

# A novel approach to digital breast tomosynthesis for simultaneous acquisition of 2D and 3D images

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## Abstract

**Objective** The complexity of anatomical structure within the breast represents the ultimate limit to signal detection on a mammogram. To increase lesion conspicuity Digital Breast Tomosynthesis (DBT) has been recently proposed and several manufacturers are currently performing clinical trials. In this study we investigate the potential of DBT with variable dose distribution by using a phantom in which details of interest are within a heterogeneous background. **Methods** To compare the performance of a commercial digital mammography unit and a DBT prototype, 2D and 3D images of the breast phantom were obtained at similar dose levels.

**Results** As expected, DBT showed superior performance over digital mammography. Although certain details of interest are not detectable with digital mammography, DBT can reveal their signal by reducing the complexity of tissue structures. Additionally, the potential of the central projection in variable dose DBT is similar to the standard projection obtained with digital mammography. Finally, the uniform and variable dose approaches provided almost identical reconstructed slices.

**Conclusion** This preliminary investigation demonstrates that breast tomosynthesis acquired with variable dose distribution exhibits inherent 3D reconstruction advantages for structure noise removal and provides a 2D projection with a physical image quality close to that of standard mammography.

**Keywords** Tomosynthesis · Digital mammography · Breast phantom · X-ray imaging · Variable dose

## Introduction

The lack of conspicuity is the ultimate limitation to breast cancer detection. This is particularly important in dense breasts where the overlying fibroglandular structures, which are responsible for the so-called “structure noise”, may either obscure or simulate disease. Advanced applications of digital mammography aim to increase lesion conspicuity by reducing the contribution of structure noise. Digital Breast Tomosynthesis (DBT) is one of the most promising among such advanced applications. Its main advantages are the improvement of the conspicuity of structures, the possibility of depth localisation, and the smaller dynamic range required for each reconstructed slice [1]. In tomosynthesis, a volume image is created from a sequence of projection views acquired over a limited arc. This can overcome the main disadvantages of the application of computed tomography to breast imaging, i.e. the high dose required to take the necessary number of projections, and the poor spatial resolution with respect to breast diagnostic needs. In DBT, tomographic planes are parallel to the detector surface, their thickness can be around 1 mm, and they offer an in-plane spatial resolution comparable to a 2D projection. Practical implementations of the acquisition

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geometry of a tomosynthesis device for breast imaging can be very different, depending on whether one prefers to stress in-plane or off-plane spatial resolution. Among the parameters that can be varied, the most important are: angular range, angular spacing, number of projections, tube motion, position of the axis of rotation and dose distribution.

Clinical studies with investigational devices developed by different manufacturers of digital mammography systems have explored the diagnostic potential of DBT. Poplack et al. [2] compared DBT with diagnostic film-screen mammography, based on a cohort of 98 women with an abnormal digital screening mammography. The prototype tomosynthesis unit, manufactured by Hologic (USA) recorded 11 low-dose images while the X-ray source moved in a 28° arc. Acquisition time was approximately 19 s. No information was provided on the reconstruction algorithm. The total radiation dose for each tomosynthesis acquisition was approximately twice the dose delivered in standard mammography, for a mean breast thickness. The authors concluded that, although the results of the study were promising, further investigations are needed to define the role of tomosynthesis in breast imaging.

Breast cancer visibility between DBT and full-field digital mammography (FFDM) was compared by Andersson et al. [3] in a population of cancers. DBT was performed on a prototype unit adapted from a digital mammography system manufactured by Siemens (Germany). Twenty-five projection images were acquired over an angular range of 50°, with double the dose of one-view FFDM. Acquisition time was 20 s and image reconstruction was performed by filtered backprojection. For the number of cases studied, which included only women with subtle mammographic findings, the results suggested that DBT may have a higher sensitivity for breast cancer detection than FFDM.

Gennaro et al. [4] compared the clinical performance of DBT with that of FFDM in a diagnostic population of 200 women. By using prototype equipment manufactured by GE Healthcare (USA), the acquisition protocol was set to 15 projections over 40°. An iterative SART (simultaneous algebraic reconstruction technique) algorithm was applied for 3D reconstruction. The organ dose delivered by DBT in one view was comparable to that of standard screen film mammography in two views. Although an increase in lesion conspicuity was found with DBT compared with FFDM, the authors concluded that such an increase did not allow a measurable improvement of diagnostic performance.

