Abstract
The study was aimed to evaluate the image quality and radiation dose during female chest computed tomography (CT) screening using organ-based tube current modulation technology X-ray combined applications to reduce exposure (XCARE).

Five hundred sixty female individuals undergoing chest CT scan were prospectively enrolled and divided into 4 groups based on body mass index (BMI). Then they were randomly and equally divided into control and experimental subgroup and respectively accepted conventional low-dose and XCARE technology spiral CT scan with same parameters. Signal-to-noise ratio and contrast-to-noise ratio were calculated. The quality of the images was evaluated by 2 radiologists using a 5-point scale.

Among experimental subgroups of the 4 BMI groups, Signal-to-noise ratios, CT dose index of volume, dose-length product, effective dose, and contrast-to-noise ratio all displayed significant differences, as well as in control subgroups (P < .001). Both the experimental and control subgroups showed an increasing trend in radiation dose with the increasing of BMI. Parameters of image quality and radiation dose displayed no significant differences between control and experimental subgroups in the 4 groups. In multiple linear regression analysis, age and scanning protocol were not associated with radiation dose (P > .05), while BMI was significantly associated with increased CT dose index of volume (P < .05). The display of the lesions for the patients in the control and experimental subgroups of the 4 groups with different BMIs exhibited no statistically significant difference.

The same image quality and radiation dose can be obtained using XCARE technology compared to conventional chest CT scans, which can be used regularly in female patients.

1. Introduction
Currently, low-dose helical computed tomography (CT) screening for lung cancer has been widely accepted.[1,2] However, with conventional chest CT scans, the mammary gland is unavoidably exposed to direct radiation. Recently research shows that digital mammography average glandular dose is the same range as glandular tissue dose for lung cancer screening CT exams.[3] The mammary gland is highly sensitive to radiation.[4] Therefore, reducing direct radiation of the breast is extremely important for the prevention of breast cancer and breast diseases in women.
who undergo a CT scan during a physical or follow-up examination.

The X-ray combined applications to reduce exposure (XCARE) scan sequence is option of Siemens application. XCARE uses exposure technology that involves an automatically adjusted tube current. That is, when the tube is rotated to the position above the body, the tube current is reduced to lower the radiation dose to the sensitive area, and when the tube is rotated to the back side of the body, the tube current is adjusted back to the normal level. The lowest tube current is reduced to 25% of the average, which can effectively reduce the radiation dosage to the sensitive area of patient.

This study aimed to apply the XCARE technology to female CT screening for lung disease and to explore the application value of the XCARE technology in female lung screening compared with regular chest CT scan.

2. Patients and methods

This study was approved by the Institutional Review Board of our hospital and informed consent was sought from all individuals participating in the study.

2.1. Patient selection

From February 2018 to August 2018, we prospectively assessed 608 consecutive female participants referred to our department for chest CT screening. Exclusion criteria included history of total breast resection (n = 6), severe respiratory symptoms that interfered with the process of CT scan (n = 22), fail to lie on their back with arms raised over the head (n = 14), declined to participate (n = 6). Finally, a total of 560 patients were enrolled in our study. Patient height and weight were recorded before CT scan to calculate body mass index (BMI = body weight/height^2 [kg/m^2]). All the participants were divided into the following 4 groups based on BMI: Group 1, BMI <25; Group 2, BMI ≥ 25 and <28; Group 3, BMI ≥28 and <32; Group 4, BMI ≥ 32. Then each group of participants were randomly and equally divided into experimental and control subgroup (Fig. 1).

2.2. Chest CT scan protocol

All participants were scanned with a Somatom Definition Flash CT (Siemens Healthineers, Germany) instrument, and the scan range covered the entire lung, from the level of the lung apex to the liver dome. Patients were required to hold their breath at the end of deep inhalation during the examination. For all the participants, the underwear and other metal objects were removed before the scanning procedure.

The scanning parameters were as follows: for the experimental group, 100kV and CAREDose4D, with 5-mm and 1-mm layer thickness; the collimator was 128 × 0.6 mm; pitch 0.6; option value of sinogram affirmed iterative reconstruction (SAFIRE) was 2; the convolution kernel of the pulmonary window 170f was very sharp; the mediastinal window of 131 was medium smooth; none IV contrast and the scanning program that included the XCARE function to protect sensitive organs was selected for the scanning procedure. For the control group, all the conditions were identical to those for the experimental group except that the XCARE function was not used (Fig. 2).

2.3. Image quality assessment

The 5-mm layer thickness axial images were selected for each patient. The left pectoralis major on the apex level, the descending aorta on the carina level, and the left atrium were selected in the mediastinal window (width, 400 HU; level, 40 HU) as the region of interest to measure and record the average CT HU value and background noise (standard deviation [SD]). The circular region of interest was 200 mm^2. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated. CNR = (average CT HU value of descending aorta–average CT HU value of same layer muscle/background noise).

