WHITE PAPER

# Does the pixel size of a full-field digital mammography detector* matter for early detection of breast cancer?

AGFA

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# 1 Introduction

Full-field digital mammography (FFDM) is a highly demanding technological market. In many countries, it remains the preferred technique for screening mammography. However, the method involves exposing healthy women to ionizing radiation to detect early signs of cancer, implying a certain risk for the women.

The technology transfer from screen-film or Computed Radiography (CR) to Direct Radiography (DR)-based screening mammography systems is in an advanced stage in many countries. Recently, we have seen digital breast tomosynthesis (DBT) begins to become the preferred diagnostic technique. In some centers, the synthetic 2-D image derived from the DBT images is used for routine screening, but for many screening centers, it remains a too-expensive and -complex technique.

CR mammography systems present certain workflow disadvantages, but are less expensive than FFDM; they also offer customers the possibility to use their conventional modalities, further reducing the cost compared to immediately implementing a new FFDM modality. Customers can also use a retrofit mammography panel to make use of existing conventional mammography modalities – as with CR – but with the advantage of the FFDM workflow.

Commercial detectors for FFDM have different designs. CR systems use cassettes with a storage phosphor plate; these are digitized in a laser-based scanning read-out system. Flat panel detectors can be either of the indirect type, based on a scintillator (CsI) and photodiode coupled with an active pixel matrix, or of the direct type, based on a direct conversion layer (a-Se) coupled with an active pixel matrix.

One of the main design parameters that can impact diagnostic image quality in digital mammography is the pixel size of the digital detector. Early detection of breast cancer is often based on the recognition of micro-calcifications, and on the geometry of the micro-calcification. Therefore, the resolution of the detection system is often considered extremely important in mammography.

For early detection of breast cancer, the question for digital mammography is: ***to what extent does pixel size really matter?*** And further: is there an optimal pixel size? This white paper answers the first question by comparing the technical image quality properties of several common FFDM, DR mammography retrofit and CR systems of various pixel sizes.

How important is pixel size
in digital mammography?
This white paper provides an answer.

# 2 Commercial FFDM: properties and pixels

Technical image quality data and contrast detail data have been collected for a set of commercial mammography detectors. The selected systems have a pixel size ranging from 50 µm to 100 µm, and represent all the technologies offered in current commercial digital mammography systems.
An overview is given in Table 1.

**TABLE 1**
Overview of FFDM detectors and certain technological parameters of the systems.

| System – commercial name | | Pixel size (µm) | Pixel matrix | Technology |
|---|---|---|---|---|
| **Agfa DR 24M** | Analog modality (tested with Siemens Nova) | 76 | 3072 x 3840 | CsI/ a-Si TFT |
| **Agfa DX-M HM5.0** | Analog modality (tested with Siemens Nova) | 50 | 4708 x 5844 | CR Needle IP |
| **Fuji Amulet** | Integrated modality | 50 | 3540 x 4740 | a-Se/optical switch |
| **GE Essential** | Integrated modality | 100 | 2394 x 3062 | CsI/ a-Si TFT |
| **Hologic Selenia** | Integrated modality | 70 | 2560 x 3328 | a-Se/TFT |
| **Siemens Inspiration** | Integrated modality | 85 | 2658 x 3318 | a-Se/TFT |

# 3 How does pixel size influence diagnostic image quality?

## 3.1 COMMERCIAL FFDM - TECHNICAL DETAILS

The systems listed in Table 1 were fully characterized. Technical details are reported in (N.W. Marshall, 2011) and (P. Monnin, 2011). For the new Agfa retrofit detector, internal data are given here; these are to be confirmed through independent tests by the Flemish certifying bodies for mammography centers. For comparison, technical data for a screen-film mammography system have been added, as reported in (Bunch, 1999).

## 3.2 NOISE: QUANTUM VERSUS ELECTRONIC OR FIXED PATTERN NOISE

Most of the detectors under consideration here are operated under quantum-limited conditions; this means that, in the exposure range used for FFDM screening, the image noise is mainly quantum noise, while electronic or fixed pattern noise are negligible. Under these operational conditions, the signal level is proportional to the number of X-ray quanta contributing to the signal; and as the number of X-ray quanta is Poisson distributed, the noise is proportional to the square root of the number of X-ray quanta. The number of X-ray quanta contributing to the signal level is proportional to the pixel area (= $PS^2$; PS is pixel size). Under quantum-limited operational conditions, the SNR is thus proportional to $PS^2/PS$ or

$$SNR \sim PS \qquad \text{Eq.1}$$

Expressed in a different way, the exposure level needed to reach the same SNR is proportional to the inverse of the ratio in pixel sizes. Consider a 76 µm and a 100 µm detector under quantum noise-limited operation; the exposure level to reach the same SNR could potentially be 24% higher for the 76 µm than for the 100 µm system; there is thus a fundamental physical reason to focus more deeply on the effect of the pixel size in an FFDM system!