Several studies are still being carried out to define the optimal DBT configuration, and we focus here on the possibility of unevenly distributing radiation exposure among the projections. Thanks to a collaboration with Dixela (UK), IMS (Italy) can exploit the advantages shown

in the paper of Wu et al. [5], and patented by Stanton et al. [6], in which the use of both variable angular spacing and dose distribution have been suggested. In particular, we think that there could be a double advantage in increasing the radiation exposure of the central projection (0°) of the tomosynthesis, total dose being equal. The higher statistics of the central projection could in fact be used as 2D image mammography for standard diagnosis and it could also improve the quality of the reconstructed image. This kind of approach has already been explored by a simulation study [7], with inconclusive results. However, it is worth noting that DBT performance is strongly affected by the specific geometry adopted for the system, as well as the reconstruction algorithm used for generating the tomographic planes.

The aim of this preliminary study is to evaluate the feasibility of a novel approach to DBT in which sufficient dose is given to the central projection so as to simultaneously obtain a 2D mammogram and a 3D reconstruction of the breast. Physical image quality has been investigated by means of a phantom that exhibits the characteristics of real breast tissue and a comparison between FFDM and DBT in both uniform and variable dose configurations is presented.

## Materials and methods

### Imaging systems

The tomosynthesis device used in this study is a prototype developed by IMS [8]. The system is equipped with an a-Se digital detector (ANRAD LMAM [9]), with a sensitive area of 24×30 cm<sup>2</sup> and a squared pixel pitch of 0.085 mm, resulting in an image size of 2,816×3,584. The detector is operated in the so-called “Tomo Mode” configuration, i.e. a dedicated firmware and settings that optimise performance for fast, low-dose acquisitions.

In particular, the optimisation provides higher gain and faster read-out process, with respect to the standard mammographic configuration, albeit at the cost of a narrower dynamic range. The ANRAD detector has been fully characterised for tomosynthesis application [10], showing that larger oblique angles and lower dose do not affect significantly image quality, and that the detector performance is limited by quantum noise at the low exposures used in each view of tomosynthesis.

The movable x-ray source spans an overall angular range of ±17° and thus, acquiring a configurable number of projections at the requested positions. In the present work, uniform angular spacing has been chosen. Our configuration consists of 13 projections acquired in 2.8° increments. The angular step chosen is similar to the optimal value

found in the literature [11, 12]. The prototype uses a W-target/Ag-filter x-ray source for all breast thicknesses. No antiscatter grid is used. Exposure values for DBT in one view were defined as a function of breast thickness so as to deliver a radiation dose not higher than that for digital mammography in two views (see the 4th ed. of the European Guidelines [13]).

The mammographic images of the phantom have been recorded with the Giotto 3D, a commercial FFDM unit also manufactured by IMS. The unit selects the W-target/Ag-filter combination for all the breast thicknesses above 2 cm and is equipped with the ANRAD digital detector operated in the standard configuration (or “Mammo mode”). Exposure parameters were determined by AEC.

Phantom

The phantom used for the whole study is model 020 BR3D produced by Computerized Imaging Reference Systems Inc. (CIRS) [14], designed to assess detectability of lesions of various sizes within a complex background that is generated by a heterogeneous tissue-equivalent material. The phantom consists of a set of six semicircular slabs, 1 cm thick, each made of two tissue-equivalent materials mimicking 100% adipose and glandular tissues “swirled” together in a approximate 50/50 ratio by weight. One of the slabs contains 6 clusters of CaCO<sub>3</sub> specks, 7 fibres and 6 spheroidal masses. For the experiment we assembled the phantom as a 5 cm thick object, composed of the slab containing the details sandwiched between two pairs of heterogeneous background slabs.

