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Evaluation of the technical performance of three different commercial digital breast tomosynthesis systems in the clinical environment

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ABSTRACT

The aim of this work was to research and evaluate the performance of three different digital breast tomosynthesis (DBT) systems in the clinical environment (Siemens Mammomat Inspiration, Hologic Selenia Dimensions, and Fujifilm Amulet Innovality). The characterization included the study of the detector, the automatic exposure control, and the resolution of DBT projections and reconstructed planes.

The modulation transfer function (MTF) of the DBT projections was measured with a 1 mm thick steel edge, showing a strong anisotropy (30–40% lower $MTF_{0.5}$ frequencies in the tube travel direction). The in-plane $MTF_{0.5}$, measured with a 25 μm tungsten wire, ranges from 1.3 to 1.8 lp/mm in the tube-travel direction and between 2.4 and 3.7 lp/mm in the chest wall–nipple. In the latter direction, the MTF peak shift is more emphasized for large angular range systems (2.0 versus 1.0 lp/mm). In-depth resolution of the planes, via the full width at half maximum (FWHM) from the point spread function of a 25 μm tungsten wire, is not only influenced by angular range and yields 1.3–4.6 mm among systems. The artifact spread function from 1 mm diameter tungsten beads depends mainly on angular range, yielding two tendencies whether large (FWHM is 4.5 mm) or small (FWHM is 10 mm) angular range is used. DBT delivers per scan a mean glandular dose between 1.4 and 2.7 mGy for a 45 mm thick polymethyl methacrylate (PMMA) block.

In conclusion, we have identified and analysed specific metrics that can be used for quality assurance of DBT systems.

1. Introduction

Breast cancer is the second most common type of cancer in the world and it is the second cause of death in women in developed countries after lung cancer [1]. Early detection through breast screening programs could significantly reduce breast cancer mortality [2]. However, the two-dimensional nature of conventional mammography (FFDM) generates tissue superposition, which leads to a reduction in sensitivity (lesions can be masked by the anatomical background) and specificity (normal features in the breast can overlap and appear like a lesion of interest). Digital breast tomosynthesis (DBT) is an imaging technology extension incorporated into a FFDM system, which can overcome this limitation by generating a quasi-3D image of the breast, and hence reduce the effect of overlapping structures [3].

The technical principle of breast tomosynthesis lies in the acquisition of a limited number of low-dose X-ray projections [3], from different locations of the X-ray source along a limited angular arc (hereinafter angular range) (Fig. 1). This way, the structures at different depths into the breast are imaged at different positions depending on the tomosynthesis projection angle. The subsequent reconstruction provides slices (reconstructed planes throughout the text), usually 1 mm thick. These are parallel to the breast support table and contain the information of the structures at that depth. Due to the limited angular range and number of projections (undersampling in the *z*-direction), structures at other depths (out-of-focus) generate artefacts in the different reconstructed planes.

Several technical optimization studies have been carried out in order to determine the most suitable DBT parameters for image quality [4–8]. However, no optimal general configuration has been found since generally every advantage comes at a cost, which leads to a wide variety of DBT configurations observed in current commercial systems (see Table 1). The most important differences lie in the angular range (15–50°), number of projections (9–25),

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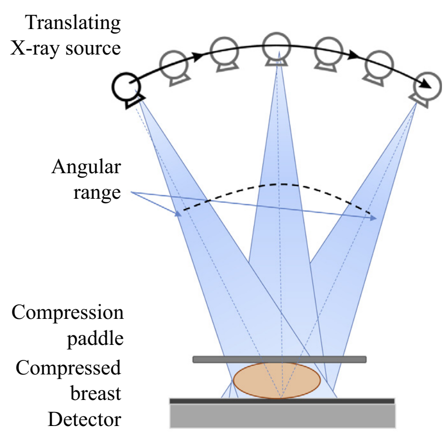

Fig. 1. Schematic of a digital breast tomosynthesis system.

Table 1
Technical characteristics of the DBT systems employed in the study.

