR-Pb 2 wt%	112.14	123.73	3.12	127.71	2.07	120.97	2.85	126.25	3.91
SR-Pb 3 wt%	112.14	126.69	3.32	128.98	2.45	120.67	2.69	127.59	3.87
SR-Pb 4 wt%	112.14	128.84	3.20	129.15	2.30	120.71	2.64	127.71	3.60
SR-Pb 5 wt%	112.14	129.78	4.17	128.62	2.33	122.58	2.69	127.74	3.95
WP	112.14	211.05	19.42	143.98	3.09	133.34	3.39	135.30	3.64
Radibarrier	112.14	778.39	148.69	215.36	8.29	296.51	18.15	202.38	6.67

To ensure that the SR-Pb thyroid shield does not cause artifact in the resulting image, a detailed evaluation using subtraction image between the image with and without thyroid shield was conducted. The subtraction images are shown in Figure 8. This shows that using the SR-Pb with various percentages of Pb from 0-5 wt%, the resulting image can be maintained for diagnostic purposes because there is only a small artifact. Conversely, WP and the Radibarrier cannot be used for diagnostic purposes because both cause severe artifact in the image.

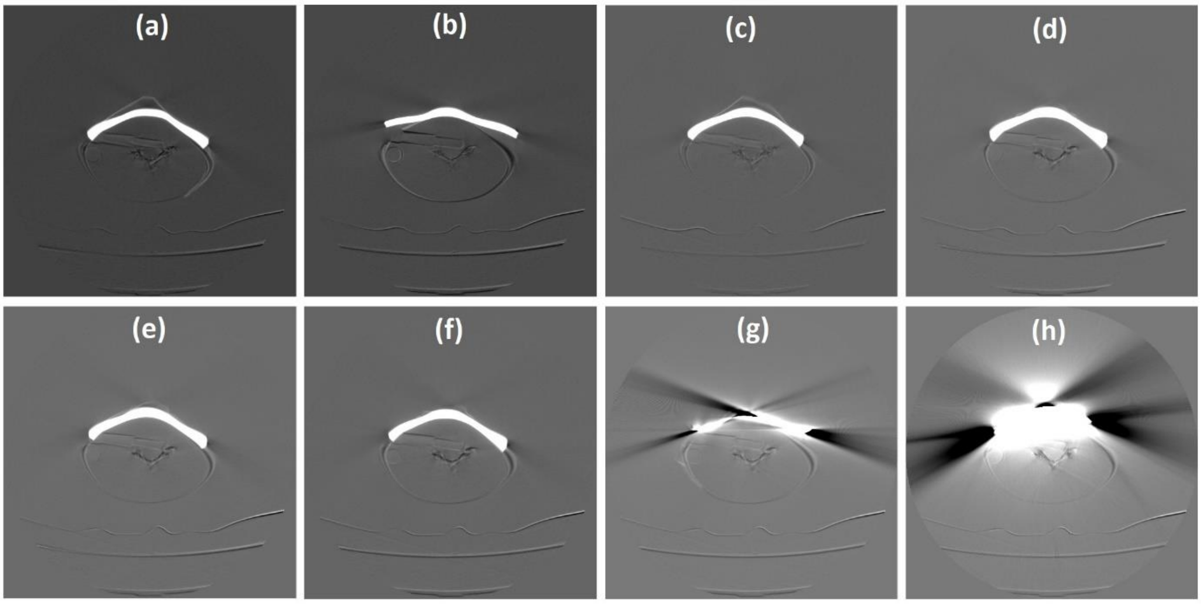

Figure 8. Images of the image subtraction between with and without thyroid shields. (a) SR-Pb 0 wt%, (b) SR-Pb 1 wt%, (c) SR-Pb 2 wt%, (d) SR-Pb 3 wt%, (e) SR-Pb 4 wt%, (f) SR-Pb 5 wt%, (g) WP, and (h) Radibarrier. Window-width (W) is 600 and window-level (L) is 16.

Discussion

One straightforward method to reduce the surface dose on CT examination, including the dose on the surface of the thyroid, is to use an organ shield. The main problem with the use of organ shields is the appearance of artifacts in the image that can interfere with diagnosis [24-28]. In the hope of avoiding artifact, a previous study developed a new material for an organ shield from SR material mixed with variation percentages of Pb from 0 to 5 wt% [35]. Increasing the Pb content leads to an increase in the dose reduction of the surface of aye lens. The addition of Pb 5 wt% in the SR-Pb shield can reduce the eye dose up to 50% [35]. Dose reduction in the thyroid (34%) is smaller than in the eye lens likely because the SR-Pb shield protects from many sides (i.e. above, right and left sides), while in the thyroid, the SR-Pb shield protects radiation only from above. A better design of the thyroid shield may be able increase dose reduction.