Acquisition conditions

We performed the following image acquisitions for this comparative study: one FFDM, one DBT with uniform dose distribution and one DBT with variable dose distribution. All radiographs of the phantom have been recorded with the same setting of 28 kV. The dose distribution for the two DBT configurations is shown in Table 1.

From the variable dose acquisition, the central projection has been extracted for comparison with FFDM. Characteristics of the acquisitions are listed in Table 2. As the

**Table 1** Dose distribution among projections in digital breast tomosynthesis (DBT) of the phantom

DBT acquisition configuration	image weights [−17° ··· 0° ··· +17°]
Uniform dose	1 ··· 1 ··· 1
Variable dose	0.81 ··· 3.3 ··· 0.81

**Table 2** Acquisition parameters for the phantom evaluation

Breast imaging technique	grid	average glandular dose [mGy]	acquired images	angular range
FFDM	yes	1.4	1	0°
Central projection	no	0.6	1	0°
DBT (variable)	no	2.8	13	±17°
DBT (uniform)	no	2.8	13	±17°

tomosynthesis system does not use the antiscatter grid, the statistics obtained on the detector by the central projection of the DBT with variable dose is similar to the one obtained by a standard FFDM.

Software for tomosynthesis reconstruction

Reconstruction is the process by which data from the acquired projections are used to create a 3D volume. The reconstruction algorithm is an important element for optimisation of the system, as it contributes to determining the overall image quality as well as the mechanical, geometrical and dosimetric parameters. The algorithm adopted by IMS has been developed by Dexela [15] and is based on an iterative method that uses Total Variation regularisation. Iterative methods have been proposed as alternative to the common Filtered Back Projection methods in the case of a limited number of x-ray projections so as to reduce streaking artefacts and to increase the signal-to-noise ratio [16]. The projections are first converted into density images and then back projected into the volume which is expected to contain all the projected information. The volume is then forward projected to form comparisons with the original projections. The error is obtained and penalty function applied [17]. The update is then back projected. The volume is regularised by slice and then re-projected for the next iteration. Dexela can also use a multi-scale approach to increase the iterations possible in a given time which also helps to smooth noisy data. Dexela’s technology allows images to be reconstructed for any geometrical configuration of the system. The number of projections as well as their angular position and their relative weight in the reconstruction process can be varied. Pixel size of the image can be chosen as any multiple of the detector pixel and slice thickness can be freely chosen. Input weights in the present work were all set to 1, except for the central projections of the variable dose configuration, for which the normalised dose ratio was used (see Table 1 for details). Reconstructed volume was 20 cm×14 cm×5 cm, i.e. slightly larger than the phantom volume, and the voxel size was 0.085 mm×0.085 mm×1 mm.

