Evaluation of the *BreastSimulator* Software Platform for Breast Tomography: Preliminary Results

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Abstract. The aim of this work is the evaluation of the software *BreastSimulator*, as a tool for the creation of 3D uncompressed breast digital models and for the simulation and the optimization of computed tomographic (CT) equipment. Three 3D digital breast phantoms were created, having different sizes and with realistic anatomical features. We calculated 2D X-ray CT projections simulating a breast tomogram with a dedicated cone-beam CT scanner. From the reconstructed CT slices, the power-law exponent, β, has been evaluated from the Noise Power Spectrum function $S(f) = \alpha/f^{\beta}$. The results were then verified by comparison against clinical CT and published data. The preliminary results of this study showed that the simulated model complexity may reproduce the real anatomical complexity of the breast tissues as described, in terms of β values, since the measured β coefficients are close to that of clinical CT data from a dedicated breast CT scanner.

Keywords: Breast Computed tomography, Noise Power spectrum, breast software phantoms, X-ray simulations.

1 Introduction

Digital Mammography (DM) is a fundamental technique in breast cancer diagnosis. DM returns a two-dimensional representation (2D) of a compressed three-dimensional object. Therefore, tissues belonging to different planes are all projected on the same X-ray image plane, making it difficult to detect possible abnormalities. In order to overcome this limitation, CT scanners dedicated to the breast have been developed using monochromatic [1, 2] or polychromatic [3, 4] X-ray beams, which return tomographic 3D images of the breast anatomy. However, these techniques need to be optimized before applying them clinically; thus, there is the need to develop X-ray imaging models for the compressed as well as uncompressed breast. Physical phantoms with realistic anatomical characteristics used for image quality assessment, have a high cost. On the other hand, the increasing use of powerful computers allows designing digital phantoms rather than physical phantoms.

Simple mathematical breast phantoms, usually in the form of a cylinder, a half-ellipsoid or slabs of homogeneous material with a given glandular to adipose breast ratio, are widely used in simulations particularly for dosimetry and optimization of acquisition geometry [5, 6]. However, when it is necessary to investigate the detectability of lesions, the performance of image processing algorithms, the reconstruction algorithms, etc., the use of a homogeneous background is a limitation, since the anatomical noise is not reproduced.

BreastSimulator [7] is a software support tool for research in breast imaging. It allows the creation of realistic 3D uncompressed breast models. With this software, it is possible to simulate mammographic, tomosynthesis and tomographic breast imaging geometries with monochromatic and polychromatic beams.

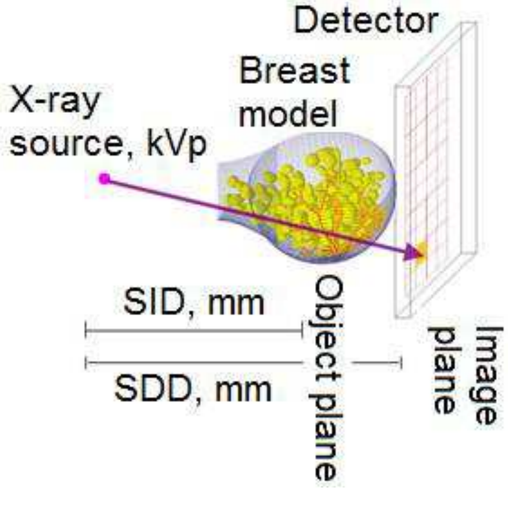

Fig. 1. Example of the simulated X-ray projection setup with the X-ray imaging module.

This software was previously evaluated as a reliable tool for the simulation of DM systems [8] with good results. In this study, we evaluated *BreastSimulato*r, as an appropriate X-ray simulator for dedicated breast CT. This investigation is based on the measure of anatomical noise, evaluated by calculating the β exponent deduced from the power spectral analysis of the CT simulated images.

2 Material and Methods

2.1 Breast Simulator

The main components of Breast Simulator [7, 8] are the X-ray imaging module and the breast composition model. The first module contains information for the acquisition geometry, number of projections images, gantry angles and detector type. X-ray projections images are obtained with simulation of monochromatic X-ray photon transport starting from the X-ray source, passing through the breast model and reaching the detector (fig. 1). The Siddon's algorithm for tracing the X-rays from the source to detector pixels is applied. Poisson quantum noise is also added to the original ideal images, using a Gaussian random number generator, with a variance set equal to the number of photons incident on each detector pixel. For simulating a polyenergetic beam, the images obtained at each monochromatic energy were averaged by weighting for the corresponding photon fluence in the spectrum.

The Breast module is used to generate breast models. The simulated features include breast shape, skin, the duct system (fig. 2a) and terminal ductal lobular units, Cooper's ligaments (fig. 2b), the pectoral muscle, the 3D mammographic background (glandular and adipose tissue) and breast abnormalities (masses, lesions, microcalcifications).