DBT system	Siemens Mammomat Inspiration	Hologic Selenia Dimensions	Fujifilm Amulet Innovality (ST/HR)
X-ray tube anode/filter (thickness in μm)	W/Rh (50)	W/Al (700)	W/Al (700)
X-ray tube motion	Continuous	Continuous	Continuous
Angular range (°)	50 [−25,+25]	15 [−7.5,+7.5]	15 [−7.5,+7.5] 40 [−20,+20]
Number projections	25	15	15
DBT scan time (s)	21	3.7	4/9
mAs/projection	Uniform	Uniform	Uniform
Detector type	Integration a-Se	Integration a-Se	Integration a-Se with HCP*
Detector movement	Static	Rotating	Static
Detector pixel size (μm)	85	70	50
Detector binning	No	Yes (2 × 2)	Yes (2 × 2)/No
Reconstructed plane pixel size (μm)	85	97–112†	50/100††
Reconstruction method	FBP	FBP with iterative optimization	FBP
Clinical AEC mode	OpDose	Autofilter	Intelligent AEC-N

* HCP hexagonal close pattern.
† The dimensions uses a projective reconstruction method which generates a variable pixel size in the reconstructed planes (smaller with increasing plane height). The exact pixel size for each reconstructed plane can be obtained from the DICOM image header.
†† Under quality control conditions. Reconstructed planes of clinical images are usually binned to 150 and 100 μm for the ST and HR mode respectively.

reconstruction algorithms (FBP, iterative) and tube motion (continuous or *step-and-shoot*).

Regarding the clinical potential of DBT, several large-population based breast screening trials and research studies indicate that DBT examinations increase the cancer detection rate and reduce the recall rate [9–14]. As a consequence, tomosynthesis value in breast cancer screening and diagnostic assessment keeps growing and spreading throughout medical imaging services worldwide. Therefore, since it is a relatively new X-ray technique in the clinic, further research and development of quality control (QC) procedures are essential to optimize and assure the best image quality at the lowest patient dose as possible.

Testing protocols and performance standards are well established and documented for FFDM at national and international levels but not for DBT. The particular characteristics of this new breast imaging modality make a specific testing procedure for DBT systems necessary. The most complete QC protocol for DBT systems has recently been proposed by the European Reference Organisation for Quality Assured Breast Screening and Diagnostic Services (EUREF) [15]. Moreover, specific QC protocols for DBT have been recently drafted in the context of different screening programs [16,17]. These protocols have relevant differences in methodology but provide general basis about the most important aspects to be considered in DBT.

This study firstly aimed to characterize the performance of three different DBT units in a clinical context from a technical point of view. Furthermore, we also investigated the technical differences between 2D and 3D mammography since these systems can operate in both FFDM and DBT modes. As a result of the research on characterization of the tomosynthesis systems, we propose several tests that could be used for quality control purposes, and we provide further insight into some of the QC tests included in the above-mentioned protocols.

We have considered three main components to characterize the performance of the DBT systems. First component is the detector, which is essential to determine the system sharpness, noise and performance stability through time. The influence of pixel binning, and tube and detector motion on resolution of the projection images was quantified by computing the modulation transfer function (MTF) of the system at different conditions. The second component is the automatic exposure control (AEC) which was investigated by testing the dependence of the signal-difference-to-noise ratio (SDNR) on breast thickness. SDNR was analysed for both the projections and the reconstructed planes, as well as in FFDM for reference purposes. In addition, dose values were also computed for different phantom thicknesses with the two image modalities (DBT and FFDM). Last component refers to the image quality of the reconstructed planes. The role of angular range, number of projections and reconstruction algorithms on the three-dimensional spatial resolution and artefact spreading was investigated via the in-plane MTF, the in-depth z-PSF and the artefact spread function.

The results must be carefully considered only for reference and comparison purposes since there are no requirements or limiting levels regarding image quality in DBT systems nowadays. Further experience with DBT clinical performance and the technical aspects of all the commercially available DBT systems is a key element for better QC optimization.

2. Materials and methods

2.1. DBT systems

Three commercial DBT systems with technical principles as stated in the previous section were analysed. The studied systems were: a Siemens Mammomat Inspiration PRIME version VB41B-SL13P14 (Siemens S.L.U Healthcare, Erlangen, Germany), a Hologic Selenia Dimensions version V1.8.3.63 with C-View V1.8.3.63 (Hologic Inc, Bedford, MA, USA), and a Fujifilm Amulet Innovality version V5.2.0006 (Fujifilm Corp, Tokyo, Japan). For simplicity, the systems will respectively be referred as Inspiration, Dimensions and Innovality throughout the text. The main technical characteristics of these three DBT systems are included in Table 1.

Tomosynthesis measurements were made in the raw scan projections (hereinafter, DBT projections) as well as in the reconstructed planes. FFDM measurements were performed on the raw 'For Processing' images. All the images were obtained either with manual exposure (described in the following sections), or with the AEC clinical modes mentioned in Table 1.

Projections and reconstructed planes in the Dimensions were extracted using the 'gexpand' utility provided by Hologic Inc. The Dimensions reconstructed planes were acquired in the Flatfield

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