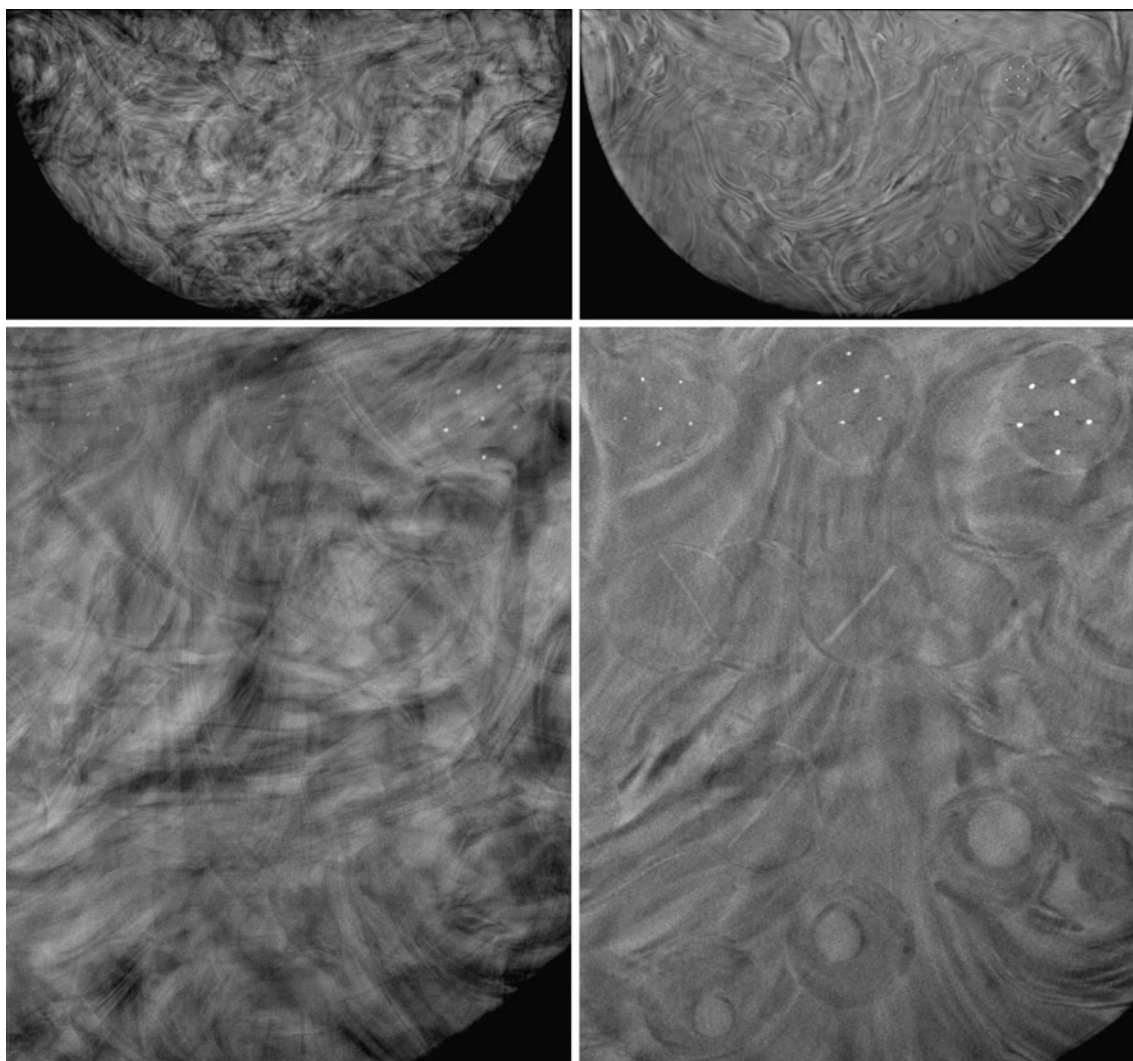
## Results and discussion

The recorded images can be paired for three main purposes: comparison of FFDM and DBT to investigate the effect of structural background removal, comparison between standard FFDM and central projection in variable dose DBT to evaluate the potential of the standalone projection in medical diagnosis, and comparison between DBT reconstructed images obtained from the uniform dose distribution and the variable dose distribution to study the effect of the different approaches.

### 2D projection vs 3D reconstruction

The radiograph of the CIRS phantom is compared in Fig. 1 with the tomosynthetic slice containing the phantom details.

The lower images also show an enlarged region that contains three masses, three specks and three fibres. Despite phantom repositioning and a slightly different image magnification between FFDM and DBT, there is no doubt that the strong difference in the detectability of the details is due to the nature of the two imaging techniques. All the details are apparent in the DBT slice, but only the specks are immediately visible on the mammography. This example confirms that lesion conspicuity is the fundamental limit to signal detection, particularly in dense breasts where the overlying fibroglandular structures may obscure subtle signs of breast cancer [18]. Indeed, the reduction of structure noise significantly increases the conspicuity of low-contrast details (masses and fibres) whilst the high-contrast details (specks) are already detectable on the mammogram.



