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The Feasibility of Tube Current Modulation (TCM) to Reduce dose of the Surface Breast in Various Breast Sizes

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ABSTRACT

This study aims to develop three sizes of breast phantoms from silicone rubber (SR) material and evaluate tube current modulation (TCM) to reduce surface doses of the developed breast phantoms. The in-house breast phantom has three sizes: small (cup 34), medium (cup 36), and large (cup 38). The cross-sectional areas of cup 34, 36, and 38 are 78.5, 113.04, and 153.87 cm2, respectively. The in-house phantom was attached to the adult anthropomorphic phantom for dose measurement. Dose measurement was performed using an Optically Stimulated Luminescence (OSL) dosimeter. Scans were performed with and without TCM technique. It was found that the TCM effectively reduce the radiation dose to the breast surface up to approximately 60%. However, the dose reduction was accompanied by a 66% increase in noise when using the TCM technique.
Keywords : Computed Tomography, Breast Surface Dose, Noise, Breast Phantom.

I. INTRODUCTION

Computed tomography (CT) scans are widely used in healthcare systems because of their excellent diagnostic capabilities and short scan times [1]. However, CT scans deliver more radiation doses to patients than other medical imaging devices. The International Atomic Energy Agency (IAEA) reported that CT scans are used in approximately 25% of all radiological examinations and account for about 60-70% of the total radiation dose [2]. It is essential to highlight that the radiation dose received by patients imposes a risk of the incidence of cancer in the population [3]. This risk is mainly in radiosensitive organs such as the thyroid, gonads, and breast [4-6]. The study by Guerra et al. [7] found that the use of CT thorax increased the risk of breast cancer incidence up to 3% per additional exposure (berikut kalimatnya: Chest X-ray exposure doubled breast cancer (BC) risk. A 3% increased BC risk per additional exposure was observed. Being 20 years old or younger at first exposure or being exposed before first full-term pregnancy did not seem to modify this risk. Birth after 1960 or carrying a rare likely deleterious coding variant in a DNA repair gene other than BRCA1/2 modified the effect of chest X-ray exposure). Therefore, dose reduction efforts must be taken to achieve the As Low as Reasonably Achievable (ALARA) principle [8]. One widely used method to achieve this goal is by implementing tube current modulation (TCM). TCM continuously adjusts the tube current to the specific size and shape of the patient so that the dose received by the patient remains low, but the resulting image quality is not compromised [9]. The effectiveness of TCM in reducing breast dose has been reported by several investigators [10-13]. The study by Vollmar et al. [14] reported that using TCM to reduce the breast dose is up to 11.3% without deteriorating the image quality. However, this study investigated a breast size that is simulated with a water-filled bag, so it cannot represent breasts that are mostly fat [15]. In addition, the larger breast size, the lower dose will be received [16]. Therefore, the development of breast phantoms made of materials other than water is needed to simulate the dose received by the breast in real life [17]. Many breast phantoms have been developed from various materials, including polystyrene, bulk materials, water, gelatin, silicone, and polyvinyl [18]. However, these materials do not have a long shelf life and are challenging to mold [19]. A material that has more extended durability and is easy to mold in the manufacturing process is silicone rubber (SR) [20]. A previous study by Lestari et al. [21] reported that the SR-breast phantom can be used to investigate the dose received by the breast. However, the previous study [22] was only conducted with one breast size. Therefore, it is essential to develop breast phantoms from SR of different sizes and evaluate the dose reduction by implementing TCM for dose optimization on the developed phantoms. This study aims to develop three sizes of breast phantoms from SR material and evaluate the TCM to reduce the dose on the developed breast phantoms.

