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An Experimental Study of the Scatter Correction by Using a Beam-stop-array Algorithm with Digital Breast Tomosynthesis

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Digital breast tomosynthesis (DBT) is a technique that was developed to overcome the limitations of conventional digital mammography by reconstructing slices through the breast from projections acquired at different angles. In developing and optimizing DBT, The x-ray scatter reduction technique remains a significant challenge due to projection geometry and radiation dose limitations. The most common approach to scatter reduction is a beam-stop-array (BSA) algorithm; however, this method raises concerns regarding the additional exposure involved in acquiring the scatter distribution. The compressed breast is roughly symmetric, and the scatter profiles from projections acquired at axially opposite angles are similar to mirror images. The purpose of this study was to apply the BSA algorithm with only two scans with a beam stop array, which estimates the scatter distribution with minimum additional exposure. The results of the scatter correction with angular interpolation were comparable to those of the scatter correction with all scatter distributions at each angle. The exposure increase was less than 13%. This study demonstrated the influence of the scatter correction obtained by using the BSA algorithm with minimum exposure, which indicates its potential for practical applications.

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I. INTRODUCTION

The digital mammography system is a major tool for early detection of breast cancer. It has been applied to reduce cancer mortality throughout the world, and it has a high sensitivity, wide dynamic range and a relatively low patient radiation dose compared to screen-film mammography. However, digital mammography is far from perfect due to several limitations. The most significant downfall of mammography is its representation of three-dimensional breast information in a two-dimensional projection, which can create two problems. First, the sensitivity is reduced because lesions and dense glandular tissue can be obscured by overlap. Second, the normal tissues parallel to the detector's surface, which is vertically separated from it, can be misdiagnosed as a lesion [1,2].

Due to these above limitations, three-dimensional breast imaging has been investigated with 3D imaging modalities such as dedicated breast computed tomography (CT) and the digital breast tomosynthesis (DBT). Although breast CT has been studied for a decade in breast cancer screening, this modality is not clinically viewed as having a practical role in breast cancer screening due to concerns about radiation dose and cost effectiveness [3]. Although dedicated breast CT is still promising, the DBT system has received approval for clinical use around the world. Tomosynthesis is a system of technique that enables pseudotomographic imaging by acquiring multiple X-ray images at a set of angles while the detector is stationary or rotating. The projections are then combined into a reconstructed three-

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dimensional dataset in thin slices with high in-plane resolution. DBT can be performed with doses comparable to those of conventional mammography scans within a short examination time [4,5].

The major scattering processes between X-ray photons and materials in the range of the X-ray spectrum used for most medical diagnostic purposes are the Compton effect and coherent scattering. Scattering events within the irradiated object have a major influence on the conspicuity of the details within the images, including contrast reduction, loss of image sharpness, and increased in image noise [6]. Moreover, scattering radiation causes errors in the reconstruction of the linear attenuation coefficient (LAC), which produces cupping artifacts and reduces the tissue contrast or contrast-to-noise ratio (CNR). Consequently, the image quality of the reconstruction image and the detectability of small tumors are degraded.

In breast imaging, the probability of photoelectric absorption in the breast is important. Nevertheless, the probability of Compton scatter X-rays in the breast is still high. To compensate for these effects, the conventional mammography system generally applies an anti-scatter grid to limit the intensity of radiation scatter created in a radiographic exposure reaching the image receptor while the intensity of the primary radiation is reduced. For the DBT system, however, the use of an anti-scatter grid presents several challenges due to the projection geometry of the rotation of the X-ray tube and radiation dose considerations [6,7]. Given these limitations of conventional scatter reduction methods for the DBT system, computerized methods, involving the use of computer imaging processing to compensate for scatter signals after image acquisitions, were introduced. Two major methods for computerized scatter corrections have been developed. The first method is a convolution filtering scheme, which assumes that the distribution of scatter signals is equivalent to a blurred version of the distribution of primary signals. The second method is a scatter sampling scheme based on both the assumption that the scatter distribution is equivalent to a low-frequency surface and the determination of the scatter signal in individual pixels in order to determine the overall scatter distribution [6].

Several previous studies applied a beam-stop-array algorithm to cone-beam breast CT to demonstrate the practicality and the effectiveness of scatter reduction. The limitations of the original BSA algorithm are an increased patient dose and an increased data-acquisition time due to the additional exposure that is needed to acquire the scatter pattern. In digital breast tomosynthesis imaging, the shape of the compressed breast is roughly symmetric, and the scatter distribution shows a similar trend between two projections acquired with both sides of the tube angles based on 0°. This makes projection at each angle unnecessary, and all the scatter patterns are analogized from a few additional projections with a beam stop array. This newly-introduced scatter correction technique for digital breast tomosynthesis reduces the number of additional scans required for scatter estimates with the beam-stop-array, resulting in minimal exposure increase with reduced scatter [8–11].

The purpose of this study was to apply the beam-stop-array (BSA) algorithm for acquiring only two scans with a beam-stop-array to estimate the scatter distribution and to demonstrate the influence of the scatter correction obtained by using the BSA algorithm. Given the minimal radiation exposure of this technique, the results indicate a potential for practical applications in clinics. In addition, X-ray scatter in digital breast tomosynthesis over different angular positions with varying breast thickness was characterized.

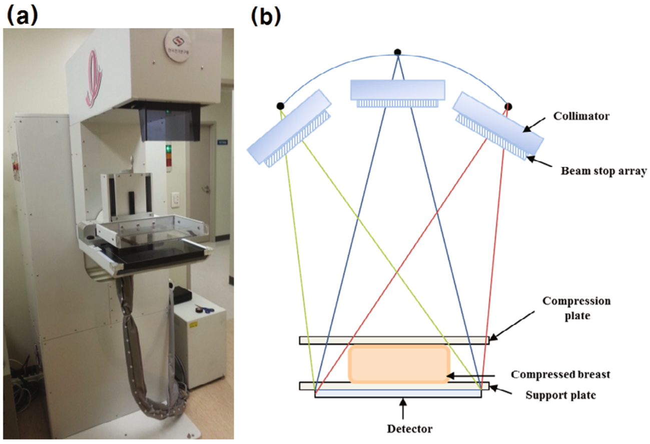

Fig. 1. (Color online) Illustration of the DBT prototype: (a) system overview and (b) schematic diagram.

II. MATERIAL AND METHODS

1. Image Acquisition System

Figure 1 describes the prototype DBT system [KERI DBT system, Korea Electrotechnology Research Institute (KERI), Korea] used in this study. This system was developed by KERI and was prepared for clinical application with ongoing clinical research. The KERI DBT system consists of an X-ray tube, a CsI phosphor/CMOS (complementary metal-oxide-semiconductor) flat-panel detector (2923MAM, Dexela Ltd., UK), a compression paddle, and a PC. The detector for the DBT system is optimized for very low exposures with a rapid readout. The pixel gain setting was chosen for a low-full mode, enabling high sensitivity for low dose per frame, which was optimized for fluoroscopy, cone-beam CT, and tomosynthesis. The active area of the detector was 29.1 $\times$ 23 cm^2, with a 3072 $\times$ 3888 matrix size, and the pixel size was 0.0748 mm. An X-ray tube (XM1016T, Industria Applicazioni Elettroniche, Italy) was used in this study; it had a nominal focal spot size of 0.3 mm. A target/filter combination of tungsten (W)/rhodium (Rh)