

## Comparison of the Breast Dose based on the Existence of the Bismuth Breast Protection Shield for Automatic Exposure Control and Manual Exposure Control with the Coronary Artery CT Angiography

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### ABSTRACT

The effective dose and the organ absorbed dose, which are given to a breast in the cases of using and not using the bismuth breast protection shield for the protection of a breast with the coronary artery CT angiography, have been measured and compared for the manual exposure control (MEC) and the automatic exposure control (AEC). In the cases of using and not using the bismuth breast protection shield, it has been found that the measured dose shows the reduction of about 23 to 26% for the MEC and about 22 to 25% for the AEC when the shield is used compared to the case of not using it. By comparing the shield and non-shield cases for the AEC and the MEC, it can be said that the value measured by carrying out the scanning process with the AEC mode has decreased by about 24 to 30% compared to the case of applying the MEC mode. Such a result shows that it is recommended to use the AEC mode for the reduction of the patient's exposure dose during the CT examination.

*Keywords: coronary artery CT angiography, bismuth breast shield, MEC, AEC, breast dose.*

### 1. INTRODUCTION

The artificial radiation exposure is about 20% of the total amount of radiation exposure for human beings, and more than 15% of the artificial radiation exposure is caused by medical processes. It is known that 11% of the exposure is caused by the diagnostic X-ray[1]. The examination carried out by using the diagnostic X-ray can be largely classified into the general X-ray examination and the CT. Even if the CT is one of the strongest diagnostic methods, its dose received by a patient is relatively higher than that of the general X-ray examination[2]. In other words, even if the examination frequency of the CT is only 4% of every X-ray examination, the collective dose is 40% [3,4]. According to the report in 2003, the figure could reach 47% of the total collective dose of diagnostic radiation[5]. Recently, due to the tendency of obtaining high-quality images fast, the patient exposure dose has increased[6-8]. Even if the exposure dose of the patient who receives a diagnosis is excluded from the group which is subject to the application of the dose limit, it is necessary to minimize the patient exposure dose in achieving

the given medical objectives. Also, in case of the digital image system which has been introduced with the development of computer technologies, the quality of each image is proportional to the exposure dose, making it possible for a patient to experience unnecessary radiation exposure with excessive exposure to radiation. Therefore, even in case of fair medical activities, it is extremely important to evaluate the exposure dose of a subject in the medical radiation procedure regarding the optimization of protection. Furthermore, in terms of the public radiation health, it is important to evaluate the exposure dose of a subject person in case of the CT with a high level of contribution made by the average radiation of the diagnostic radiation, since the exposure dose given to a patient during the process of obtaining a number of tomographic images is extremely great. Even if there are some differences according to the actually-diagnosed parts or objectives, it has been reported that the dispersion of the absorbed dose in one's body based on the CT is about 10 to 100mGy[9], which is an extremely large range of exposure dose. Such a large range cannot even be compared to the exposure dose based on the conventional X-ray examination. The researcher of this study has carried out a quantitative evaluation for the exposure dose by measuring the organ dose and the effective dose, in order to

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figure out the amount of radiation exposure given to woman's breasts in case of the coronary artery CT angiography for the 64-MDCT. For such a process, with the method of reducing the exposure dose of a breast, the cases of using and not using the bismuth latex shield have been compared for manual exposure control (MEC) and automatic exposure control (AEC), in order to find out the method of minimizing the exposure dose of a breast.

## 2. MATERIALS AND METHODS

### 2.1 CT scan

For the CT scan, the Philips Brilliance 64-MDCT has been used. The bismuth breast shield (0.060 mmPb equivalent) (F&L medical product Co.1129 Industrial Park Road Vandergrift, PA15690 USA) has been used as a breast shield. The humanoid phantom (Alderson Rando phantom, USA), which has been used to measure one's exposure dose, consists of the equivalent components of bones, lungs, airways and tissues, showing the same structure as a human body. Such scan parameters as 120kVp, 500mAs, 0.4 second rotation time and pitch 0.4 have been used, while the scan length has been fixed as 14cm. In order to provide the same scan parameters for the application of the coronary artery CT angiography to actual patients, the electrocardiogram (ECG) gating has been used when scanning the phantom.

### 2.2 Absorbed dose measurement

The thermoluminescence dosimeter 100 (TLD-100) has been inserted in the middle of the phantom of the right breast and the left breast one by one. In the cases of shielding and not shielding the breast of the phantom by using the bismuth breast shield, the organ dose has been measured for MEC and AEC. In order to reduce measurement errors, the measurement process has been repeated five times for each factor.

