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Original paper

Digital breast tomosynthesis: Dose and image quality assessment

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ABSTRACT

The aim of this work was to evaluate how different acquisition geometries and reconstruction parameters affect the performance of four digital breast tomosynthesis (DBT) systems (Senographe Essential – GE, Mammomat Inspiration – Siemens, Selenia Dimensions – Hologic and Amulet Innovality – Fujifilm) on the basis of a physical characterization.

Average Glandular Dose (AGD) and image quality parameters such as in-plane/in-depth resolution, signal difference to noise ratio (SDNR) and artefact spread function (ASF) were examined.

Measured AGD values resulted below EUREF limits for 2D imaging. A large variability was recorded among the investigated systems: the mean dose ratio DBT/2D ranged between 1.1 and 1.9.

In-plane resolution was in the range: 2.2 mm^{-1}–3.8 mm^{-1} in chest wall-nipple direction. A worse resolution was found for all devices in tube travel direction.

In-depth resolution improved with increasing scan angle but was also affected by the choice of reconstruction and post-processing algorithms. The highest *z*-resolution was provided by Siemens (50°, FWHM = 2.3 mm) followed by GE (25°, FWHM = 2.8 mm), while the Fujifilm HR showed the lowest one, despite its wide scan angle (40°, FWHM = 4.1 mm).

The ASF was dependent on scan angle: smaller range systems showed wider ASF curves; however a clear relationship was not found between scan angle and ASF, due to the different post processing and reconstruction algorithms.

SDNR analysis, performed on Fujifilm system, demonstrated that pixel binning improves detectability for a fixed dose/projection.

In conclusion, we provide a performance comparison among four DBT systems under a clinical acquisition mode.

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1. Introduction

Full Field Digital Mammography (FFDM) is a fast, non-invasive X-ray modality that involves low doses of ionizing radiation. That's why mammography has become the main tool for breast cancer screening. However, the two-dimensional (2D) nature of mammography leads to a tissue superposition, involving loss of sensitivity when overlapping structures hide true lesions (false negative) or loss of specificity, when normal tissues look like pathologic (false positive).

To overcome tissue superposition two kinds of technologies have been developed: breast CT and digital breast tomosynthesis (DBT), which has made a 3D breast imaging possible. The former is still employed for experimental purposes only [1], the latter spread widely in the clinical practice.

A third promising modality is the *phase contrast DBT* in which projection images are acquired in *refractive mode* that allows to overcome the poor contrast between tumour structures and normal tissues, which is a typical feature in absorption mode imaging (digital tomosynthesis). Bliznakova et al. [2] demonstrated that phase contrast DBT enhances object edges, improving lesions and microcalcifications detection in tomosynthesis imaging.

Nowadays, however, digital breast tomosynthesis is the most common 3D breast imaging.

Several studies stressed the benefits of tomosynthesis in addition to 2D standard FFDM either as screening or diagnostic tool. The most important large-scale clinical European trials [3–6] have shown that mammography screening with DBT can potentially reduce false-positive recalls and increase cancer detection rate compared to traditional 2D mammography. In the last five years, early results about the introduction of DBT as an adjunct to

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standard mammography or even as a replacement of one FFDM view in screening programmes have been published [7,8].

On the other hand, the increasing spread of DBT in clinical practice suggests two needs: to estimate the risk of radiation-induced cancer and to characterize image quality of these systems in order to understand similarities and differences respect to a standard 2D FFDM. Both objectives represent an open topic of debate. A recent paper demonstrates that the effective risk is quite the same between DBT and FFDM [9]. Nevertheless, Ferreira et al. [9] show that an increase of induced lung cancer risk is observed in DBT scan, respect to FFDM, especially when the beam energy is not optimized in terms of image quality and absorbed dose [10]. Finally, investigations on lesion detectability in DBT imaging respect to FFDM have been recently reported [11–13].

The tomosynthesis imaging, introduced by Niklason et al. [14], is a limited-angle tomography in which a series of projection images are acquired at different angles. The breast volume is reconstructed and displayed through planes parallel to detector surface. A DBT system is very similar to a FFDM system in its hardware components and in its geometry of acquisition, except for the tube motion.

At the state of art, there are several manufacturers offering different technological solutions to implement the tomosynthesis imaging. The reader is referred to [15–17] for a complete review.

In this work a comparison of four systems is proposed: Mammomat Inspiration (Siemens), Selenia Dimensions (Hologic), Amulet Innovality (Fujifilm) and Senographe Essential[1] (GE) which differ for detection process (direct/indirect), scan angle, number of projections, tube motion and reconstruction algorithms.