The use of a SR-Pb shield has only a slight impact on the resulting image. The quality of the image is maintained for diagnostic proposes, even though the SR-Pb thyroid shield is in contact with the surface of the organ, i.e. thyroid or eye lens.

The WP and Radibarrier shields reduce thyroid dose by more than the SR-Pb shield, viz. 36% and 67%, respectively. However the resulting images suffer severe artifacts which can lead to mis-diagnosis in the anterior, posterior and lateral areas. Radiation absorption depends on the atomic number (Z) of material, with higher atomic number material having a greater ability to absorb radiation [33, 39]. Tungsten (W) has a Z value of 71 and its percentage in the WP shield is about 80%, while the Radibarrier has a lead equivalent of 1.1 mm, where lead has a Z value of 82. Unfortunately both cause significant artifacts and noise in the resulting image. In the SR-Pb shield, the Pb content is low (0-5 wt%) so that the Pb is distributed uniformly in the SR-Pb sheet, hence artifact can be avoided.

The protection of thyroid gland is crucial because the thyroid is one of the most radiosensitive organs and is vulnerable to stochastic effects such as cancer. Based on our results, the SR-Pb thyroid shield may be recommended in the CT examination of the neck replacing the bismuth thyroid shield. Even though the reduction dose of SR-Pb is smaller than bismuth shield, it is preferred because artifact is almost non-existent in the SR-Pb.

The SR-Pb thyroid shield is non-toxic, so it is safe to use. Another advantage is its elasticity, so it is easy to use, easily positioned and removed, and has sufficient flexibility to cover an organ. It is not time-consuming to use, and therefore dose reduction does not prolong examination time. It is light –weight so that patients will feel comfortable when using it. It may also reduce the patient's anxiety about the impact of radiation, because the patient is aware that he/she is protected.

The limitations of this study are that validation was only performed on a phantom, with a single size representing an average-size patient not pediatric or obese patient, and the image quality was evaluated quantitatively without observation by expert radiologists. A further study on SR-Pb thyroid shield with a possible combination of the ATCM might be more challenging. In the CT examination equipped with ATCM, the SR-Pb placement before the scout might change the current in the ATCM, so that in clinical applications, SR-Pb should be placed after scout image is obtained.

Conclusions

The thyroid shield made from SR-Pb has been successfully synthesized and validated. The use of the SR-Pb thyroid shield can reduce thyroid dose. The reduction in dose increases with the increasing percentage of Pb. In SR-Pb 5 wt% the decreasing in dose was 34% compared with having no thyroid shield. The resulting image is of high quality withouth artifact even at higher percentage of Pb so that it can be used without mis-diagnosis. The SR-Pb thyroid shield is very practical because it can be placed directly above the surface of the thyroid, and is sufficiently flexible to cover the thyroid. Hence, we recommend its adoption for clinical CT neck examinations.

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BPEX-101752
An artifact-free thyroid shield in CT examination: a phantom study

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Referee: 1

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AUTHORS GENERAL RESPONSES:

Thank you very much for your valuable comments and suggestions. We have revised the manuscript accordingly and have carefully proof-read the manuscript.

SPECIFIC RESPONSES:

1. We have changed the statement "the reduction thyroid shield is in range from 23% to 35%" to "the reduction of dose by thyroid shield is in range from 23% to 35%". Please see the revised manuscript, page 2, line 49.
2. We have changed "because ATCM depending on ..." to "because ATCM depends on..." as suggested. Please see the revised manuscript, page 2, line 61.
3. We have made a new section in the Method, i.e., “Characterization of the SR-Pb Shield”. This section explains the elasticity and the effective atomic number (Zeff) of the SR-Pb section. Please see the revised manuscript, page 3, lines 41-100.
4. We have moved the description about the elasticity of the SR-Pb in Result part to a new section in the Method. Please see also the 4th point. Please see the revised manuscript, page 3, lines 41-100.
5. We have used two different markers to differentiate the two datasets in Fig 5. Note: We have added a new figure (Figure 4), therefore the Figure 4 becomes Figure 5. Please see the revised manuscript, page 5, lines 152.
6. Thank you very much for your useful suggestion. However, it is difficult for us to do. We measure Young modulus in one laboratory in Indonesia, while the two shields (WP and Radibarrier) are in Japan.
7. We have erased this statement due to it does not support our finding. Please see the revised manuscript.
8. We have added an information of the window-width (W) and window-level (L) in the figure. All images have the same W and L. The W is 350 and L is 60. Please see the new Figure 7 and its caption in the revised manuscript, page 7, lines 175-177.
9. We have added an information of the window-width (W) and window-level (L) in the figure. All images have the same W and L. The W is 600 and L is 16. Please see the new Fig 8 and its caption in the revised manuscript, page 8, lines 184-185.
10. We have calculated the Zeff of SR-Pb and we have included in the particular section in Method and Results. We have also added one figure on Zeff of SR-Pb. Please see the revised manuscript, page 3, lines 41-100 and page 4 line 133 to page 4 line 141.
11. We have re-phrased the paragraph accordingly. “Tungsten (W) has a Z value of 71 and its percentage in the WP shield is about 80%, while the Radibarrier has a lead equivalent of 1.1 mm, where the lead has Z value of 82. Unfortunately, both cause significant artifacts and noise in the resulting image. In the SR-Pb shield, the Pb content is (0-5 wt%) so that the Pb is distributed uniformly in the SR-Pb sheet, hence artifact can be avoided.”. Please see the revised manuscript, page 8 line 205 to page 9 line 208.
12. We have re-phrased the paragraph accordingly. “The protection of thyroid gland is crucial because the thyroid is one of the most radiosensitive organs and is vulnerable to stochastic effects such as cancer. Based on our results, the SR-Pb thyroid shield may be recommended in the CT examination of the neck replacing the bismuth thyroid shield. Even though the reduction dose of SR-Pb is smaller than bismuth shield, it is preferred because artifact is almost non-existent in the SR-Pb”. Please see the revised manuscript, page 9 lines 209-2013.