II. METHODS AND MATERIAL

Anthropomorphic and Breast Phantoms

In this study, an anthropomorphic phantom, a Kyoto Kagaku PBU-50 semi-transparent, was used. This phantom represents an adult human body with a height of 178 cm and mass of 73.5 kg. To simulate the female breast tissue phantom, the in-house phantoms were made from SR (RTV 52). The breast size in this study was determined by conducting the measurement to the bras in the market. Study from Li et al. [23] reported that the average breast size of Chinese women was 75B or a bra size of 34. Since the breast size of South East Asian women was slightly bigger rather than the Chinese women [24], we varied the bras by the size of 34 for the small breast, 36 for the medium breast, 38 for the large breast. We bought the bras in Indonesian market and measured the bras manually. Bra 34 has a volume of 150 cc, while the 36 and bra had a volume of 250 and 350 cc, respectively. The aluminum-based mold was created referred to the measured volume. The synthesis was carried out by mixing the SR solution with 2% bluesil catalyst. The solvent was stirred ± 5 minutes until they were well-mixed. The mixture was poured into the breast mold coated with silicone oil and was dried thoroughly at 20-25°C (1 × 24 hours). The in-house breast phantoms were then placed on the chest of an anthropomorphic phantom to investigate the TCM technique. Radiation dose measurements were performed using the NanoDot of the Optically Stimulated Luminescence Dosimeter (OSLD) [25] positioned at the right and left breast nipples, as shown in Figure 1(b). The NanoDot of OSLD is a passive detector made of highly sensitive alumina with minimum and maximum absorbed detection limits of 0.05 mGy and 10 Gy [26]. The chips were packaged in a plastic container with dimensions of 10 mm × 10 mm × 2 mm. Before measurement, all OSLDs were calibrated at the National Research and Innovation Agency (BRIN). The dose measurement is depicted in Figure 1(c). Background values were obtained from unexposed OSLD. The OSLD reading was performed by the National Research and Innovation Agency of Indonesia (BRIN) using Equation (1). The PMT counts referred an average of the OSLD response, while the sensitivity and the calibration factor (CF) was the batch sensitivity and the calibration factor of OSLD under the measurement condition, respectively. The sensitivity of the OSLD was 0.87, while the CF was 0.45.

$$Reading\ dose\ (mGy) = \frac{PMT\ Caount}{Sensitivity\ x\ CF} \quad (1)$$

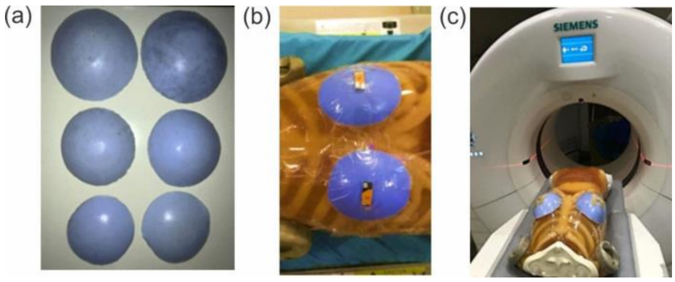

Fig 1. Photographs of (a) in-house breast phantoms of three sizes, (b) position of the NanoDot OSLD on the breast nipple, and (c) position of the phantom on the CT table.

The phantoms were scanned with a Siemens Somatom Definition Flash 160 Slice CT scanner. The scan was performed with a tube voltage of 120 kV, rotation time of 0.35 s, slice thickness of 5.0 mm, field of view (FOV) of 311 mm, axial scan type, and two imaging techniques (TCM and non-TCM). The TCM technique automatically modulates the tube current at each position of the z-axis (longitudinal modulation component) and projection angles (angular modulation) [22]. The tube current for non-TCM was set at 200 mA. All images were stored in Digital Imaging and Communications in Medicine (DICOM) format and analyzed further.

Noise Measurement

The image quality evaluation of the examinations with and without TCM was quantitatively assessed by measuring CT number and image noise using a MicroDicom viewer (MicroDicom Ltd, Sofia, Bulgaria). The images from CT examinations with and without TCM were compared to identify the presence of artifacts in the images. The images were evaluated by placing two regions of interest (ROIs) in the right and left breast. The size of each ROI was 70.04 mm² [21]. The locations of the ROIs in the image are shown in Figure 2.