### 2.3 Effective dose measurement

The ionization chamber which is exclusively reserved for the CT has been used. The ionization chamber of Radical Corporation (Model 206-3) and the reader of Siemens (PTW DIADOS 11003/1383) have been used. When carrying out the measurement process, the gauge factor of 0.998 has been calculated as 1. In the center and on the surface of the acryl cylindrical phantom with the diameter of 320mm, holes have been made to insert the pencil ionization chamber in the directions of 12 o'clock and 3, 6, 9 o'clock with the depth of 1cm for the measurement process. The process has been implemented in the cases of shielding and not shielding the cylindrical phantom with the volume computed tomography dose index (CTDIvol) of MEC and those of shielding and not shielding the phantom with the CTDIvol of AEC. In order to minimize errors for measurement values, the measurement process has been implemented repeatedly five times for each factor. The measurement process for the effective dose has focused on the calculation of the CTDIvol and dose length product (DLP). The DLP has been multiplied by the effective dose ratio for each DLP, which is recommended by International Commission on Radiological Protection 102

(ICRP102) [10]. The following calculation process has been executed [Equation 1-5].

$$CTDI_{100} = \frac{1}{NT} \int_{-50mm}^{+50mm} D(z) dz \quad (1)$$

$D(z)$ : The dose as a function of position along the  $z$  axis coordinate for a single scan dose profile at a given point  $\{x,y\}$

$N$ : The number of slices

$T$ : Slice thickness

$$CTDI_w = \frac{1}{3} CTDI_{100,center} + \frac{2}{3} CTDI_{100,peripheral} \quad (2)$$

$$CTDI_{vol} = \frac{CTDI_w}{pitch} \quad (3)$$

$$DLP(mGycm) = CTDI_{vol}(mGy) \cdot scan\ length(cm) \quad (4)$$

$$E = kDLP \quad (5)$$

$E$ : effective dose

$k$ : effective dose ratio

By measuring the exposure dose in the center of and around the phantom, which have been obtained through the scanning process with the reader, the average value and the CTDI have been calculated. In order to carry out more clear evaluations for the patient dose, the value has been changed into the dose indicator of the weighted CTDI (CTDI<sub>w</sub>). After dividing the calculated CTDI<sub>w</sub> with pitch 0.4, which has been used for the actual measurement process, and changing it into the CTDI<sub>vol</sub>, the value has been multiplied by the scan length of 14cm for the measurement process in order to calculate the DLP. The DLP has been multiplied by the effective dose ratio of 0.014 [Table 1] for the chest examination, which has been suggested to ICRP102, in order to calculate the effective dose[10].

Table 1. Regular effective dose ratio for each DLP regarding each body part of an adult.

| Body part          | k (mSv mGy <sup>-1</sup> cm <sup>-1</sup> ) |
|--------------------|---|
|                    | Adult                                       |
| Head and neck      | 0.0031                                      |
| Head               | 0.0021                                      |
| Neck               | 0.0059                                      |
| <b>Chest</b>       | <b>0.014</b>                                |
| Abdomen and pelvis | 0.015                                       |
| Trunk              | 0.015                                       |

### 2.4 TLD calibration & reading

For the calibration of the TLD, the X-ray of 6 MV from the medical linear accelerator (MEVATRON, SIEMENS, Germany) has been used. The TLD reader is Harshaw5500 (Harshaw, Solon, USA). Also, the dosimeter is the LiF TLD chip (TLD-100, Solon/Harshaw, USA), the thermo-luminescent substance

produced by LiF:Mg,Ti in the form of  $3.2 \times 3.2 \times 0.9 \text{ mm}^3$ . Regarding the calibration of the TLD, the solid phantom with the thickness of  $30\text{cm} \times 30\text{cm} \times 1.5\text{cm}$  has been put on the TLD with the irradiation range of  $10 \times 10 \text{ cm}^2$  and the distance of SSD 100cm. The value has been corrected to deliver 1 cGy per Monitor Unit (MU). The element correction coefficient (ECC) value has been used to compensate sensitivity for each element with the average sensitivity value of the selected element group of the TLD, while light has been transformed into currents by detecting each element emitting light after receiving heat with the photomultiplier tube (PMT). The currents show the accumulated direct charges with the nanocoulombs (nC). The reader calibration factor (RCF), which transforms the accumulated charges into the units of absorbed dose, has been calculated. The ECC generated on each element related to the average response of the group, and the one applying the RCF that leads to the transformation into each unit of absorbed dose to each element have been calculated to read and revise the TLD.