All patient and scanner demographic data were removed and the analysis of images was independently performed by 2 senior radiologists with a double-blind method. The clarity of the display of the mediastinum, great vessels, pleura, chest wall soft tissue, lung segment, and sub-segmental bronchi, as well as the details of anatomical structures, particle size, and artifacts were primarily observed. A 5-point scale was used as the criteria to subjectively assess the image quality: 5, anatomic details and lesions were clearly shown, and the image could be simply and clearly evaluated; 4, the anatomical structures and details as well as the lesions were somewhat clearly shown, and the image was evaluable but was not particularly good; 3, most of the anatomical structures and lesions could meet the diagnostic requirements, but a small number of images could not be evaluated; 2, the display of the anatomical structures and lesions was not clear, and the details could not be observed; 1, the anatomical structures and lesions were too vague for a diagnosis.

A score of 3 and above can meet the diagnostic requirements.

The anatomical details were associated with the analysis of the mediastinal window and lung window (width, 1500 HU; level, –700 HU), including the ability to display the lesion morphology, size, and boundary. The lesions (normal, ground-glass nodules, fibrous cord, calcification, empty cavity, and lesion of thymus) in each patient were evaluated by 2 radiologists.

2.4. Radiation dose

The CT dose index of volume (CTDIvol) and dose-length product (DLP) for each participant were recorded. The CTDIvol reflects the average dose throughout the entire scan volume, while the DLP was used to evaluate the total radiation dose for the participant during a full CT scan. DLP was converted to effective dose (ED) in millisieverts (mSv) by multiplying it by the thoracic conversion factor of 0.0144 mSv mGy^{-1} cm^{-1}.

2.5. Statistical analysis

Statistical analysis was carried out by SPSS 22.0 software (IBM SPSS Statistics, Armonk, NY) and GraphPad Prism (Prism for Windows, Version 7.0a; Graph-Pad Software, Inc., La Jolla, CA). Values were described with either mean ± SD or median with interquartile range after testing the normality of variables using Shapiro–Wilk test. Parameters among the 4 groups were compared by Kruskal–Walls test. The average CT HU value, the noise (SD), SNR, CNR, CTDIvol, and DLP for the 2 subgroups of images were compared with the Mann–Whitney U test or Dunnett t-test for 2 independent samples. The agreement of the scores obtained from the evaluation by different physicians was determined using the Kappa test, for which can be interpreted as follows: ≤0, no agreement; 0.01 to 0.20, as none
Figure 1. Flowchart of research participants examined by chest CT scan. BMI = body mass index, CT = computed tomography.

Figure 2. The quality of all the images met the diagnostic requirements. (A) Displays a case in which the XCARE technology was not used, while (B) shows a case with the use of the XCARE technology. XCARE = X ray combined applications to reduce exposure.
Table 1

Patient characteristics, radiation dose, and image quality in the 4 groups.

|                  | Total       | Group 1       | Group 2       | Group 3       | Group 4       | P   |
|------------------|-------------|---------------|---------------|---------------|---------------|-----|
| Patients n [%]   | 560         | 220 [39.3]    | 160 [28.6]    | 120 [21.4]    | 60 [10.7]     | .26 |
| Age (yr)         | 40 (36-62)  | 40 (36-66)    | 48 (33-63)    | 47 (35-59)    | 52 (41-60)    | .001|
| BMI (kg/m²)      | 26 (22.9-29.4) | 22.1 (20.5-23.7) | 26.3 (25.7-27.2) | 30.2 (29.0-31.1) | 33.1 (32.3-33.7) | .001|
| CTDIvol (mGy)   | 6.3 (5.7-8.0) | 5.5 (5.1-5.9) | 6.5 (6.0-7.1) | 8.4 (7.8-8.8) | 10.1 ±.7 | .001|
| DLP (mGycm)     | 151.5 (129.4-192.1) | 126.6 (115.1-137.3) | 158.85 (143.7-173.2) | 220.4 (181.1-259.5) | 277.2 ±43.0 | .001|
| ED (mSv)        | 2.1 (1.8-2.7) | 1.8 (1.6-1.9) | 2.22 (2.01-2.4) | 3.1 (2.5-3.6) | 3.9 ±.6 | .001|

Imaging quality

| SNR1            | 6.23 (5.06-7.56) | 6.85 (5.82-7.98) | 7.03 ±.87 | 4.83 ±.100 | 6.13 ±.163 | .001|
| SNR2            | 4.77 (4.01-5.60) | 4.65 (4.01-5.60) | 7.09 ±.71 | 3.96 ±.06 | 4.13 ±.04 | .001|
| SNR3            | 4.80 (4.01-6.52) | 4.37 (3.86-5.42) | 8.34 ±.30 | 4.16 ±.06 | 4.74 ±.06 | .001|
| SNR4            | 2.84 (1.74-4.03) | 3.78 (2.88-4.64) | 2.80 (1.84-4.25) | 1.24 (0.61-1.96) | 2.51 ±.91 | .001|

Values were described with either mean ± standard deviation (SD) or median with interquartile range (IQR) after testing the normality of variables using Shapiro-Wilk test.