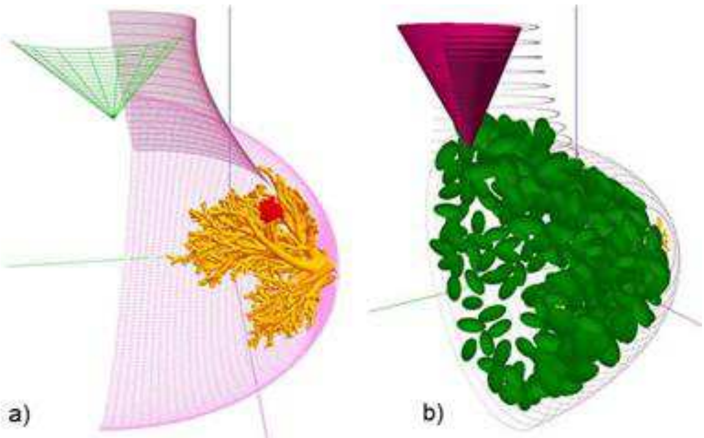

Fig. 2. Example of simulated breast elements (duct system (a) and Cooper's ligaments (b)) with the Breast module.

2.2 Setup Description

The simulated setup was a cone-beam irradiation geometry, with source to isocenter distance (SID) and source to detector distance (SDD) set to 458 mm and 866 mm, respectively. The detector was modeled with a size of 700×700 pixels, and a resolution of 3 pixels/mm, in order to match the resolution of the available clinical CT scan images. Scatter and detector responses have not been included in this simulation. Three realistic 3D uncompressed breast models were created with 64 bit Linux operating system on a Intel Core 2 Quad Processor Q8200 2.33 GHz, with 8 GB RAM. Figure 3 shows the CT views for one of these models.

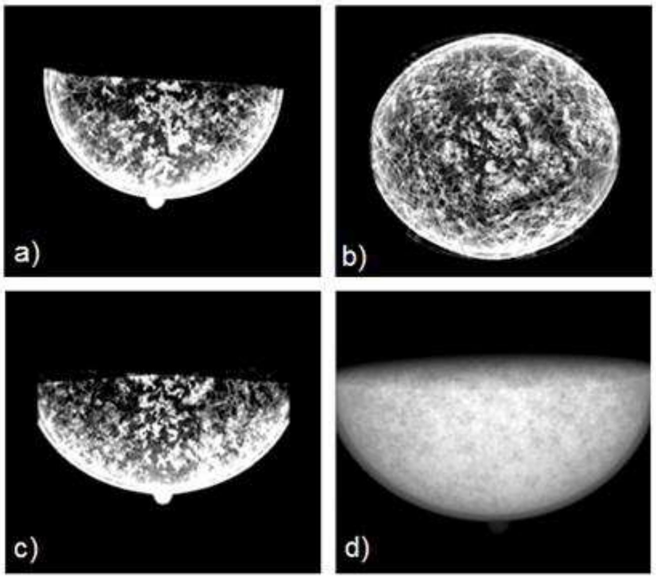

Fig. 3. Example of a sagittal (a), axial (b) and coronal (c) reconstructed CT slices and an X-ray projection (d) obtained with *BreastSimulator* software.

2.3 Assessment of the β parameter

The projections of the simulated uncompressed breast (fig. 3d) were reconstructed with a commercial software (Exxim COBRA) implementing the FDK algorithm, providing axial, coronal and sagittal views (fig. 3a,b,c) in a virtual CT image of $(512)^3$ voxel of $(0.300\text{ mm})^3$. From these reconstructed slices, the power-law exponent β derived from the Noise Power Spectrum (NPS) fitting function $S(f) = \alpha/(f^{\beta})$ has been evaluated [9], where f is the spatial frequency, evaluated in the range 0.05–0.5 mm^{-1}. To derive this value, 100 ROIs have been selected randomly inside a single coronal slice (fig. 4a). Then, the 2D NPS was computed by means of the Fast Fourier Transform for each ROI and the mean 2D NPS was determined by averaging the NPS from the 100 ROIs. In order to obtain a 1D NPS, a radial profile was evaluated. Finally, we calculated the β coefficient, as the negative slope of the fitting line returned by computing a linear fit of log(1D NPS) vs log(f) (fig. 4c).

In order to make a comparison with measured clinical data the same procedure for the β evaluation was applied on clinical tomographic images kindly provided by the team at University of California Davis Medical Center (UCDMC) (1 patient) and Radboud University Medical Center (RUMC) (3 patients) which adopt two different clinical breast CT scanners (described in refs. [9, 10], respectively) (fig. 4c).