### 3. RESULTS AND DISCUSSION

#### 3.1 Absorbed dose

The results for the execution of the process of matching the CTDI<sub>vol</sub>, which is shown on the monitor after the scan parameters (manual mAs) are manually inserted, and the manual exposure CTDI<sub>vol</sub>, which is shown with AEC (automatic mAs), are shown in Table 2.

Table 2. Comparison of the absorbed dose (mGy) for breasts (One way ANOVA analysis, PASW statistics V18.0, mean  $\pm$  SD,  $p < 0.5$ ).

|            | Breast | MEC              | AEC              |
|------------|--------|------------------|------------------|
| Shield     | Right  | $30.52 \pm 0.25$ | $21.26 \pm 0.57$ |
|            | Left   | $30.32 \pm 0.61$ | $23.09 \pm 0.58$ |
| Non-shield | Right  | $39.73 \pm 0.45$ | $28.25 \pm 0.42$ |
|            | Left   | $40.83 \pm 0.40$ | $29.53 \pm 0.16$ |

#### 3.2 Effective dose

The results of the execution of the process of matching the CTDI<sub>vol</sub>, which is shown by inserting the examination parameter (manual mAs) in the same way as the one for MEC, and the manual exposure CTDI<sub>vol</sub>, which is shown by applying the protocol of the automatic exposure (auto mAs), are shown in Table 3. With the development of the CT technology, it has been possible to gradually improve the quality of images and reduce the level of the patient's radiation exposure. However, the potential level of danger which a patient would receive during the CT examination due to radiation is still relatively higher than those of other radiation examinations. Therefore, it is very important to minimize the dose which a patient would receive while receiving the CT examination. According to the diagnostic reference levels (DRLs) [11] suggested by the European Guidelines on Quality Criteria for Computed Tomography regarding the qualitative standard of the CT

published in EUR 16262, there are some differences for each scanned part. However, it is possible to know that the effective dose of the CT examination is greater than that of the simple X-ray examination by dozens of times. Therefore, it is important to reduce the patient dose during the CT examination for both the operator and the patient, since the patient dose for the CT examination is relatively higher than other radiation examinations. Also, when carrying out the coronary artery CT angiography, the dose has a significant influence for the quality of images. The organ dose represents the amount of radiation energy absorbed by a certain organ or system for unit per mass. In this study, it has been found that the absorbed dose for the right breast is  $39.73 \pm 0.45 \text{ mGy}$  in case of the manual exposure non-shield, while the dose for the left breast is  $40.83 \pm 0.40 \text{ mGy}$ . Such dose figures are relatively high in terms of the diagnostic radiation field. According to the chest CT examination carried out by Shrimpton et al. [12] in 1991, the dose for a breast was 21 mGy, while the lumbar spine CT showed 28 mGy. Therefore, by comparing such values, it can be said that the patient absorbed dose of the coronary artery CT angiography is relatively high.

Table 3. Comparison of the CT dose.

| CT dose                   | MEC        |        | AEC        |        |
|---------------------------|------------|--------|------------|--------|
|                           | Breast     | Breast | Breast     | Breast |
|                           | non-shield | shield | non-shield | shield |
| CTDI <sub>w</sub> (mGy)   | 31.62      | 21.31  | 21.43      | 14.55  |
| CTDI <sub>vol</sub> (mGy) | 79.05      | 53.28  | 53.58      | 36.38  |
| DLP (mGy <sub>cm</sub> )  | 1106.7     | 745.92 | 750.12     | 509.32 |
| Effective dose (mSv)      | 15.49      | 10.44  | 10.5       | 7.13   |

The effective dose is the dose index which reflects the danger of radiation. It is used for the purpose of predicting potential danger which could occur. The ICRP recommends the use of the effective dose as a method to suggest the tissue weighted factor which could cause cancer, evaluate the level of danger based on the radiation which is intermittently irradiated for the purpose of diagnosis, or compare the danger of radiation for various radiation tools relatively[13]. In this study, the effective dose has been calculated by multiplying the measured DLP with the regular effective dose ratio for each DLP regarding each body part of an adult suggested by ICRP 102[10]. In this study, it is important to focus on the results of the comparison between the DLP and effective dose in the cases of shielding and not shielding breasts by using the bismuth breast shield for MEC and AEC during the actual measurement process of the coronary artery CT angiography and the diagnostic reference level of the DLP (mGy cm)[14]-[16] and effective dose for each CT examination through several studies about adults [Table 4,5].