**Fig. 1** Comparison between the two breast imaging techniques. *Left*: FFDM of the CIRS phantom. *Right*: 1-mm slice containing the features of the phantom reconstructed from a uniform dose DBT. *Top*: Full image. *Bottom*: Magnification of the larger details

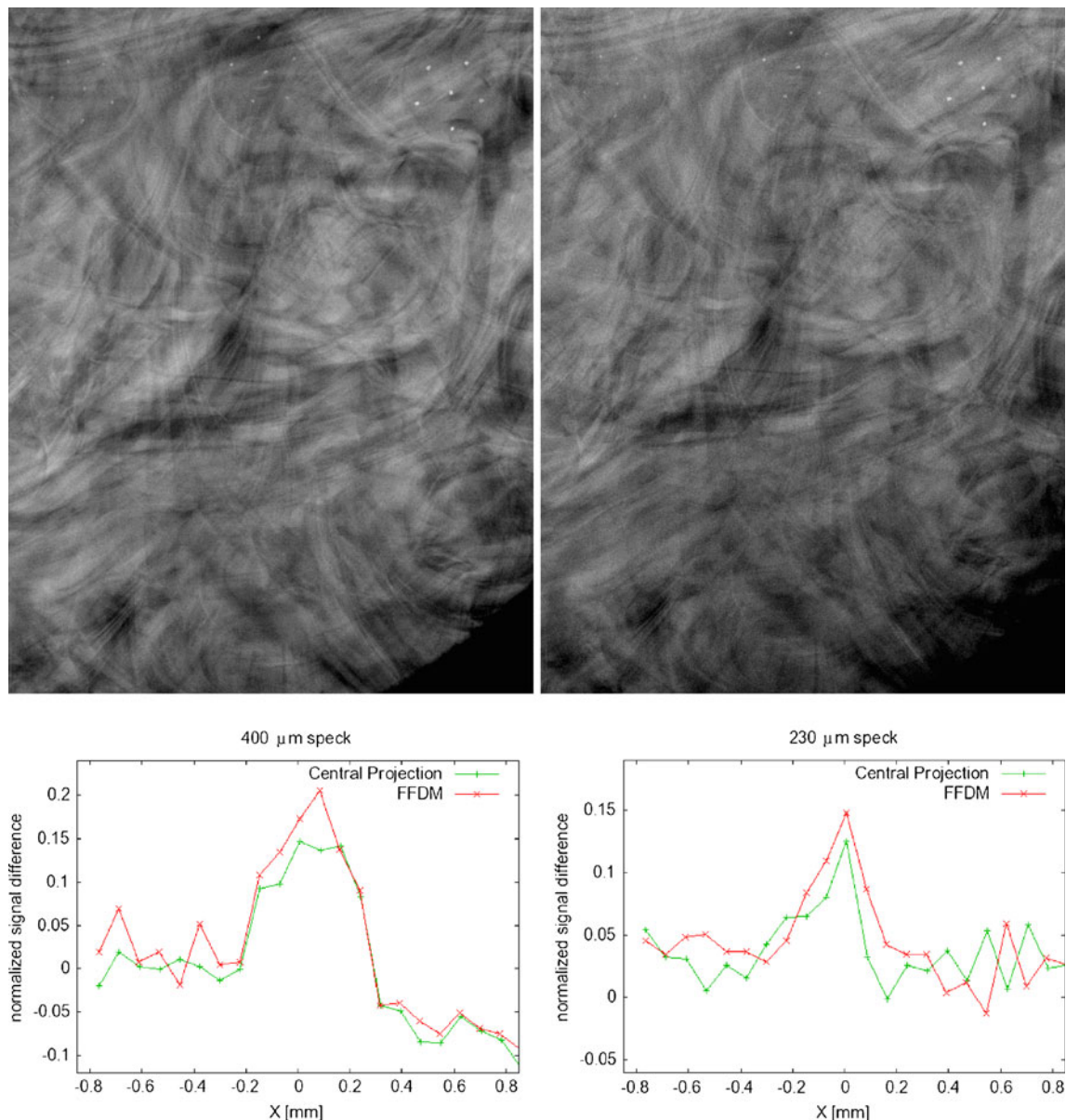
## Planar images: FFDM vs central projection of variable dose DBT

As already discussed, the advantage of a variable dose approach lies in the combination of structural background removal via tomosynthesis and the recording of a more familiar mammogram in the same acquisition.

In Fig. 2 the mammography of the phantom is compared with the central projection of the variable dose DBT. Although the image quality of the mammography is slightly different from that of the DBT projection, the same number of details is visible in the magnification: in both images all the specks are clearly visible while the others details are only barely visible.