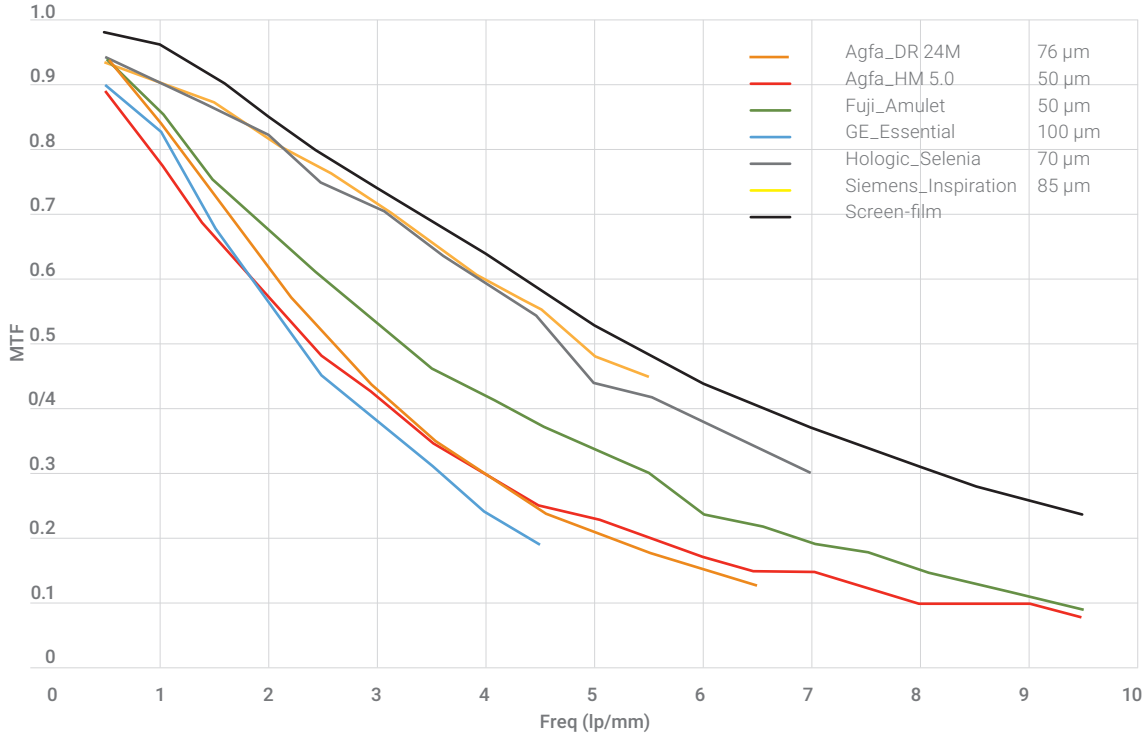
As indicated in (N.W. Marshall, 2011), at low exposure levels, electronic noise can become a dominant noise component and in that case the relation eq. 1 is not valid for these low exposure levels, mainly representing the important dense part of the breast in the image.

> Digital mammography detectors with small pixel size could require higher patient dose to reach similar image quality to detectors with larger pixel size, if all other design parameters are disregarded.

## 3.3 IS SHARPNESS DETERMINED BY PIXEL SIZE?

Conventional screen-film systems offer very high sharpness; the image particles in the film on which the diagnostic reading are done are very small, and screen-film is a nearly continuous medium. The attainable spatial resolution in digital mammography, however, is determined by the number of pixels utilized to construct the digital image, and for a fixed detector format is thus directly related to the pixel size. The spatial resolution is characterized as the detector Modulation Transfer Function (MTF). An overview of the detector MTF for the FFDM detectors considered here is given in Figure 1. The MTF of a high-resolution screen-film system is also shown, for comparison.

**FIGURE 1**
Detector MTF for the various FFDM detectors under the optimal beam quality conditions, as calibrated in the systems for 50 mm PMMA (data from (N.W. Marshall, 2011), (Bunch, 1999)(=screen-film) and internal data =(DR 24M)).