BMI= body mass index, CTDIvol = CT dose index of volume, DLP = dose-length product, ED = effective dose, SNR = signal to noise ratio. SNR1 = SNR of the left pectoralis major on the apex level, SNR2 = SNR of the descending aorta on the carina level, SNR3: SNR of the left atrium.

3. Results

3.1. Descriptive statistics and image quality in 4 groups

Descriptive statistics of the parameters of 4 groups were summarized in Table 1. All the 560 female participants successfully completed the chest CT scan (age, 48 ±15.0 years; BMI, 26.2 ±4.2 kg/m²). The ED was 2.4 ±0.8 mSv. No significant difference was found with respect to age among the 4 groups. But CTDIvol, DLP, ED, SNRs, and CNR were significantly different among them (P <.001). CTDIvol, DLP, and ED showed an increasing trend with the increase of BMI.

Among experimental subgroups of the BMI groups, SNRs at different levels, CTDIvol, DLP, ED, and CNR all displayed significant differences, as well as in control subgroups (P <.001). Both the experimental and the control subgroup obtained the maximum SNR value in group 2 (BMI, 25-28) (Fig. 3A-C), and the maximum CTR value in group 1 (BMI <25). In control subgroup, both of the BMI < 25 and BMI 25 to 28 groups could obtain higher CNR values, while in experimental subgroup, there was no advantage of CNR between BMI 25 to 28 (group 2) and BMI >32 (group 4) (Fig. 3D). Both the experimental and control subgroups showed an increasing trend in radiation dose with the increasing of BMI (P <.001) (Fig. 3E and F).

3.2. Image quality and radiation dose in subgroups

Table 2 summarizes the average CT values, the noise, and SNR at different levels, as well as CNR in control and experimental subgroups at different BMI levels, which were not significantly different from each other. The radiation doses including CTDIvol and DLP for the subgroups were shown in Table 3. There were no significant differences between control and experimental subgroups in 4 groups.

The scores reflecting the image quality for the control and experimental subgroups in the 4 groups with different BMIs were showed in Table 4, and none of differences between the experimental and control subgroups were statistically significant (P >.05). Good inter-observer agreement was found for Group 1, and moderate inter-observer agreement was found for Group 2, 3, and 4. Furthermore, the quality of all the images met the diagnostic requirements (Fig. 2). In multiple linear regression analysis, age (β=0.001, 95% confidence interval, −0.01 to 0.00, P >.05) and scanning protocol (β=0.02, 95% confidence interval, −0.12 to 0.15, P >.05) were not associated with radiation dose, while BMI was significantly associated with increased CTDIvol (β=0.34, 95% confidence interval, 0.32–0.35, P <.005) (Supplement Table, http://links.lww.com/MD/E702). Correlation was significant between BMI and CTDIvol (correlation coefficient, 0.863, P =.000).

3.3. Number of detected lesions

The display of the lesions for the patients in the control and experimental subgroups of the 4 groups with different BMIs exhibited no statistically significant difference (Table 5). In the control group, 3 cases were diagnosed with ground glass lesions of 3 to 6mm, in 2 cases of which the lesions were in the right upper lung lobe, and the lesion was in the left lung lobe in 1 case. In the experimental group, 4 cases were diagnosed with ground glass lesions of 3 to 5mm; in 2 cases, the lesions were in the right upper lobe, and in 1 case each, the lesion was in the right middle lobe and the left upper lobe.

4. Discussion

With consideration of the extremely radiosensitive glandular tissue in the female breast, dose saving algorithms have to be applied, if possible. In chest CT examinations, breasts are usually not diagnostically targeted, but they receive a considerable amount of unnecessary radiation dose. Previous studies have shown that the tissues in the mammary gland are highly sensitive to radiation, and the irradiation of these tissues is thus more likely to cause tumors than the irradiation of other organs. One of the main goals is to minimize the exposure of the breast to radiation. The increasing number of diagnosed breast cancer...
cases is a cause of concern. A number of studies evaluated the influence of medical radiation exposure on future occurrence of malignant tumors in women who were exposed to high radiation doses due to multiple radiation examinations or treatment by radiotherapy.\textsuperscript{[14–16]} However, the advantages of lung CT examination in revealing small pulmonary lesions has gradually become an important tool in physical examinations. In the conventional chest CT scanning procedure, the direct exposure of the breast to radiation is not avoidable, and the breast is not the target organ in lung CT screening; therefore, it is self-evident that the biological effect of frequent examinations or large doses of radiation might be a potential cancer risk.\textsuperscript{[13]}