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Body: Dear Dr Sutanto,

Re: "An artifact-free thyroid shield in CT examination: a phantom study" by Sutanto, Heri; Irdawati, Yulia; Anam, Choirul; Hidayanto, Eko; Arifin, Zaenal; Fujibuchi, Toshioh; Dougherty, Geoff; Soedarsono, Johni; Bahruddin, Bahruddin
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ACCEPTED MANUSCRIPT

An artifact-free thyroid shield in CT examination: a phantom study

Heri Sutanto[1], Yulia Irdawati[2], Choirul Anam[3], Toshioh Fujibuchi[4], Geoff Dougherty[5], Eko Hidayanto[6], Zaenal Arifin[7], Johni Wahyuadi Soedarsono[8] and Bahruddin .[9]

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herisutanto@live.undip.ac.id

[1] Physics, Universitas Diponegoro, Jl. Prof.SOedarto, SH-Tembalang, Semarang, 50275, INDONESIA

[2] Diponegoro University Faculty of Science and Mathematics, Semarang, Jawa Tengah, INDONESIA

[3] Department of Physics, Universitas Diponegoro, Jl. Prof Soedarto, Tembalang, Jl. Prof Soedarto, Tembalang, Semarang, Central Java, 50275, INDONESIA

[4] Department of Health Sciences, Faculty of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka, Fukuoka 812-8582, Japan, Fukuoka, JAPAN

[5] Applied Physics and Medical Imaging, California State University Channel Islands, Camarillo, CA 93012, USA., Camarillo, California, UNITED STATES

[6] Physics, Universitas Diponegoro, Semarang, Jawa Tengah, INDONESIA

[7] Physics, Diponegoro University Faculty of Science and Mathematics, Semarang, Jawa Tengah, INDONESIA

[8] Department of Metallurgical and Materials Engineering, University of Indonesia, Depok, Jawa Barat, INDONESIA

[9] Chemical Engineering, Riau University, Pekanbaru, Riau, INDONESIA

Heri Sutanto https://orcid.org/0000-0003-3404-0337

Choirul Anam https://orcid.org/0000-0003-0156-6797

Eko Hidayanto https://orcid.org/0000-0002-3438-0369

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Abstract

Synthetic thyroid shields based on silicon rubber (SR)–lead (Pb) composites was evaluated and compared to a tungsten paper (WP) and a radibarrier thyroid shields in CT examination of the neck. Reduction of thyroid doses and the resulting image qualities were assessed in this study. The SR-Pb thyroid shield with a variation percentage of Pb from 0 to 5 wt% has a thickness of 0.6 cm. Scanning on the neck of an anthropomorphic phantom was performed with and without the SR-Pb, WP, and radibarrier thyroid shields. The thyroid shields were placed directly on the neck surface. The thyroid dose was measured using radio photo-luminescence (RPL) detectors. The image quality was characterized by consistency of the Hounsfield unit (HU) values and its standard deviation on the areas of anterior, posterior and lateral of the neck phantom. Detail evaluation of the image quality was employed by image subtraction. It is found that surface of thyroid dose decrease with the increase of Pb pecentage in the SR-Pb shield. The thyroid dose reduction is 34% for Pb percentage of 5 wt%. The reduction of thyroid dose using WP and radibarrier are 36% and 67%, respectively. It is clear that the thyroid dose reduction when using the WP and radibarrier is higher than when using SR-Pb 5 wt% thyroid shield. However the existence of artifact in the WP and the radibarrier deteriorates the image quality, indicated by a significant change of HU value, i.e. the increases of HU in posterior area are 77% for the WP and 553% for the radibarrier, while using the SR-Pb shield the resulting image has very light artifact, marked by only small increase of the HU value before and after using SR-Pb shield, i.e. the increase of HU in the posterior area is only 9%.