From Figure 1, it is clear that the attainable high-contrast resolution in FFDM depends primarily on the detector technology; the a-Se-based direct conversion detectors have the highest MTF, at 4 lp/mm. The CsI-based, indirect-type detectors have the lowest MTF at 4 lp/mm. The needle-storage, plate-based CR system has approximately the same MTF as a CsI-based detector.

The maximum size of a detail that can ideally be recognized is achieved when one pixel in the image has a high signal level and an adjacent pixel has a low signal level. The maximum detectable frequency without aliasing or artefacts is thus 1/(2 x PS); this is called the Nyquist frequency. In Figure 1, the MTF is represented (per 0.5 lp/mm) in the range 0.5 to the Nyquist frequency. Although the MTF of the a-Se-based detectors is high up to the Nyquist frequency, at higher frequencies, details cannot be imaged. Systems with smaller pixel size can still represent such details, but the contrast for the detail will be lower (lower MTF); while noise (quantum noise + electronic noise) will also decrease detectability.

The pixel size limits the minimum size of detectable details. The real visual sharpness, however, is linked to the detector design, determining detectability at low contrast due to the contribution of system noise and limited system MTF, mainly caused by light scattering in some of the detectors. Small details are imaged at low contrast, and noise hinders the detection.

Pixel size limits the minimum size of detectable details but does not determine the overall sharpness of a system. Sharpness means that a small object can be detected with sufficient contrast above the noise in the image.

## 3.4 DQE AND DETECTABILITY OF DETAILS

Detective quantum efficiency (DQE) describes the ability of the detector to preserve the signal-to-noise ratio from the radiation field to the resulting digital image. DQE integrates the applied exposure level, the detector sensitivity, the detector MTF and the noise properties of the detector, and is hence a more integral measure for image quality. The higher the DQE at a certain frequency, the better the detectability of the detail corresponding to that frequency (= 1/(2 x detail size)).

The DQE for the FFDM systems was characterized and reported in (N.W. Marshall, 2011) for the optimal user conditions; i.e. for the beam quality and at the reference exposure as close as possible to the AEC exposure conditions for 50 mm PMMA. An overview of the exposure conditions per system is given in Table 2. DQE data is represented in Figure 2 in the frequency range 0.5 to the Nyquist frequency.

**TABLE 2**
Exposure conditions for the characterization of the technical image quality per system.

| System | kV | A/F | Air Kerma (µGy) |
|---|---|---|---|
| **Agfa DR 24M** | 30 | MO/RH | 80 |
| **Agfa DX-M HM5.0** | 29 | MO/RH | 104 |
| **Fuji Amulet** | 29 | MO/RH | 88 |
| **GE Essential** | 29 | RH/RH | 83 |
| **Hologic Selenia** | 29 | W/RH | 100 |
| **Siemens Inspiration** | 28 | W/RH | 98 |

**FIGURE 2**
DQE for the various systems under optimal user conditions for 50 mm PMMA
(data from (N.W. Marshall, 2011), (Bunch, 1999)(=screen-film) and internal data =(DR 24M)).

