Showa Univ J Med Sci 25(1), 49～58, March 2013

Original

Reduced Radiation Exposure to the Mammary Glands in Thoracic Computed Tomography using Organ-based Tube-current Modulation

Jiro MUNECHIKA[1)], Yoshimitsu OHGIYA[1)], Takehiko GOKAN[1)],
Toshi HASHIMOTO[2)] and Tsugunori IWAI[3)]

Abstract : Organ-based tube-current modulation has been used to reduce radiation exposure to specific organs. However, there are no reports yet published on reducing radiation exposure in clinical cases. In this study, we assessed the reduction in radiation exposure to the mammary glands during thoracic computed tomography (CT) using X-CARE. In a phantom experiment, the use of X-CARE reduced radiation exposure at the midline of the precordial region by a maximum of 45.1%. In our corresponding clinical study, CT was performed using X-CARE in 15 patients, and without X-CARE in another 15. Compared to the non-X-CARE group, radiation exposure was reduced in the X-CARE group at the midline of the precordial region by 22.3% ($P < 0.05$) and at the medial sides of the right and left breasts by 16.8% and 14.2%, respectively ($P < 0.05$ for each). Analysis of the visual quality of CT images as well as CT values for the muscles of the chest walls showed no difference in either assessment between the X-CARE and non-X-care groups ($P > 0.05$). X-CARE thus reduced radiation exposure at the midline of the precordial region and allowed us to obtain consistent CT values without increasing noise. However, this study revealed increases in radiation exposure at the lateral sides of the breasts. It is conceivable that patients' breasts were laterally displaced by gravity under the standard thoracic imaging conditions. Further studies that consider factors such as body size and adjustment of imaging conditions may be needed in the future.

Key words : CT, radiation exposure, X-CARE, organ-based tube current modulation, mammary glands

Introduction

Computed tomography (CT) scanners generate data by rotating an X-ray tube and an X-ray detector around a patient. A computer then reconstructs this data and displays the resulting tomograms. While the tube is rotating, the patient is continuously exposed to X-ray radiation, and although highly radiosensitive organs such as the mammary glands, thyroid, and crystalline lens of the eye are rarely targeted by CT scans, they are often incidentally irradiated. In

1) *Department of Radiology, Showa University School of Medicine,* 1-5-8 Hatanodai, Shinagawa-ku, Tokyo 142-8666, Japan
2) *Department of Radiology, Showa University Fujigaoka Hospital.*
3) *Department of Radiological Technology, Showa University Fujigaoka Hospital.*

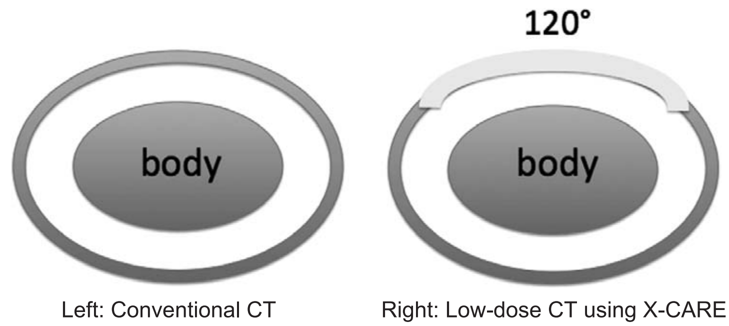


Fig. 1 X-CARE reduces radiation dosage to the mammary glands by modulating X-ray output doses to the subject's anterior body surface over a 120° radial arc.

particular, according to the 2007 recommendations of the International Commission on Radiological Protection, the tissue weighting factor for radiation exposure to the breast was increased from 0.05 to 0.12 [1], making it preferable to expose the breasts to as little radiation as possible during imaging examinations. X-CARE is an organ-based tube-current modulation system for critical organs, such as mammary glands, that can be added as an option to Siemens products including the SOMATOM Definition CT. This system reduces radiation doses by modulating the X-ray output dose to the anterior body surface over a 120° radial arc without changing the total administered dose (Fig. 1). Although previous studies have used phantom experiments to examine the effects of X-CARE on reducing radiation exposure to the mammary glands, no such effects have ever been reported in the clinical setting. In the present study, we examined the ability of X-CARE to reduce radiation exposure to the mammary glands in clinical use and evaluated the associated image quality.

