Areas of breast tissue covered in cone beam breast CT imaging

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Abstract. The value of cone beam breast computed tomography (CBBCT) imaging on covered areas of breast tissue, which is the relation between imaging quality and CT dose were studied. Multi-energy spectrum was used to radiate same-size built-in calcifications and lump breast motifs under the condition of the same number of particles by utilizing the Monte Carlo-based GATE simulation software; breast motif images were restructured by using FBP restructuration algorithm to gain the distribution of radiation dose in the breast motif; radiation dose was calculated and signal-to-noise ratio (SNR) to define how quality factor M and dose efficiency η reflect the relations between radiation dose and imaging quality. Based on the comparison of the calcification number, diameter, and the diameter of tumor among head side, foot side, inner side, outer side and rear side, the difference was meaningless in terms of statistics. Based on the comparison between SNR and contrast-to-noise ratio and between dose efficiency η and quality factor M in different areas, the difference was not statistically significant. In conclusion, the imaging quality of CBBCT was good in the head, foot, inner, outer and rear sides of breast, with acceptable CT dose.

Introduction

The incidence rate of breast cancer ranks the first among tumors suffered by females in China and breast cancer is becoming increasingly common among young women, severely threatening women's health and life quality (1). Accordingly, the prognosis of breast cancer is closely related to lesion size and pathological staging (2). Consequently, early diagnosis and treatment remains the key to increase the prognosis of breast cancer. Indeed, breast X-ray examination is the primary method in health screening and primary diagnosis while regular molybdenum target inspection is extremely sensitive to calcification. However, 2-dimensional (2D) imaging may overlook a micro-lesion or lesion in the overlapping part among tissues (3). Therefore, breast X-ray 3-dimensional (3D) imaging technology comes into being, such as digital breast tomosynthesis (DBT) and cone beam breast computed tomography (CBBCT) imaging. CBBCT features vivid 3-dimensional imaging, quick scanning, high spatial resolution ratio, and isotropy, all of which is conducive to detecting lumps and micro calcification in breast (4). When scanning, breast needs not to be pressed, eliminating the pain caused by pressure on breast for the inspected (5). The areas of breast covered in the imaging and the display of breast lesion is similar or superior to breast X-ray radiography examination (6). Imaging quality and radiation dose are two attention-catching important factors in CBBCT examination. The increase of tube voltage and tube current can effectively enhance imaging quality, but the radiation dose increases accordingly at the same time (7). Thus, how to strike a balance between imaging quality and radiation dose will be a hot issue in research. Based on this, the present study analyzes the relations between the two by utilizing computer simulation technology.

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Materials and methods

Basic introduction to CBBCT. CBCT1000 from Tianjin Kening Medical Equipment Co., Ltd. (Tianjin, China) was used. GATE software was a Geant4-based open software for users and features effective physical model, complicated and changeable geometrical model, changeable 3D and visualization function, 3D rendering tool. GATE simulation software contains 8 modules: Detector, motif, physical process, ray source, collecting pattern, electronics model, dose motif and output data type modules.

Breast motif structure. The breast motif mainly consists of 1 mm outer skin, wrapped in which was inner breast structure, consisting of 50% glands and 50% fat (Fig. 1). The inner glands of the breast mainly consist of lobule and lactiferous vessel, where most of the breast cancer incidence occur. Take the average gland dose, that was the dose absorbed by the

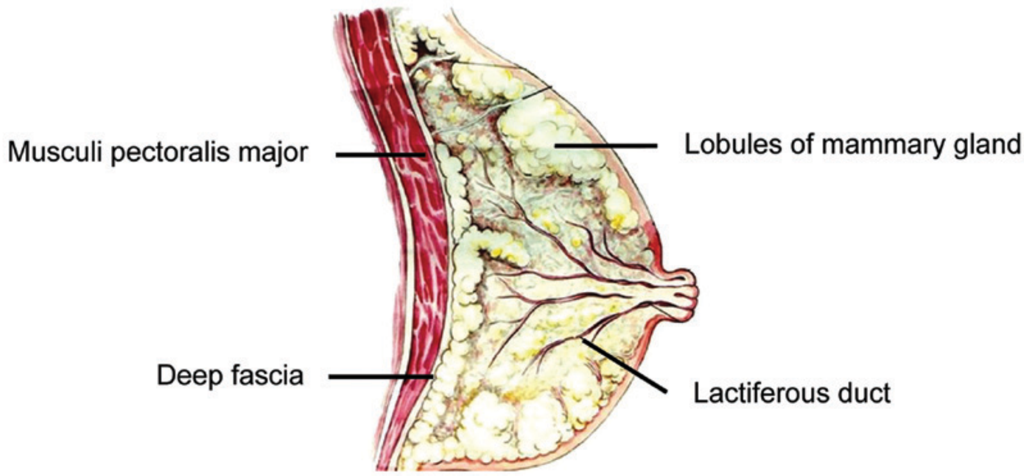

Figure 1. Schematic diagram of breast.