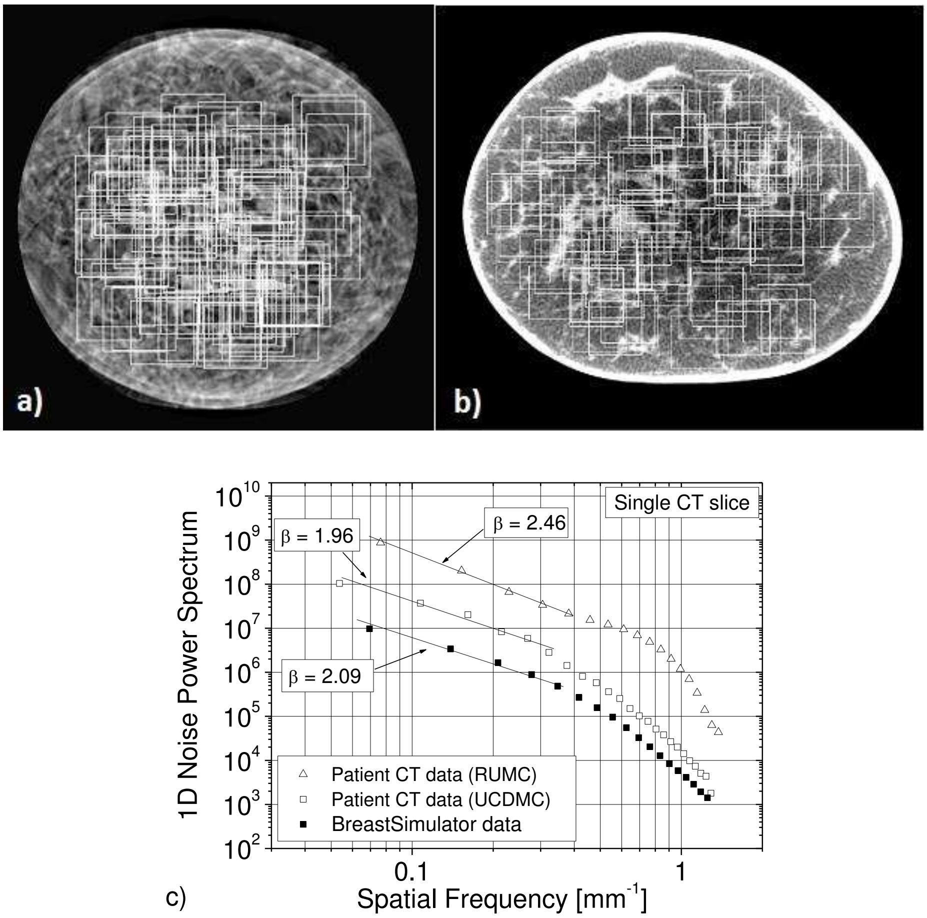

Fig. 4. a) Example of the sampling carried out on an X-ray reconstructed axial slice obtained with BreastSimulator software and b) on a real breast acquired with the RUMC scanner (@49 kV). c) The NPS evaluated from these CT data and from a breast CT scan with the UCDMC scanner (@80 kVp).

3 Results

A number of 360 angular views were simulated, with a monochromatic (27 and 35 keV) and polychromatic X-ray beam (80 kVp). After CT reconstruction of such projections, from the resulting CT slices we evaluated the β coefficient; an example of NPS plots is shown in fig. 4c, together with NPS data evaluated from two clinical breast CT slices.

We note that the trend of the NPS curves for simulated breasts is similar to that of the breast CT scan data, with a similar slope β of about 2 but with a different intercept ($\ln\alpha$). Hence, the simulated data show a lower power, at all frequencies, than patient data. In tab. 1 are reported the measured β values for all the simulated and real breasts.

4 Discussion

The results from the evaluation indicate that the parameter β (tab. 1), calculated from the power spectral analysis on the simulated images, assumes values similar to those calculated on tomographic images from a dedicated breast CT scanner, with values of the exponent β close to 2. These values are in agreement also with published breast CT data for which the exponent was 1.86 on the average [11, 12].

Table 1: Measured β values on simulated and clinical CT scans

	Mono 27 keV	Mono 35 keV	Poly 80 kV	Poly 49 kV
Model Breast 1	2.73	2.87	2.42	
Model Breast 2	2.12	2.08	2.09	
Model Breast 3	2.04	2.29	2.33	
RUMC scanner (3 patients)				1.86–2.46
UCDMC scanner (1 patient)			1.96	

5 Conclusions

In conclusion, we evaluated *BreastSimulator*, an X-ray simulation software for CT dedicated to the breast. Different breast models were simulated and the anatomical noise properties were evaluated by calculating the β exponent from the power spectral analysis of simulated images. The closeness between simulated and measured β in a clinical scan indicates the potential of *BreastSimulator* in devising digital phantom for describing the complex anatomy of the female breast. We expect that by increasing the complexity of the present models for breast CT with *BreastSimulator* an even better description of the corresponding complexity of the anatomical structure will be obtained, in the uncompressed breast. This is related to the computing power evaluable for simulation. This would be particularly important for the description of dense breasts, for which the parameter β may be higher than in low-glandular function breasts [12].

Future work is related to the design of more complex and realistic software breast phantoms via the implementation of a GPU based version of *BreastSimulator*, and to validation with a larger database of breast CT scans. Evaluation of the β values dependence from the thickness and the position of the slice will also be investigated.

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