Materials and Methods

Phantom experiment

We used a 128-row multi-slice CT scanner (SOMATOM Definition AS+, Siemens Medical Solutions, Erlangen, Germany), with a tube voltage of 140 kV, tube current modulation of CARE Dose 4D, standard dose of 73 mAs, rotation speed of 0.5 seconds / rotation, collimation of 64 × 0.6 mm, slice thickness of 5.0 mm, and helical pitch of 0.6 in the phantom part of the study. Human body phantom THRA1 (Kyotokagaku Co., Ltd. Kyoto, Japan) and fluorescent glass dosimeters (AGC Techno Glass Co., Ltd. Shizuoka, Japan) were used to measure the radiation doses. The fluorescent glass dosimeters were placed on the body surface of the phantom (10 sites) and in the breasts (4 sites) (Fig. 2). Absorbed doses with and without the use of X-CARE were measured at each site.

Clinical study

The subjects were 30 female patients (range, 45 ~ 75 years; median, 69 years) who were hospitalized or receiving outpatient treatment at the Department of Diabetes, Metabolism, and

Fig. 2 Dosimeter placement sites on a thoracic phantom (1) Right chest, (2) Right breast (lateral), (3) Right areola (lateral), (4) Right areola (medial), (5) Precordial region (midline), (6) Left areola (medial), (7) Left areola (lateral), (8) Left breast (lateral), (9) Left chest, (10) Dorsal region (midline), (11) Inside of the right breast (lateral), (12) Inside of the right breast (medial), (13) Inside of the left breast (medial), (14) Inside of the left breast (lateral).

Endocrinology or the Department of Gastroenterological and General Surgery at Showa University Hospital between September 4 and October 25, 2012, and who were scheduled to undergo CT scans of areas encompassing the mammary glands. CT scans were performed with X-CARE in 15 of the 30 patients, using the Siemens SOMATOM Definition AS+. CT scans were performed with a tube voltage of 120 kV, tube current modulation of CARE Dose 4D, standard dose of 180 mAs, rotation speed of 0.5 seconds / rotation, collimation of 64 × 0.6 mm, slice thickness of 5.0 mm, and helical pitch of 0.6. Prior to initiating the CT scans, a total of eight fluorescent glass dosimeters were directly fixed to the skin on the lateral sides of both breasts, both areolas, the medial sides of both breasts, the midline of the precordial region, and the midline of the dorsal region; all dosimeters were kept at as close to the same level as possible (Fig. 3). The glass dosimeters were collected after the CT scans were completed, and patients' radiation exposures were measured with a dosimeter reader. Because radiation doses varied among patients due to body size, doses at each measuring site were converted to a ratio of the total radiation dose (radiation dose ratio) in each patient. The Mann-Whitney test was used to analyze the differences in the median radiation dose ratios between the X-CARE group and the non-X-CARE group. This study was planned in accordance with the Declaration of Helsinki and Good Clinical Practice and the study protocol was approved by the local institutional review board. Written informed consent was obtained from all patients in the study.

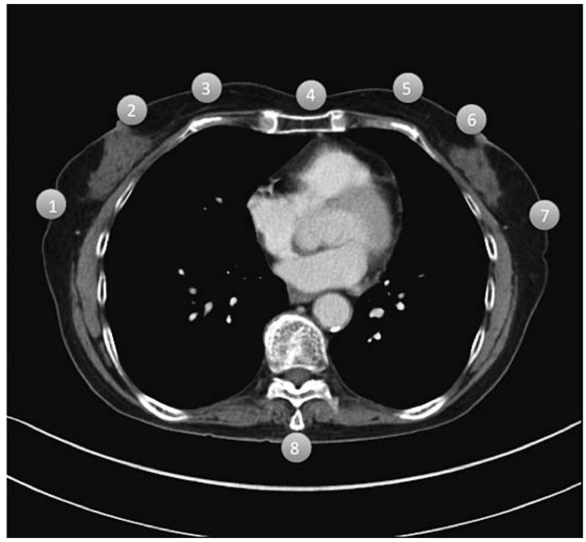


Fig. 3 Dosimeter placement sites on a patient
(1) Right breast (lateral), (2) Right areola, (3) Right breast (medial), (4) Precordial region (midline), (5) Left breast (medial), (6) Left areola, (7) Left breast (lateral), (8) Dorsal region (midline).

