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# Digital mammography with synchrotron radiation: characterization of a novel computed radiography system

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**Abstract.** Breast X-ray imaging is a continuous research field to define dedicated equipment, with specialized X-ray sources and efficient detectors to improve image quality with an equal or even lower patient dose. The Needle Imaging Plate HM5.0, produced by Agfa, has been characterized using synchrotron radiation to assess the performance of this novel imaging chain in comparison to conventional mammographic equipment. The detection performance has been initially assessed in terms of Detective Quantum Efficiency (DQE) and its computation showed that DQE curves are very close to the typical results for digital radiography systems. Image threshold contrast has been then evaluated using the CDMAM phantom. The analysis has been completed with a scoring of visible details in the radiographs of the TORMAM phantom. The characterization thus confirms that monochromaticity leads to an equal image quality with a lower glandular dose and phase-contrast effects lead to an increase in anatomical structure detectability. Finally, a preliminary evaluation of clinical images showed a clear improvement in image quality thanks to phase-contrast contribution and to detector performance.

## 1. Introduction

It is well known that mammography is one of the most challenging techniques in medical imaging because of the low contrast between healthy and cancer tissues, high breast sensitivity to radiation effects and lesion conspicuity issues [1, 2]. Therefore, breast X-ray imaging is a continuous research field to improve image quality with an equal or even lower patient dose thanks to dedicated equipment, with specialized X-ray sources and efficient detectors.

The proposed imaging system has been designed to take advantage of the unique characteristics of its components: the Synchrotron Radiation (SR) and the detection performance of a novel Computed Radiography (CR) system. SR is considered an ideal X-ray source thanks to its monochromaticity and high spatial coherence. Monochromaticity helps to reduce patient dose avoiding low-energy components of conventional X-ray tubes. Furthermore, the high spatial coherence of the synchrotron beam allows the observation of phase-effects and the implementation of Phase-Contrast Imaging (PCI) [3, 4, 5]. Finally, the chosen device is a Needle Imaging Plate (NIP), produced by Agfa since 2010 (model HM5.0), based on the use of new phosphor material, the CsBr:Eu$^{2+}$. Detection efficiency and spatial resolution are improved

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with respect to the widespread Powder Imaging Plates (PIP) because of different structure and production method [6].

The analysis has been based on the comparison of the novel system with a clinical Full-Field Digital Mammography (FFDM) system available at the Cattinara Hospital in Trieste (Italy). The first part of the work consists in a quantitative evaluation of the detector performance according to the IEC standard. In the second part, Contrast-Detail (CD) performance and phase-contrast evidences have been analysed through the imaging of different test objects (mammography phantoms). Finally, the observed improvements have been verified in the clinical setting by analysing breast tissue images.

## 2. Description of the imaging chain

Radiographic images have been recorded at the ELETTRA Synchrotron facility located near Trieste. One of ELETTRA bending magnets is devoted to the SYRMEP collaboration (SYnchrotron Radiation for MEdical Physics), producing a flux of about $10^8$ photons $s^{-1}$ $mm^{-2}$ [4]. The source is positioned about 30 m far from the sample to assure a high degree of spatial coherence and high collimation. At the SYRMEP beamline, the implemented PCI technique is the Propagation-based Phase-Contrast Imaging (PPCI) [3]. In particular, in the medical examination room a patient accommodation system allows the scanning of the patient's breast with the SR laminar beam [7]. The detection device is located in an anti-scatter holder which is placed on a 2 m-long rail. The detector can be thus translated to allow maximization of phase-contrast effects [4]. Previous studies at ELETTRA have been performed using screen-film and Dual-Side Imaging Plates [8]. The novel Agfa HM5.0 CR system uses a photostimulable phosphor deposited by Physical Vapour Deposition (PVD). In certain temperature and pressure conditions, phosphor crystals grow as needles. The used phosphor, $CsBr{:}Eu^{2+}$, is deposited with a density of 4.5 g $cm^{-3}$, an effective thickness of 110 $\mu$m and a 90% fill factor [9].

## 3. Analysis of detection system performance

The figure of merit suggested by the IEC standard is the Detective Quantum Efficiency (DQE) [10]. It is obtained as a function of the spatial frequency $u$ from the Modulation Transfer Function *MTF(u)* and the Normalized Noise Power Spectrum *NNPS(u)*:

$$\mathrm{DQE}(u) = \frac{\mathrm{MTF}^2(u)}{q_0 \cdot \mathrm{K} \cdot \mathrm{NNPS}(u)}, \tag{1}$$

where $q_0$ is the number of photons per unit air kerma per $mm^2$ for the pertinent spectrum and $K$ is the air kerma at the detector surface [9].

The resulting *DQE(u)* curves have been compared with the ones obtained with a conventional X-ray tube for mammography. Figure 1 shows that the detector performance is not influenced by the use of SR. Finally, it is worth noting that the Agfa HM5.0 shows detection performance comparable to state-of-the-art Digital Radiography (DR) systems, as reported by Marshall *et al* [9].

## 4. Analysis of Contrast-Detail (CD) Performance

CD performance of the novel imaging chain has been investigated with the CDMAM phantom (version 3.4, Artinis Medical System, The Netherlands) as suggested in the European Guidelines for Quality Assurance in Breast Cancer Screening and Diagnosis [11]. The limited horizontal dimension of the synchrotron beam does not allow to include the whole phantom surface. This prevents us from using the automatized CDCOM reader and human observations need to be performed following a common protocol. Figure 2 shows a comparison between a FFDM system manufactured by GE Healthcare and the analysed imaging chain. Although delivering a similar

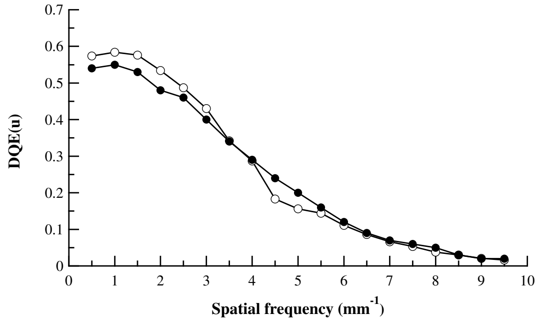

Figure 1: Horizontal DQE for the Agfa HM5.0 detector. Comparison between the use of SR (○) and the use of a conventional X-ray tube (●). Entrance air kerma values are 61 $\mu$Gy and 77 $\mu$Gy, respectively.