Fig 2. Region of interest (ROI) position for image quality analysis on a breast phantom with a cross-sectional area of 70.04 mm²

III. RESULTS AND DISCUSSION

Figure 3 shows axial images of in-house breast phantoms resulted from CT without activating TCM (first row) (a-c) and with activating TCM (second row) (d-e). Small breasts are at first column (a and d), medium breasts are at second column (b and e), and large breasts are at third column (c and f). Visually, no significant image difference between images resulted from CT with and without TCM. Figure 4 shows the radiation dose measured with and without TCM at three breast sizes: small, medium, and large breasts. The breast dose at the nipple position with TCM is smaller than without TCM at all breast sizes. In the scan without TCM, it can be obtained that as the volume of the breast phantom increases, the average surface dose of the right and left breasts increases by technique reduced the dose from 57-63% compared to non-TCM. Dose reduction of this study is higher compared to the results of previous studies [27] which showed a dose reduction in the use of TCM techniques is 35.2% [27].

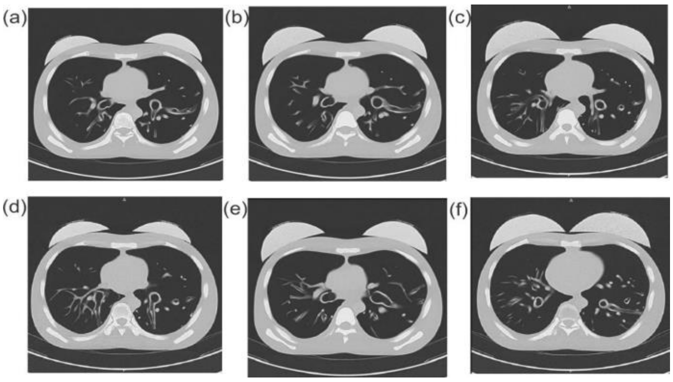

Fig 3. Axial images of in-house breast phantoms resulted from CT without activating TCM (first row) (a-c) and with activating TCM (second row) (d-e). Small breasts are at first column (a and d), medium breasts are at second column (b and e), and large breasts are at third column (c and f)

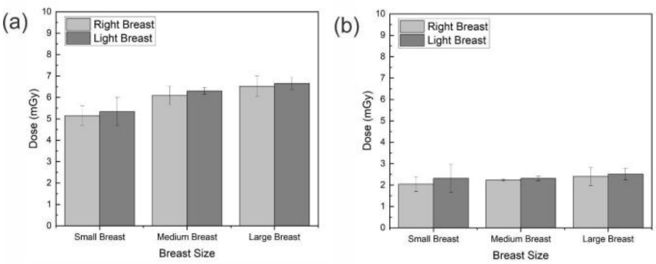

Fig 4. Surface dose results on breast nipple without TCM (a) and with TCM (b)

Figure 5 presents the noise levels measured on images resulted from CT with and without TCM at all breast sizes. The noise is higher on images resulted from CT with TCM compared to those without TCM at all breast sizes. In the scan without TCM, the noise on the right and left breast increases by 2-3% as the volume of the breast phantom increases (small, medium, large). In contrary, when TCM is activated, 1-3%, and with the TCM technique, the average surface dose of the right and left breasts increases by 5-7%. The overall TCM the noise slightly decreases as the volume of the breast phantom increases. The overall, noise with the TCM technique increased by 66% compared to without TCM. An increase in noise was also reported by a previous study [28], which found that the increase in noise using TCM was about 36% to 44%.

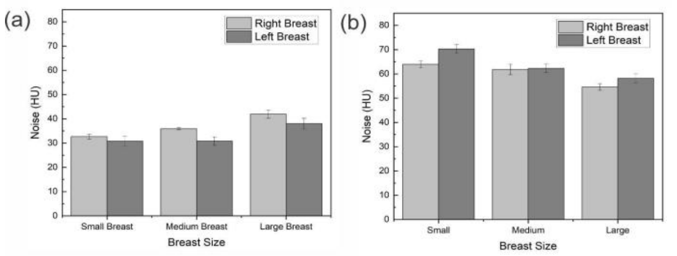

Fig 5. Noise results of images scanned without TCM (a) and with TCM (b)

IV. CONCLUSION

Three in-house breast phantoms have been successfully developed. The in-house breast phantoms and anthropomorphic phantoms were used to investigate the TCM technique. It was found that the TCM effectively reduce the radiation dose in the breast surface up to approximately 60%. However, the dose redcution was accompanied by an increase noise in the TCM technique by 66%.

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