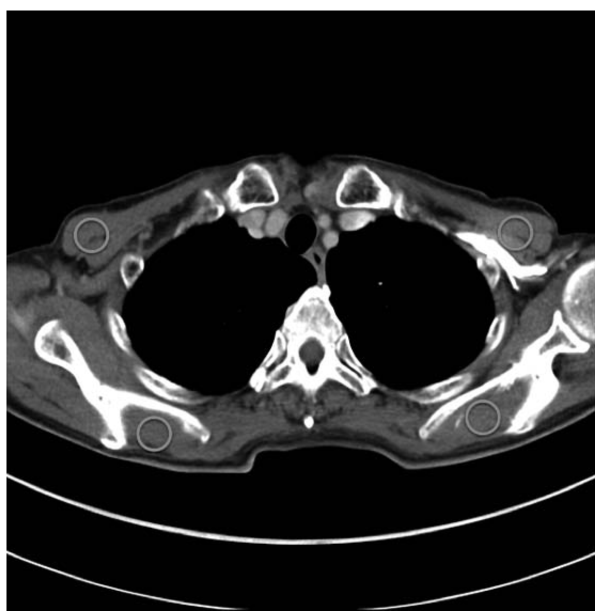
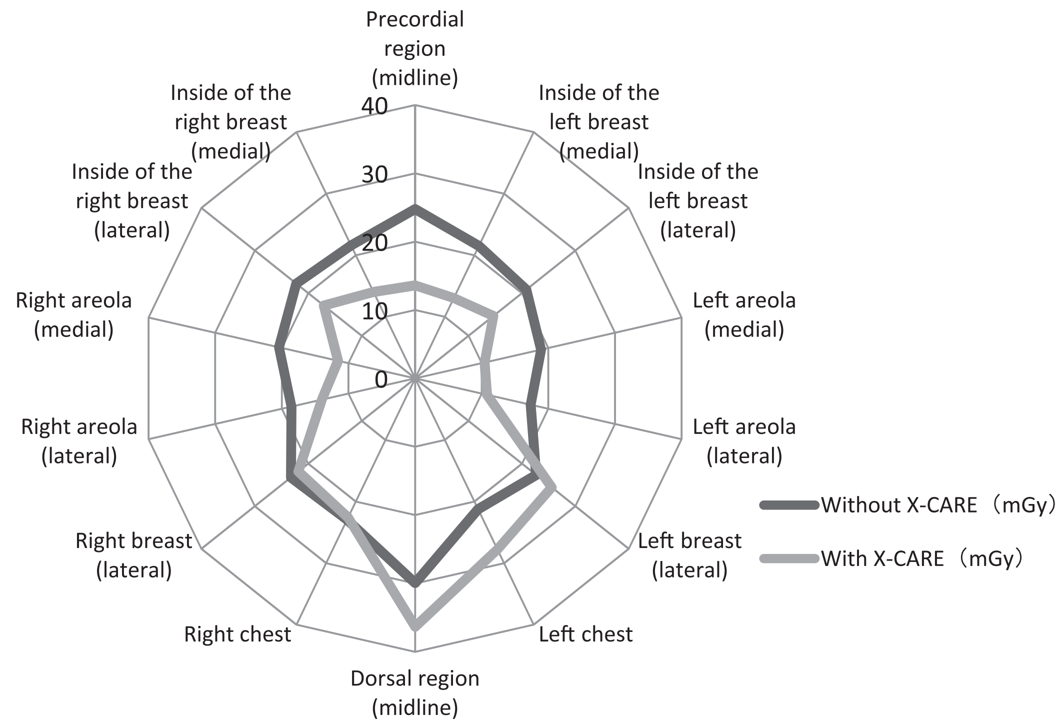


Fig. 4 Thoracic CT image (mediastinal window)
Four regions of interest were set at the muscles of the anterior and posterior chest walls, and CT (HU) and SD values (HU) were measured.

