Original Investigation

Opportunistic Breast Density Assessment in Women Receiving Low-dose Chest Computed Tomography Screening

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Rationale and Objectives: Low-dose chest computed tomography (LDCT), increasingly being used for screening of lung cancer, may also be used to measure breast density, which is proven as a risk factor for breast cancer. In this study, we developed a segmentation method to measure quantitative breast density on CT images and correlated with magnetic resonance density.

Materials and Methods: Forty healthy women receiving both LDCT and breast magnetic resonance imaging (MRI) were studied. A semiautomatic method was applied to quantify the breast density on LDCT images. The intra- and interoperator reproducibility was evaluated. The volumetric density on MRI was obtained by using a well-established automatic template-based segmentation method. The breast volume (BV), fibroglandular tissue volume (FV), and percent breast density (PD) measured on LDCT and MRI were compared.

Results: The measurements of BV, FV, and PD on LDCT images yield highly consistent results, with the intraclass correlation coefficient of 0.999 for BV, 0.977 for FV, and 0.966 for PD for intraoperator reproducibility, and intraclass correlation coefficient of 0.953 for BV, 0.974 for FV, and 0.973 for PD for interoperator reproducibility. The BV, FV, and PD measured on LDCT and MRI were well correlated (all $r \geq 0.90$). Bland-Altman plots showed that a larger BV and FV were measured on LDCT than on MRI.

Conclusions: The preliminary results showed that quantitative breast density can be measured from LDCT, and that our segmentation method could yield a high reproducibility on the measured volume and PD. The results measured on LDCT and MRI were highly correlated. Our results showed that LDCT may provide valuable information about breast density for evaluating breast cancer risk.

Key Words: breast density; low dose chest CT; magnetic resonance imaging.

INTRODUCTION

Mammographic density has been proven as an independent risk factor for breast cancer (1,2). Women with dense breast tissue visible on a mammogram have a cancer risk of 1.8–6.0 times that of women with little density (3). A great research effort has been devoted to incorporate breast density into risk prediction models to better estimate each individual's cancer risk. Because the two-dimensional mammography-based measurement is subject to tissue overlapping, thus not able to provide true volumetric information, other emerging technologies based on three-dimensional (3D) imaging for assessing breast density are being developed. Among these new modalities, magnetic resonance imaging (MRI) is most well studied (4–6). Although breast MRI is suitable for volumetric analysis and segmentation tools are available, not many women can receive breast MRI because of its high cost. Currently, only high-risk women with lifetime breast cancer risks more than 20% will receive breast MRI for screening (7).

Low-dose chest computed tomography (LDCT) is increasingly being used for the screening of lung cancer (8–10) and diagnosis of other pulmonary diseases (11,12). According to a report from The National Lung Screening Trial, there was a 20% reduction in deaths from lung cancer among current or former heavy smokers who were screened with LDCT compared to those screened by chest X-ray (9). The overall average effective dose was approximately 2 mSv for LDCT, which was much lower than an average effective dose of 7 mSv for a typical standard-dose chest CT examination (13). Despite general radiation concern, LDCT is considered a safe screening tool, and its clinical use is anticipated to increase. Among the examinees, more than 40% are women (9). As

Acad Radiol 2016; ■:■■–■■

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http://dx.doi.org/10.1016/j.acra.2016.05.003

its popularity in clinical practice increases, besides lung cancer screening, LDCT has potential to provide additional information about breast density for personalized management of breast cancer screening.

Quantification of breast density using LDCT is, however, challenging because of the noisy imaging quality (14,15), which makes the segmentation of the fibroglandular tissue difficult. Thus, robust segmentation algorithms are required. A quantitative density segmentation method for LDCT was reported recently, showing that breast density measured from LDCT was lower than mammographic density (22 ± 0.6% vs. 34 ± 1.9%), but with a high Pearson correlation coefficient of r = 0.88 (16).

Our group has developed an automatic 3D MR-based method for breast density segmentation using sophisticated computer-assisted algorithms (17). In this study, we modified the method for segmentation on LDCT to explore the potential role of LDCT as a new density measurement method. We evaluated the intra- and interoperator reproducibility, and further, compared the volumetric density results analyzed from LDCT to those analyzed from 3D MRI as the ground truth.