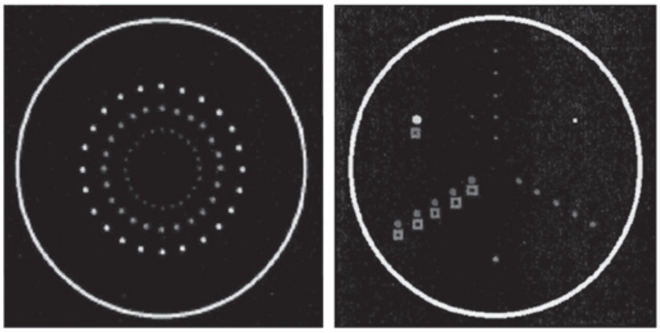

Figure 2. Distribution of calcification in the breast motif (the left being the imaging quality and dose motif under different voltage; the right being the resolution ratio of radial calcification).

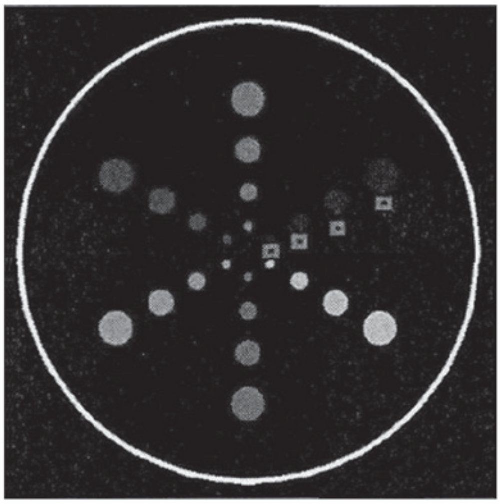

Figure 3. Distribution of lumps in the breast motif.

glands in breast tissues, as the standard to measure the radiation dose absorption level in the breast tissues. We defined the breast with over 75% glands as dense breast and breast with <25% glands mass fraction as loose breast.

Calcification: Module made up of calcium carbonate material for the calcification of hyperplasia of mammary gland simulation in the breast was used. From inside to outside 3 sets of different-size calcifications were placed in the breast motif, the diameter of which are 0.5, 0.8 and 1.0 mm, respectively. Each set consists of 24 calcifications, arranged in circular intervals. For radial resolution motifs, 6 sets of calcifications were placed in circumferential direction with 60˚ clockwise gap in between, the placed diameter of 0.5, 0.8, 1.0, 1.4, 2.0 and 3.0 mm, respectively. Five calcifications should be placed in radial location for the 3 kinds of diameters, which are 0.5, 1.0 and 2.0 mm, for the purpose of judging the resolution and beam hardening artifacts of radial calcification under the same conditions (Fig. 2).

Lump: Based in the calculation, the density of breast tissues was 1.02 g/cm^3. In our study, 5 different materials, whose density was similar to that of breast tissues, are used: PMMA, polyethylene, polytetrafluoroethylene, polyoxymethylene, and polyvinyl chloride. Moreover, air was instilled to enhance the contrast and 4 motifs of different sizes were placed along radial direction from inside to outside, the diameter of which are 2.0, 4.0, 6.0 and 8.0 mm (Fig. 3).

Evaluation of imaging quality. Signal-to-noise ratio (SNR), an important factor in imaging quality evaluation, is defined as the ratio between signal and noise. The larger the ratio is, the higher the imaging quality is; otherwise, the imaging quality is worse. In CT system, signal strength is related to photon counting received by detector. In one-time unit and with same energy, the more photon received by the detector in certain area, the better the stronger the signal is. Contrast-to-noise ratio (CNR) is the ratio between SNR comparison and the standard difference of noise. In the image gained in the simulation by GATE software, the signal is defined as gray value in the target area while noise value defined as average gray value in breast tissues. Matrix of 10x10 in the center is selected for lumps; 0.5 mm-2x1 matrix, 0.8 mm-2x2 matrix, 1.0 mm-3x3 matrix, and 2.0 mm-4x4 matrix are selected for calcification. Dose efficiency is η= Q/D1/2 and quality factor M= Q^2/D, in which Q refers to imaging quality. Calcification Q is the SNR value of 3-m diameter calcification; we selected 6-m diamater material CNR value as lump Q. The larger the quality factor is, the higher the resolution ratio of the image is providing the same amount of radiation dose is absorbed by the motif, and the higher the dose utilization the less dose waste.

Table I. Comparison of the coverage of calcification and lumps.