Image quality assessment

CT images used in the clinical setting were retrieved from the Picture Archiving and Communications System and visually assessed, and then CT values were measured. Visual assess-

Table 1. Results of the phantom experiment

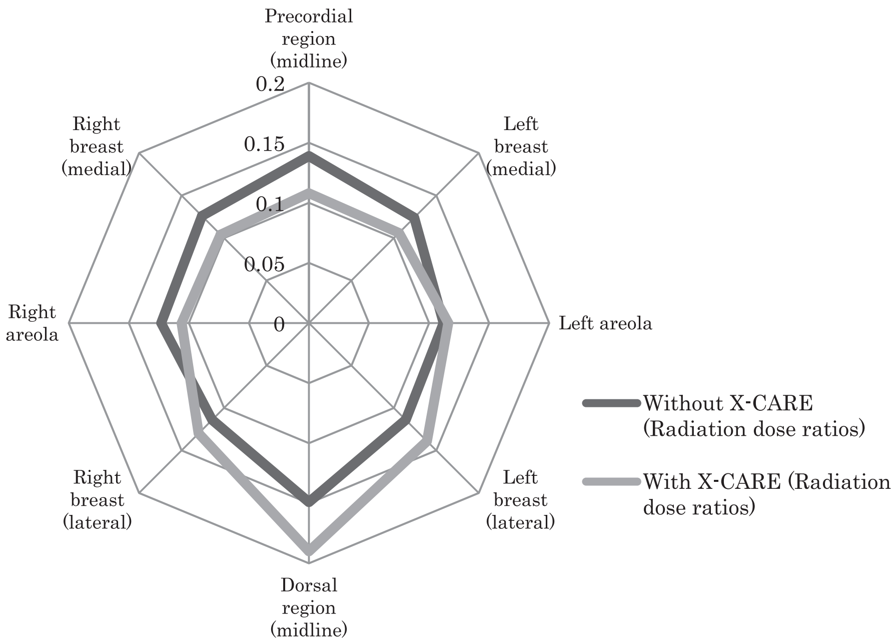


	Right chest	Right breast (lateral)	Right areola (lateral)	Right areola (medial)	Precordial region (midline)	Left areola (medial)	Left areola (lateral)	Left breast (lateral)	Left chest	Dorsal region (midline)
Without X-CARE (mGy)	22.95	23.24	18.56	20.43	24.77	18.9	17.35	22.66	21.24	29.95
With X-CARE (mGy)	22.6	21.86	13.99	11.56	13.6	10.42	10.8	25.56	27.77	36.33
Reduction rate (%)	1.5%	5.9%	24.6%	43.4%	45.1%	44.9%	37.8%	-12.8%	-30.7%	-21.3%

Without X-CARE (mGy)	Inside of the right breast (lateral)	Inside of the right breast (medial)	Inside of the left breast (medial)	Inside of the left breast (lateral)
With X-CARE (mGy)	22.24	21.59	21.51	20.81
Reduction rate (%)	17.09	14.04	13.05	14.65

ment of image quality was performed for shadows of the pulmonary vessels at the ventral and dorsal sides of one slice. Two radiologists who were blinded to the use of X-CARE graded the shadows of the pulmonary vessels at the ventral side in comparison to the dorsal side on a scale of 5 (1, very good; 2, good; 3, not different; 4, bad; 5, very bad). The Mann-Whitney test was then used to identify differences in the medians between the X-CARE group and the non-X-CARE groups. For the measurement of CT values, four regions of interest (ROIs) with an area of 200 mm^2 were set at the muscles of the anterior and posterior chest walls (Fig. 4), and then CT values (HU) and standard deviations (SD) (HU) of image noise were measured. The Mann-Whitney test was performed to assess whether there were differences in the medians between these groups.