Automatic tube-current modulation techniques have been widely used in CT examination.\textsuperscript{[17]} Spiral CT, as the name suggests, is the mode in which the tube and the detector rotate around the body, and the X-ray emitted from the tube arrives at the receiving detector through the body to obtain the image information after photoelectric conversion. Some vendors have developed organ-based tube current modulation techniques to protect superficial radiosensitive organs, such as breasts. It has been reported that with the application of organ-based tube current modulation (X-CARE, Siemens Healthcare), the tube current (mA) is reduced by 80% with a corresponding increase in the posterior region, thereby reducing the risk of breast
Lungren MP et al[20] reported that, with organ-based tube current modulation in adult anthropomorphic phantom, breast dose can be reduced by 17% to 47% with no detrimental effect on image quality. Wanyi Fu et al[18] reported that organ-based tube current modulation reduced breast dose by 38.6% ± 8.1% in 13 female anthropomorphic computational phantoms. However, there is still a lack of clinical research on the application of organ-based tube current modulation technology in female patients. Similar to the results of previous phantom researches, in our study, the objective parameters and subjective rating, the display of the lung structure and lesions also maintained the same image quality in the lung CT scan. In the subjective rating column, we concluded that there were no significant differences in image quality and radiation dose between the experimental and control groups within the same BMI range.

Thus, the tube current is reduced for tube position, where x-rays pass the patient from anterior to posterior, to reduce the direct exposure of radiosensitive organs. To maintain image quality, the tube current is increased for the remaining projections (posterior to anterior) to get the same milliampere per rotation, the shaded area indicates the region for very low-dose X-ray emission and the tube current is decreased. Considering the radiation doses distributed non-uniformly in the scan region, exposure to breast areas remain low compared to other areas of the body.

It indicated that the application of the XCARE technology for lung CT screening could reduce the irradiation of the breast while maintaining the same image quality in the lung CT scan. In the subjective rating, the display of the lung structure and lesions also showed no difference between the 2 groups of images, and the images of both groups could reveal the lesions well. Both the control and experimental groups exhibited a good performance in the detection and details of small lesions, with clear anatomical structures, and bullous emphysema, and the difference was not statistically significant, thus meeting the diagnostic requirements.

One of the limitations of our study is that no specific instrument is used to measure the radiation dose received by the patient. However, the difference in the subjective rating is small enough to indicate that the use of the XCARE technology is effective in reducing radiation dose without compromising image quality.

Table 2

| Group | BMI | Average CT HU | SNR | CTDI (mGy) | DLP (mGy) |
|-------|-----|---------------|-----|------------|-----------|
| Group 1 | BMI: 18–25 | 61.54 ± 9.00 | 39.34 ± 3.48 | 121.29 ± 15.58 | 36.59 ± 2.94 |
| Exp. | BMI: 25–28 | 60.99 ± 9.88 | 38.96 ± 3.49 | 118.21 ± 15.53 | 36.59 ± 2.94 |
| Con. | BMI: 28–32 | 59.12 ± 8.18 | 40.44 ± 4.29 | 118.21 ± 5.80 | 38.81 ± 3.87 |
| Exp. | BMI: >32 | 51.83 ± 8.90 | 38.77 ± 3.93 | 118.21 ± 5.80 | 38.81 ± 3.87 |
| Con. | BMI: 18–25 | 49.41 ± 7.81 | 39.31 ± 3.50 | 118.21 ± 5.80 | 38.81 ± 3.87 |
| Exp. | BMI: 25–28 | 49.41 ± 7.81 | 39.31 ± 3.50 | 118.21 ± 5.80 | 38.81 ± 3.87 |
| Con. | BMI: 28–32 | 62.42 ± 8.10 | 38.77 ± 3.93 | 118.21 ± 5.80 | 38.81 ± 3.87 |
| Exp. | BMI: >32 | 58.09 ± 9.03 | 37.52 ± 3.50 | 118.21 ± 5.80 | 38.81 ± 3.87 |

AveHU = average CT HU of region of interest, CTDI = contrast-to-dose ratio, Con. = control subgroup, Exp. = experimental subgroup, DLP = signal-to-noise ratio.
patient’s mammary gland during the examination. In summary, the XCARE technology in female chest CT screening can obtain the same image quality and radiation dose compared to conventional chest CT scans, which can be used regularly in female patients.

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