The comparison was carried out by means of physical parameters proposed in literature to characterize a DBT system, taking into account both image quality and absorbed dose. Average Glandular Dose (AGD), spatial resolution (in-plane and in-depth), signal difference to noise ratio (SDNR), artefact spread function (ASF) and DBT response function have been measured.

Spatial resolution and ASF have been defined and used in literature to describe Hologic and Siemens systems [18–22]. A more recent paper [23] extended this characterization to a Fujifilm system, suggesting the use of the investigated parameters as a part of a quality control program. We compared our results to those reported in literature for these three devices. Unfortunately, there are few published references about the physical characterization of GE tomosynthesis, which is the only system using step and shoot acquisition and iterative reconstruction among the studied ones. Moreover we assessed a global system response function on the reconstructed images in order to explain better some results.

Finally, in the attempt to give a complete description of artefact behaviour, beyond a quantitative analysis (ASF), we provided a qualitative evaluation of the artefact pattern, which is different among the systems.

The purpose of this work is dual: to point out how these physical parameters are affected by different constructive choices of four vendors and compare the four devices. A comparison between 2D and tomosynthesis acquisition is beyond the aim of the present work except for the dose level of the two modalities.

2. Materials and methods

2.1. Systems description

Four DBT systems were included in this study. All of them are used in clinical practice. They show differences in detector technology, X-ray tube, acquisition and reconstruction processes.

All the systems use a full field Flat Panel Detector (FPD) with direct conversion (a-Se), except GE (a-Si+ CsI). The systems use different X-ray spectra as combination of various target and filter materials (Table 1).

The parameters affecting the DBT acquisition are different for the four systems. GE system acquires 9 projections every 3° with a step & shoot tube motion for a total angular range of 25° (±12.5°). Hologic and Siemens systems have both a continuous tube motion but, while the first one has an angular range of 15° (±7.5°) acquiring 15 projections, the second one has a wider scan angle of 50° (±25°) with 25 projections. Fujifilm system acquires 15 projections on two different scan angles: 15° (standard mode – ST) and 40° (high resolution mode – HR).

The four systems differ for the reconstruction algorithm as well: iterative Simultaneous Algebraic Reconstruction Technique for the GE system (SART) and Filtered Back Projection (FBP) for the others. A complete overview of the main features of the systems is summarized in Table 1.

Tomosynthesis images are obtained by processing projection views with a reconstruction algorithm. Absolute analysis of processed DBT images is difficult since the relationship between mean pixel value (MPV) and dose in reconstructed images depends on detector response, reconstruction algorithm and post-processing. Not all systems allow access to unprocessed reconstructions, i.e. tomosynthesis images reconstructed from unprocessed projections. For this reason we decided to perform all image quality analysis on processed images.

2.2. Test equipment

The output measurements were performed with a solid state detector (Unfors Raysafe Xi, UNIDOS, PTW, Freiburg, Germany) or with a flat 30 cm^3 ionization chamber (PTW, Freiburg, Germany), the last one used when the specific calibration was not available on the first instrument.

Calibration of devices is traceable to national standards and measurement readings of the two instruments resulted in good agreement (within 5%).

The DBT response function was evaluated with an aluminium step wedge of different thickness (from 0.2 to 1 mm). Agatha phantom [24] (Leeds Test Object Ltd.) was used to evaluate the image artefacts and the in-depth system resolution. Finally, the MTF measurement was performed using an aluminium edge ($100 \times 100 \times 0.2$ mm).

2.3. DBT average glandular dose

The calculation of the glandular dose is related to the tube output by means of conversion factors (c, g, s) accounting for the different spectra and different tissue composition [25–28]. The well-known AGD formula is modified with a T-factor, which accounts for the projections delivered at non-zero angle:

$$AGD = K_T cgsT \quad (1)$$

where K_T is the entrance surface air kerma (ESAK) measured in the 0° position for the total mAs, c-g-s-factors are given in the NCCPM table based on Dance and al. [28], while T-factors are given in the AAPM report of Tomosynthesis Subcommittee TG 223 [29].

ESAK measurements were performed in manual exposition mode at different PMMA thickness from 20 to 70 mm in a 0° DBT mode. The exposure parameters (beam quality and tube load) were chosen as closer as possible to the one selected by the AEC system. The dosimeter was placed on table top, 6 cm from the chest wall edge and centred right-left on the detector.

[1] This device is the first DBT system implemented by GE. It has a tomo module that has to be mounted on the 2D system. The newer version was not available in our hospitals.

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