Table 2. Results of the clinical study



	Right breast (lateral)	Right areola	Right breast (medial)	Precordial region (midline)	Left breast (medial)	Left areola	Left breast (lateral)	Dorsal region (midline)
Without X-CARE (radiation dose ratios)	0.114	0.123	0.126	0.139	0.124	0.112	0.114	0.149
With X-CARE (radiation dose ratios)	0.130	0.106	0.104	0.108	0.106	0.116	0.139	0.190
Reduction rates (%)	-14.2%	14.0%	16.8%	22.3%	14.2%	-3.3%	-22.0%	-28.1%
P values	0.0023	0.0033	0.0000	0.0000	0.0001	0.3487	0.0002	0.0000

Results

Phantom experiment

Radiation doses and the rates of exposure reduction with and without the use of X-CARE in the phantom experiment are shown in Table 1. The X-CARE group demonstrated reduced radiation exposure at the midline of the precordial region by a maximum of 45.1%. In contrast, radiation exposure was increased at the left chest by a maximum of 30.7% and at the midline of the dorsal region by 21.3%.

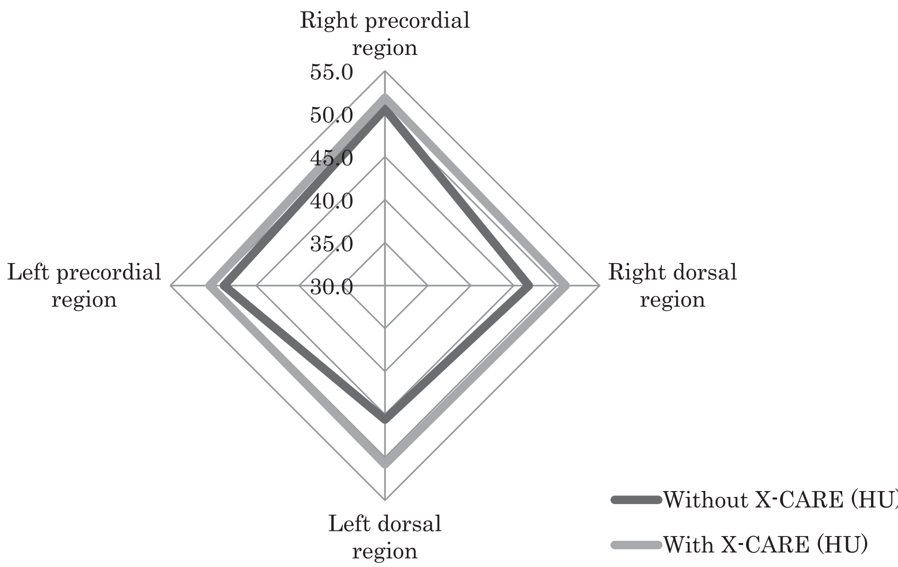
Clinical study

The radiation dose ratios and rates of reduction with and without the use of X-CARE in the clinical study are shown in Table 2. Mann-Whitney analysis of the data revealed differences between the groups in the median radiation dose ratios at all measuring sites except the left areola ($P < 0.05$). The X-CARE group showed reductions in radiation dose ratios by a maximum of 22.3% at the midline of the precordial region, by 16.8% at the medial side of the right breast, and by 14.2% at the medial side of the left breast. In contrast, radiation exposure was

Table 3. Image quality assessment by two radiologists

	Mean	SD	Median
Without X-CARE	2.77	0.57	3
With X-CARE	2.77	0.50	3

Table 4. Comparison of chest wall CT and SD values



	Right precordial region		Left precordial region		Right dorsal region		Left dorsal region	
	CT (HU)	SD (HU)	CT (HU)	SD (HU)	CT (HU)	SD (HU)	CT (HU)	SD (HU)
Without X-CARE	50.555	9.484	48.739	8.860	46.754	9.123	45.603	8.792
With X-CARE	51.855	7.472	50.401	8.133	51.052	8.500	50.815	7.445
P value	0.778	0.818	0.704	0.477	0.161	0.460	0.183	0.074

increased by a maximum of 28.1% at the midline of the dorsal region, by 14.2% at the lateral side of the right breast, and by 22.0% at the lateral side of the left breast.