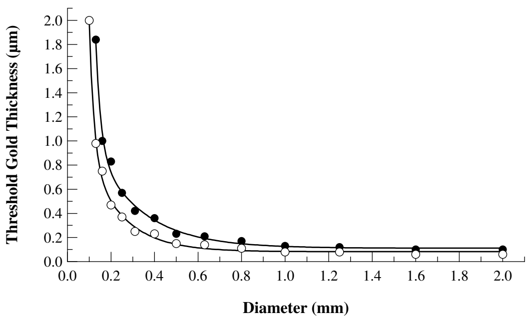

Figure 2: CD curve comparison. Data from a FFDM system have been acquired with a Rh/Rh tube, 29 kV, 50 mAs and a MGD of 1.16 mGy (●). SR data have been acquired at 18 keV and a MGD of 1.24 mGy (○).

Mean Glandular Dose (MGD), the novel imaging chain shows improved CD performance with a reduced mean threshold gold thickness. Explanations can be found in the detection performance, in the reduction of the scatter component and in the monochromaticity of the SR beam.

## 5. Phase-effect evidence in TORMAM phantom images

Images of TORMAM phantom (Leeds test objects, UK) have been acquired to compare scorings of mammography pertinent details mimicking spicules, microcalcifications and tumor masses. An example of the obtained scorings from a FFDM system and the novel imaging chain is reported in Table 1. The use of the novel imaging chain leads to an increased number of visible embedded details accompanied by the reduction of the delivered MGD. Furthermore phase-contrast significantly contributes to image formation leading to filaments detectability.

Table 1: TORMAM scoring for a phantom total thickness of 60 mm. The MGD values delivered with the FFDM and the SR systems are 3.00 mGy and 1.69 mGy, respectively.

| Imaging system | Filaments | Microcalcifications | Masses |
|---|---|---|---|
| FFDM | 0 | 1 | 4 |
| SR | 6 | 3 | 14 |

## 6. Evaluation of clinical images

A preliminary study of clinical images has been also performed by analysing mastectomy tissue radiographs kindly provided by the Cattinara Hospital in Trieste. As an example, an image comparisons is shown in Figure 3. A significant improvement of the overall image quality is apparent in the mammogram obtained with the novel imaging chain. As an average, an almost double contrast has been measured in correspondence of the microcalcifications imaged with the novel imaging chain.

## 7. Conclusions

The characterization of the novel imaging chain has highlighted that the joint use of SR with the detection performance of the Agfa HM5.0 system leads to a high quality mammography and it can expand the potential of phase-contrast imaging. TORMAM analysis investigated

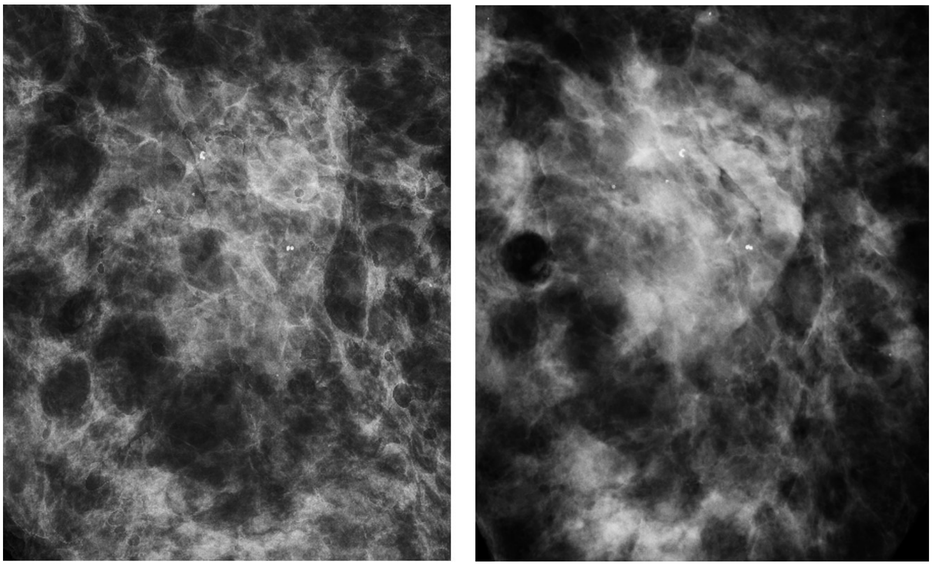

Figure 3: Tissue image comparison. On the left: image obtained with the novel imaging chain (16 keV, compressed thickness = 25 mm, MGD = 0.17 mGy). On the right: image obtained with a conventional mammography system (Mo/Mo, 23 kV, compressed thickness = 23 mm, MGD = 0.14 mGy).

the causes of higher Contrast-Detail performance: monochromaticity and phase-effects. The complete characterization has been then complemented with the radiography of breast specimen. A general improvement of image quality leads to a higher definition of the whole parenchymal structure, a confirmation of phase-contrast effectiveness.

Finally, this preliminary study demonstrated that improvements of diagnostic potential at minimum dose levels are still possible in breast X-ray imaging thanks to the latest technology developments.

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