Table 4. Comparison between the breast DLP of this study and the DRLs of the DLP (mGy cm) shown in several studies about adults.

| Body part | British MDCT DRLs [15] | Europe MDCT DRLs [16] | This study    |       |       |       |
|-----------|------------------------|-----------------------|---------------|-------|-------|-------|
|           |                        |                       | MEC           |       | AEC   |       |
|           |                        |                       | Breast shield |       |       |       |
|           |                        |                       | X             | O     | X     | O     |
| Head      | 930                    | 337                   |               |       |       |       |
| Chest     | 940                    | 267                   | -             | -     | -     | -     |
| Abdomen   | 560                    | 724                   |               |       |       |       |
| Breast    | -                      | -                     | 1160.7        | 745.9 | 750.1 | 509.3 |

The DLP increases as the scan length becomes longer. Since the effective dose is calculated by multiplying the DLP with the tissue weighted factor in case of the CT, the effective dose of the CT is influenced by the number and kinds of organs included in the scan length. Nevertheless, the reason for the high dose of the coronary artery CT angiography which has the scan length of about 13 to 15 cm, which is relatively shorter than that of the chest or abdomen, is that since images are reconstituted in the cardiac cycle stage which makes the movement of the coronary artery become the smallest through the coronary artery CT angiography, the current MDCT is scanned with the pitch with small and overlapped reconstituted images regarding the desired cardiac cycle stage through the operation of the ECG gate in the scanning process.

Table 5. Comparison of the effective dose (mSv) for each CT examination of ICRP 102 and this study.

| CT examination                 | ICRP 102 | This study    |      |      |     |
|--------------------------------|----------|---------------|------|------|-----|
|                                |          | MEC           |      | AEC  |     |
|                                |          | Breast shield |      |      |     |
|                                |          | X             | O    | X    | O   |
| Abdomen & pelvis               | 14.4     | -             | -    | -    | -   |
| Liver, kidney                  | 11.5     | -             | -    | -    | -   |
| Brain                          | 2.8      | -             | -    | -    | -   |
| Neck                           | 2        | -             | -    | -    | -   |
| Chest                          | 5.7      | -             | -    | -    | -   |
| Pelvis                         | 7.2      | -             | -    | -    | -   |
| Thoracic spine                 | 2.9      | -             | -    | -    | -   |
| Lumbar spine                   | 8.1      | -             | -    | -    | -   |
| Coronary artery CT angiography | -        | 15.5          | 10.4 | 10.5 | 7.1 |

The application of a shield for the CT examination of an adult patient must not be used to allow the increase of exposed variables. Even if such organs as breasts, thyroid, eye lens and testicles hardly become the subjects of the scanning process for the CT examination, such organs could be included in the scan

length when other body parts are scanned. Therefore, it is very important to focus on the radiation dose of such organs. Also, the chest CT provides the dose of 20 to 50 mGy to the woman's breast of an average size. The dose is similar to the amount shown in the two-view mammography examination carried out 10 to 25 times[17]. It is necessary to justify the CT examination of fertile women through the point of view indicating that the level of danger regarding breast cancer caused by radiation is high in the subject group.

#### 4. CONCLUSIONS

In the cases of using and not using the bismuth breast shield (0.060mm Pb), it is possible to know that the measured dose (organ dose, effective dose) in the case of using the breast shield decreases by about 23 to 26% in MEC and by 22 to 25% in AEC, compared to the case of not using the shield. Also, by comparing each shield in MEC and AEC, the measured dose based on AEC scan decreases by about 24 to 30% compared to the one based on MEC scan. Since this study focuses on the comparative analysis of the dose decrease in the cases of using and not using the shield, it is not proper to discuss the decreasing effect of the patient dose through the comparison between MEC and AEC in the CT scanning process only with the results of this study limited to the coronary artery CT angiography. It is necessary to analyze the technical factors of the CT scan through another approach which is different from this study. It is possible for those involved in the medical radiation field to select AEC and use the radiation protection shield for the CT scan in order to actively shield other body parts than those subject to the CT scan, reducing the unnecessary patient's exposure more. Therefore, together with the use of AEC which is the most important method to reduce the unnecessary patient dose, it is necessary to develop a proper protection shield for individual patients and study the related effect by classifying the shields for specific body parts such as one's head, neck, chest, abdomen and pelvis based on ages and genders, in order to protect the subject organs included in the scan length from the scattered radiation. Also, it is necessary to study the bismuth breast shield which is used to protect breasts from the X-ray during the coronary artery CT angiography even if breasts are not the subject organ within the scan length. It has been found that the way of using the bismuth breast shield to shield breast tissues does not influence the observation of other deep structures, decreasing the radiation dose to a great extent. As shown above, it is necessary to strictly regulate the dose for the organs with a high level of radiation sensitivity. If it is possible to select such organs, those involved in the medical radiation field must try to shield other body parts than those included in the scan length in order to minimize the patient dose.

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