Image quality assessment

Results of the visual assessment of image quality are shown in Tables 3 and 4. There was no difference in median image quality between the X-CARE and non-X-CARE groups (value of 3 in both; $P > 0.05$) (Fig. 5). Moreover, there were no differences between the groups in the CT values for the muscles of the anterior and posterior chest walls or the SD values of the image noise ($P > 0.05$ for each).

Discussion

X-CARE is an organ-based tube-current modulation system that protects critical organs during CT imaging by reducing radiation doses to the anterior body surface over a 120° radial arc and increasing doses to the posterior body surface without changing the total output dose. The

Left: Without X-CARE Right: With X-CARE

Fig. 5 Thoracic CT images (lung window)
Visual assessment of pulmonary vessel shadows at the ventral and dorsal sides showed no difference between groups.

mammary glands can thus be exposed to less radiation without an increase in image noise.

In the phantom experiment of this study, the changes in radiation exposure with X-CARE use (reduction at the midline of the precordial region and increase at the midline of the dorsal region) are consistent with those of previous reports[2, 3]. In the clinical cases, the use of X-CARE reduced the radiation dose ratios at the midline of the precordial region and the medial sides of both breasts by approximately 14 ～ 22%, which was less for the precordial region than in the phantom experiment. For any given dose of X-CARE, we found that the degree of dose reduction to the anterior body surface (or of dose increase to the posterior body surface) varied with patient body size, with more pronounced changes in smaller individuals[4, 5]. Image quality assessment showed consistent CT values without increases in image noise, verifying that the image quality of CT scans using X-CARE is equivalent to that of conventional scans. Bismuth breast shielding was previously reported to reduce radiation exposure to the breasts by approximately 30% without affecting images[2, 6–9]; now this study indicates that X-CARE could be used as a viable alternative.

In atomic bomb survivors the radiation dose-response relationship for breast cancer is linear, with a relative risk per Gray of 1.9[10]. In the setting of medical radiation exposure, the risk of breast cancer is increased following frequent radiography for a variety of conditions, including artificial pneumothorax for tuberculosis, radiation for mastitis, benign mammary gland diseases, and others[11–14]. Moreover, a retrospective cohort study indicated that even low-dose exposure might increase cancer incidence[17]. The risk is considered to be especially high when radiation exposure occurs early in life[16–18]. Thresholds for the effects of low-dose radiation exposure remain to be defined. The risk is estimated based on the hypothesis that radiation dose-response relationships are similar between low- and high-dose exposures (linear non-threshold model). Based on this model, radiation exposure during thoracic CT scans, which is approximately 9 mSV on average, would be reduced by 1.8 mSV (relative risk, 1.62×10^{-3}) with the use of X-CARE, which reduced radiation exposure to the precordial region by 20% in this study. Because the lifetime risk of developing breast cancer is 12.4%[19], this would reduce the relative risk of breast cancer by an estimated 2.01×10^{-4}. In other words, it is calculated that the use of X-CARE could reduce the incidence of breast cancer by 2 per 10,000 people undergoing one session of thoracic CT scanning.

In the present study, X-CARE increased radiation exposure to the lateral sides of both breasts, and because most of the mammary gland is located outside the breast, that type of exposure could be a problem. One possible reason for this increase is the presence of patients whose breasts were laterally displaced by gravity under the standard thoracic imaging conditions and were not included in the 120° radial arc over the anterior aspect of the body where output doses were reduced, as recommended by the manufacturer. If reduced radiation exposure to the entire breast is desired, it may be necessary to hold the breasts inward with a band, towel, etc., or further expand the range of dose reduction in the output to the front body during CT scans, in consideration of individual body size. Further studies may be needed in the future, involving increased patient numbers and accumulated cases.

In conclusion, thoracic CT scans using X-CARE could reduce radiation exposure to the mammary glands while maintaining image quality.

References

1) The 2007 recommendations of the international commission on radiological protection. ICRP publication 103. *Ann ICRP*. 2007;**37**:1–332.