Optimisation of image quality and dose in mammography requires a detector dose that is sufficient to ensure detection of small details, i.e. microcalcifications. Such details are very sensitive to quantum noise but experimental studies have shown that detection of masses is limited by the structure noise of the parenchymal pattern rather than quantum noise [19]. Again, this means that lack of conspicuity is the ultimate limitation to breast cancer detection.

It is worth noting that the DBT central projection was recorded without the anti-scatter grid, yet the detectability of small-area details is not significantly affected by the scatter PSF (Point Spread Function). This is confirmed by the comparison of contrast profiles for two specks of

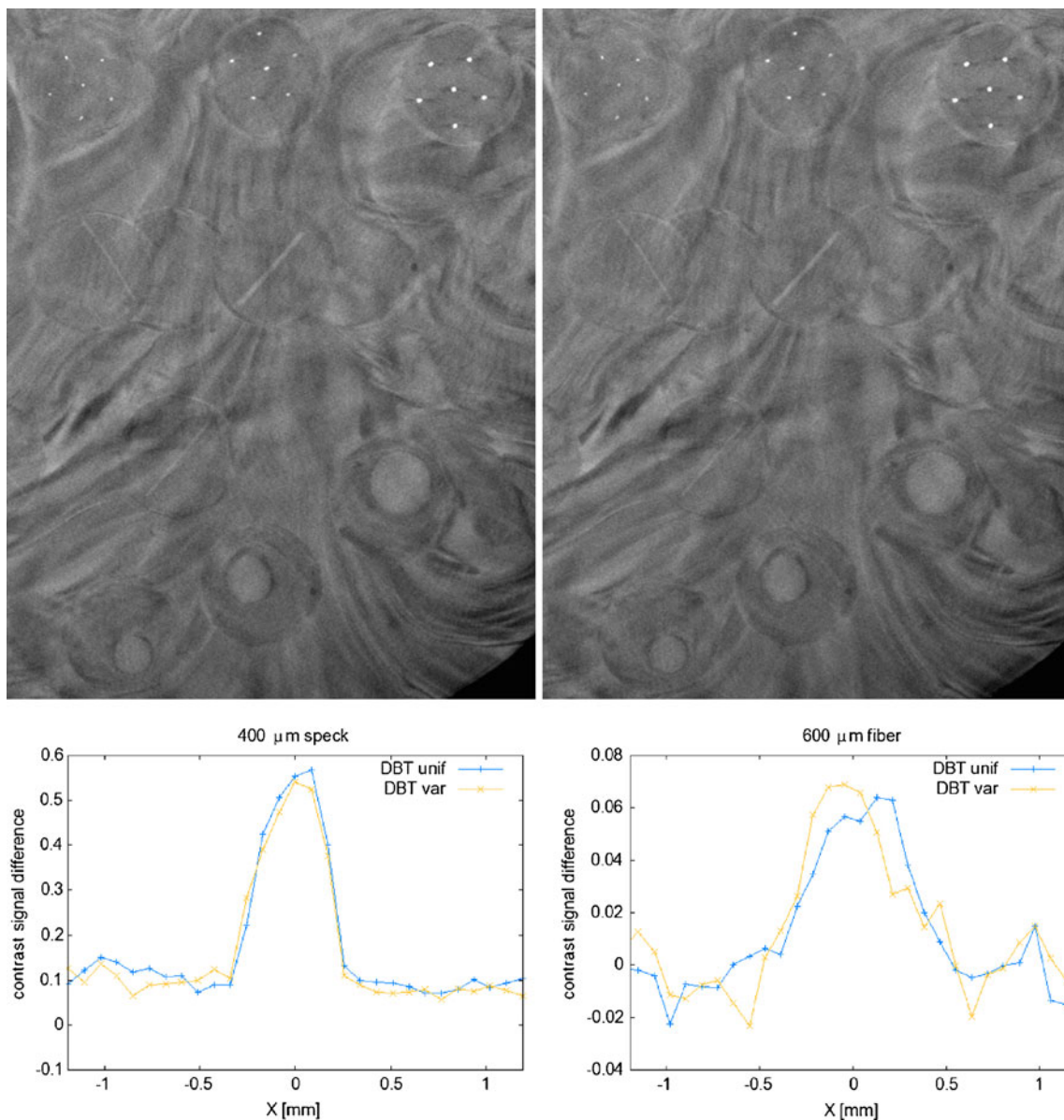


**Fig. 2** Top: Magnified feature area of planar images of the CIRS phantom. Left: FFDM. Right: Central projection from the variable dose DBT. Bottom: Contrast profiles of two details of the phantom. Left:  $\text{CaCO}_3$  of 0.400 mm in size. Right:  $\text{CaCO}_3$  of 0.230 mm in size

different sizes (see the plots of Fig. 2). The influence of scattered x-rays on image quality is a subject that has been largely investigated in the past both theoretically and experimentally, and its investigation is beyond the scope of this work. Nevertheless, clinical evaluation of the proposed DBT technique will also allow us to gain further insight into this issue. If successful, DBT with variable dose distribution will offer significant advantages over the current DBT approach. If both the 2D and 3D x-ray images of the breast are required, the simultaneous acquisition will minimise the exposure time which will also result in increased patient comfort. Most importantly, it will largely reduce the total patient dose.

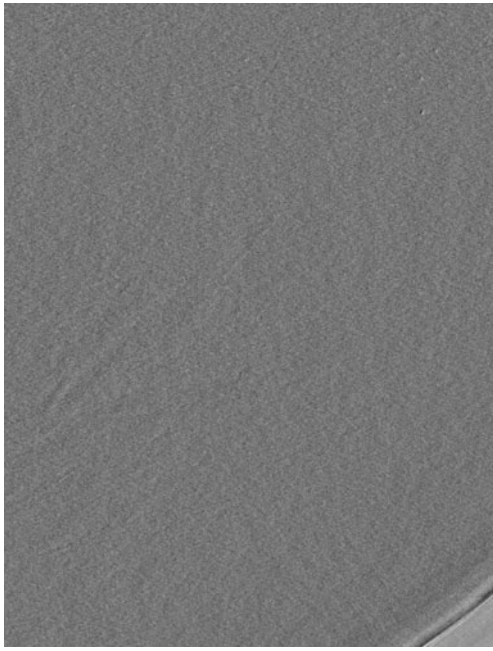