MATERIALS AND METHODS

Subjects

This study was approved by the institutional review board and complied with the Health Insurance Portability and Accountability Act. From February 2009 to October 2011, we studied 40 healthy Asian female subjects (mean age 57, range 34–81) who had both LDCT and breast MRI performed within 1 year of each other. The imaging was done as part of the physical examination package. These women chose to receive LDCT for detection of early lung lesions and breast MRI for detection of early breast cancer. Dynamic contrast-enhanced breast MRI was done. No breast lesion was found in any subject; thus, results from bilateral breasts were included in the analysis.

Imaging Studies

Low-dose Chest Computed Tomography

The noncontrast-enhanced LDCT images were acquired with the examined women in supine position using a GE multidetector CT scanner (GE LightSpeed VCT). The imaging parameters were Kvp = 120, X-ray tube current = 50 mA, slice thickness = 5 mm, field of view = 340 mm, matrix = 512 × 512, and voxel size = 0.66 × 0.66 × 5 mm^3. In this study, only the CT images covering the breast region were used for the breast density analysis.

Breast MR Imaging

The breast MR images were acquired with the examined women in prone position at a 1.5T GE MR scanner (GE SIGNA HDx). An eight-channel breast coil was used. Noncontrast-enhanced axial fast spin echo T1 weighted (T1W) images were acquired first, followed by dynamic contrast-enhanced MRI. In this study, only the nonenhanced T1W images were used for the density analysis. The imaging parameters for the T1WI were acquisition type = two-dimensional, repetition time = 583 ms, echo time = 8.6 ms, flip angle = 90 degrees, slice thickness = 5 mm, spacing between slices = 5 mm, number of average = 0.5, percent sampling = 57%, echo train length = 3, field of view = 280 × 280 mm, matrix = 512 × 512, and voxel size = 0.55 × 0.55 × 5.00 mm^3.

Breast Segmentation and Quantification of Breast Density

Because the LDCT density segmentation method was newly developed, we first conducted intra- and interoperator consistency studies (performed by YCT and PYH) based on 10 randomly selected subjects from the cohort. After this initial reproducibility analysis, one operator (YCT) who had a better reproducibility was chosen to perform the segmentation on LDCT and breast MR images of the remaining 30 subjects.

Breast Density Analyzed From LDCT

For LDCT-based breast segmentation, there were two major challenges. First, the chest wall cannot be easily removed by intensity-based methods because its brightness level is similar to that of fibroglandular tissue on the images. Second, the images are noisy, which makes segmentation of fibroglandular tissue more difficult. The segmentation methodology has three procedures: image preprocessing, breast segmentation, and fibroglandular tissue segmentation.

The image intensities within the entire CT imaging slab were in a range around 30,000, and it had a low contrast in the breast region. Therefore, the first step was to rescale the gray level to enhance the contrast. The gray-level histogram of LDCT has two peaks. The first peak includes dark signal coming from background, lung, and fat tissue; the second peak contains the fibroglandular tissue, bones, and muscles. The histogram was fitted to separate the two peaks, and the beginning point of the second peak was used as a threshold to remove tissues contained within the first peak.

To define the posterior boundary of the breast, a horizontal line that connects the lateral margin of the pectoralis muscles at the aortic arch level was manually drawn, and this line was applied to all slices as an anatomical landmark to remove the posterior nonbreast tissues (Fig 1). The operator could adjust the line dorsally to ensure that all the fibroglandular tissue was included. The superior and inferior boundaries of the breast were defined by comparing the thickness of breast fat to the thickness of the body fat. The subcutaneous fatty tissue of the nonbreast (body) region on the chest typically displays homogeneous thickness across the chest wall, which could be used to determine where the breast starts and ends.

Further, the tissues inside the thoracic cavity region needed to be removed using morphological processing, as shown in Figure 2. The dark region of the left and right lungs was first identified as a mask (Fig 2b), and then this mask was expanded using morphological dilation to cover all bright regions