2) Vollmar SV, Kalender WA. Reduction of dose to the female breast in thoracic CT: a comparison of standard protocol, bismuth-shielded, partial and tube-current-modulated CT examinations. *Eur Radiol*. 2008;**18**:1674–1682.

3) Duan X, Wang J, Christner JA, *et al*. Dose reduction to anterior surface with organ-based tube current modulation: evaluation of performance in a phantom study. *AJR Am J Roentgenol*. 2011;**197**:689–695.

4) Angel E, Yaghmai N, Jude CM, *et al*. Dose to radiosensitive organs during routine chest CT: effects of tube current modulation. *AJR Am J Roentgenol*. 2009;**193**:1340–1345.

5) Angel E, Yaghmai N, Jude CM, *et al*. Monte Carlo simulations to assess the effects of tube current modulation on breast dose for multidetector CT. *Phys Med Biol*. 2009;**54**:497–512.

6) Lungren MP, Yoshizumi TT, Brady SM, *et al*. Radiation dose estimations to the thorax using organ-based dose modulation. *AJR Am J Roentgenol*. 2012;**199**:W65–W73.

7) Fricke BL, Donnelly LF, Frush DP, *et al*. In-plane bismuth breast shields for pediatric CT: effects on radiation dose and image quality using experimental and clinical data. *AJR Am J Roentgenol*. 2003;**180**:407–411.

8) Coursey C, Frush DP, Yoshizumi T, *et al*. Pediatric chest MDCT using tube current modulation: effect on radiation dose with breast shielding. *AJR Am J Roentgenol*. 2008;**190**:W54–W61.

9) Kuwashima S. Bismuth breast shields for pediatric chest CT: effective on radiation dose and image quality. *J Jpn Pediatr Soc*. 2010;**114**:865–868. (in Japanese).

10) Preston DL, Ron E, Tokuoka S, *et al*. Solid cancer incidence in atomic bomb survivors: 1958–1998. *Radiat Res*. 2007;**168**:1–64.

11) Preston DL, Mattsson A, Holmberg E, *et al*. Radiation effects on breast cancer risk: a pooled analysis of eight cohorts. *Radiat Res*. 2002;**158**:220–235.

12) Doody MM, Lonstein JE, Stovall M, *et al*. Breast cancer mortality after diagnostic radiotherapy: findings from the U.S. Scoliosis cohort study. *Spine*. 2000;**25**:2052–2063.

13) Howe GR. Lung cancer mortality between 1950 and 1987 after exposure to fractionated moderate-dose-rate ionizing radiation in the Canadian fluoroscopy cohort study and a comparison with lung cancer mortality in the atomic

bomb survivors study. *Radiat Res*. 1995;**142**:295-304.

14) Miller AB, Howe GR, Sherman GJ, *et al*. Mortality from breast cancer after irradiation during fluoroscopic examinations in patients being treated for tuberculosis. *N Engl J Med*. 1989;**321**:1285-1289.

15) Cardis E, Vrijheid M, Bletner M, *et al*. Risk of cancer after low doses of ionizing radiation: retrospective cohort study in 15 countries. *BMJ*. 2005;**331**:77.

16) Travis LB, Hill D, Dores GM, *et al*. Cumulative absolute breast cancer risk for young women treated for Hodgkin lymphoma. *J Natl Cancer Inst*. 2005;**97**:1428-1437.

17) Land CE, Tokunaga M, Koyama K, *et al*. Incidence of female breast cancer among atomic bomb survivors, Hiroshima and Nagasaki, 1950–1990. *Radiat Res*. 2003;**160**:707-717.

18) Hildreth NG, Shore RE, Dvoretsky PM. The risk of breast cancer after irradiation of the thymus in infancy. *N Engl J Med*. 1989;**321**:1281-1284.

19) Howlader N, Noone AM, Krapcho M, *et al*. SEER cancer statistics review, 1975-2009 (vintage 2009 populations). Bethesda, MD: National Cancer Institute; 2012.

［Received December 12, 2012 : Accepted January 7, 2013］