### Reconstructed slices: uniform vs variable approach

In Fig. 3 the tomosynthetic slices reconstructed from uniform dose DBT and variable dose DBT are shown. No remarkable difference is visible by eye and the same number of details is detected: 3 specks, 3 fibres and 3 masses. The equivalence of the two acquisition techniques in terms of image quality is confirmed by the quantitative evaluation of the contrast for two details of interest, as shown in the plots of Fig. 3. Finally, the algebraic subtraction of the two images (see Fig. 4) demonstrates that the reconstructions are almost identical, except for very small variations (less than 1% from the



**Fig. 3** *Top*: Magnified feature area of tomosynthesis reconstructions of the layer insert of the CIRS phantom. Reconstructed slice is 1 mm thick. *Left*: Uniform dose configuration. *Right*: Variable dose

configuration. *Bottom*: Contrast profiles of two details of the phantom. *Left*:  $\text{CaCO}_3$  of 0.4 mm in size. *Right*: Fibre of 0.6 mm in diameter



**Fig. 4** Image difference of the magnified feature areas of tomosynthesis reconstructions shown in Fig. 3

original pixel value) because of a slight misalignment of the digital coordinates.

## Conclusions

A breast phantom made of heterogeneous tissue-equivalent material is a useful tool for evaluating lesion detectability in digital mammography and digital breast tomosynthesis. In this preliminary study, we have shown that the variable dose geometry is a viable approach to digital breast tomosynthesis with a number of potential advantages over the standard acquisition geometry. In particular, it allows the simultaneous acquisition of 2D and 3D images of the breast so as to yield in one shot a projection view and a reconstruction view. Needless to say, clinical trials are required to demonstrate that the simultaneous recording is able to provide an efficient method for tomosynthesis reconstruction and an x-ray image of the breast that is comparable to state-of-the-art mammography.

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