Groups	Calcification no.	Calcification diameter (mm)	Lump diameter (mm)
Head side	12.6±3.2	0.8±0.2	5.5±1.0
Foot side	12.3±3.0	0.7±0.2	5.6±1.2
Inner side	11.7±3.4	0.7±0.3	5.7±1.3
Outer side	13.5±3.2	0.8±0.2	5.4±1.2
Rear side	13.8±3.3	0.7±0.2	5.6±1.3
F-value	0.634	0.127	0.562
P-value	0.527	0.638	0.637

Statistics analysis. The coverage of head, foot, inner, outer and rear sides of the breast was evaluated by referring to O'Connell *et al* (4) and other standards and were demonstrated in the form of calcification number, diameter, and diameter of the lump in the area. SPSS 20.0 software (SPSS Inc. Chicago, IL, USA) was used for analysis of data and shown as mean ± standard deviation. One-way ANOVA was used to analyze the comparison among groups and data and shown as cases or percentage. A χ^2 test was used for inspecting the comparison among groups. Difference with $P<0.05$, was regarded as statistically significant.

Results

Comparison of the coverage of calcification and lumps. Comparison of calcification number, diameter, diameter of tumor in different area and the difference was not statistically significant (Table I).

Comparison of SNR and CNR in different areas. Based on the comparison of SNR and CNR in different areas, the difference was not statistically significant (Table II).

Comparison of dose efficiency η and quality factor M in different areas. Based on the comparison of dose efficiency η and quality factor M in different areas, the difference is not statistically significant ($P>0.05$) (Table III).

Discussion

It only takes 10 sec for CBBCT scanning and with 2D projection reconstructed image of the high-resolution 3D image of breast is formed, the pixel of which is 0.27/0.19 mm^3. Various tissue structures, such as skin, fat, glands, vessel, chest wall muscle, can be displayed in multi-perspective and multi-layer, so that overlapping of tissues can be eliminated. Spatial position of the lesion can be accurately located, and the feature of lesion can be clearly displayed. The phantom study evaluation on the system demonstrates (8) that CBBCT reconstructed image features isotropic spatial resolution and the resolution is the same in cross-section, coronal and sagittal images. As it is unnecessary to press the breast in CBBCT examination, in the study by O'Connell *et al* (9), 90% of the patients considered that it is as comfortable as, or even more comfortable, than breast X-ray examination. The safety of CBBCT radiation is equal to that of breast X-ray examination in diagnosis (10). Accordingly, the difference in the comparison of calcification number, diameter, and lump diameter in the head, foot, inner, outer and rear sides of breast was not statistically significant. The difference in the comparison of SNR and CNR, and dose efficiency η and quality factor M, in different areas was not statistically significant. Note that, the imaging quality of CBBCT in the head, foot, inner, outer, and rear sides of the breast is good with acceptable CT dose.

Table II. Comparison of SNR and CNR in different areas.

Groups	SNR	CNR
Head side	23.5±4.6	4.3±0.6
Foot side	24.2±4.5	4.0±0.7
Inner side	24.0±4.4	4.2±0.5
Outer side	23.6±4.3	4.5±0.6
Rear side	23.8±4.5	4.4±0.8
F-value	0.758	0.534
P-value	0.634	0.825

SNR, signal-to-noise ratio; CNR, contrast-to-noise ratio.

Table III. Comparison of dose efficiency η and quality factor M in different areas.

Group	η ($x10^2$)	M ($x10^4$)
Head side	7.5±1.0	5.3±0.4
Foot side	7.7±1.1	5.4±0.5
Inner side	7.8±1.2	5.5±0.6
Outer side	8.0±1.2	5.6±0.8
Rear side	7.9±1.3	5.3±0.7
F-value	0.326	0.424
P-value	0.521	0.936

The clinical experiments carried out in the Medical Center of American Rochester University and Elizabeth Wende Breast Care LLC demonstrate (11) that CBBCT can evaluate the density of breast glands quickly and reliably; display breast tissue accurately; display the vessel tissue with diameter less than 1 mm without using contrast agent; display 200-μm calcification and its distribution in 3D space. In the study comparing CBBCT and breast X-ray examination (12), the consistence rate of these two in breast cancer diagnosis is above 90%. CBBCT is superior to breast X-ray examination, not only in the aspect of the areas of breast covered, but also in being helpful in the display of multifocal lesion and dense breast cancer and the detection of tumors (13). In February 2015, FDA approved the KBCT system and KBCT-guided biopsy rack system. In November 2015, China's General Administration of Food and Drug approved the medical equipment registration of breast X-ray digital tomography device (model no. KBVt-1000) of Tianjin Kening Medical Equipment Co., Ltd. for use in the diagnosis and differential diagnosis of breast disease.

However, CBBCT is a new method for breast examination and currently there are no standardized operation criteria. Besides, it is necessary to further discuss the display of oxter lymph node and carry out CBBCT-guided breast puncture biopsy, by using 3D restructure image.

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