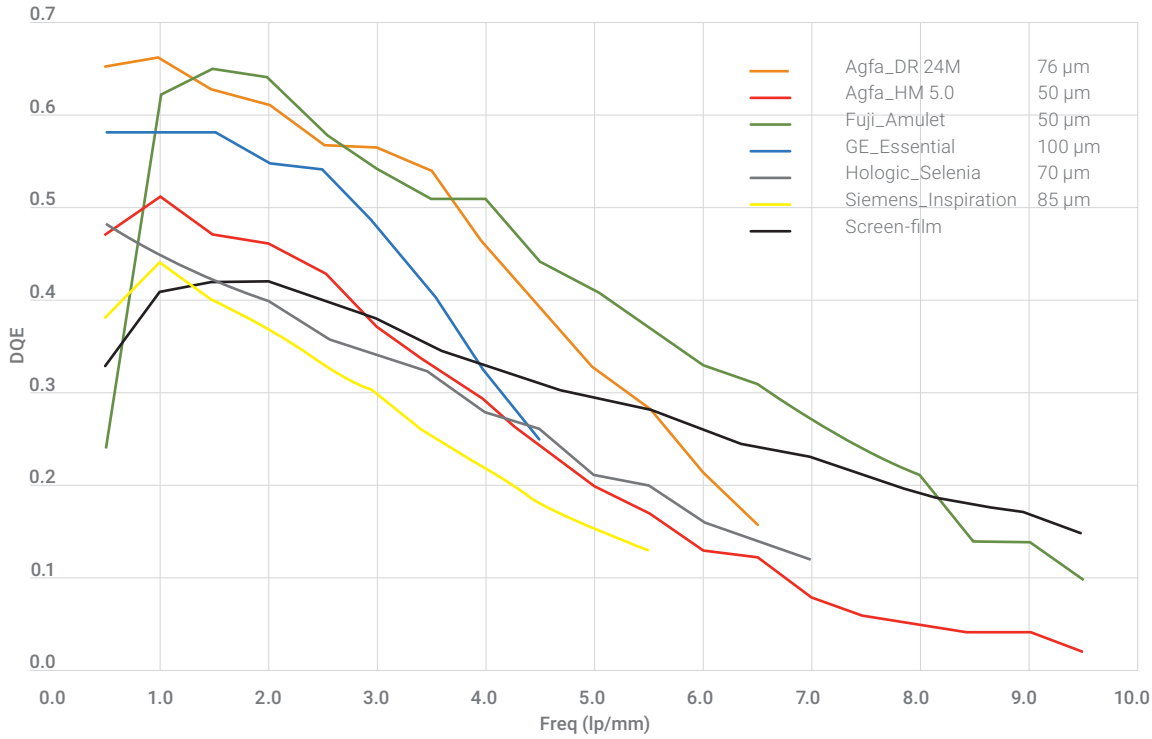



Figure 2 includes DQE data for the high-resolution screen-film system. At very high frequencies, the DQE for this screen-film system is higher than for all the digital mammography systems. But is detectability of details in that frequency range crucial for early detection of breast cancer? The results of the DMIST study did indicate similar to better diagnostic accuracy for digital systems compared to film mammography (Pisano, 2005). The workflow advantages of the digital systems, the low dynamic range and the inability to enhance images using image processing with conventional film systems, plus the results of the DMIST study, have all given a boost for further technological improvements of the digital mammography systems.

Under the tested conditions, the DQE for a-Se-based direct conversion-type systems at 4 lp/mm is lower than for both the CR system and the indirect-type CsI-based systems. That DQE is not determined solely by the pixel size is illustrated by, for example, the GE system with a 100 µm pixel size that has a higher DQE over the full frequency range than the Siemens system with a lower pixel size. Under these conditions, the Fuji Amulet system has a high DQE over the full frequency range.

The DQE of a system, however, depends on the exposure level. The data presented here at ~ 100 µGy are for a reference exposure level, where the systems are used in quantum noise-limited operation. Knowing that some details in clinical mammograms are observed in the dense part of the compressed breast, DQE data for this reference level might be misleading; for some details in the mammogram, a lower exposure level should be considered, where electronic noise can be higher than the quantum noise. At the reference exposure level, the Amulet system has the highest DQE at high frequency; but due to the high electronic noise at low exposure level relevant for the denser part of the imaged breast, DQE will decrease more than for the other systems (N.W. Marshall, 2011).

A high DQE at a certain frequency indicates a good detectability of a detail for the size corresponding to that frequency (size = 1/(2 x freq.)) with a contrast above the noise level. However, noise components extra to the always present quantum noise, such as electronic noise or fixed pattern noise, can limit the detectability, especially at low exposure levels.

> Technical image quality data indicate that for FFDM systems, in the range of pixel sizes of 50 to 100 µm, the pixel size of the digital detector on its own has no systematic influence on the detectability of small objects.

## 3.5. CDMAM PHANTOM TEST – CONTRAST DETAIL DETECTION

The CDMAM (Contrast Detail Mammography) phantom was developed to evaluate contrast detail visibility of unprocessed digital mammograms. With its array of small gold discs, it enables the calculation of a contrast threshold curve and a prediction of the human contrast detail visibility of small objects. In this respect, it allows the comparison and benchmarking of digital mammography systems when the exposures are carried out under similar conditions.

The CDMAM phantom consists of an aluminum base, with gold discs (99.99% pure gold) of varying thicknesses and diameters. The base is attached in a 2 mm deep cavity of a 5 mm thick Perspex cover (PMMA plate). The assembly (PMMA and aluminum) has a PMMA equivalent thickness of 10 mm, under standard mammography exposure conditions.

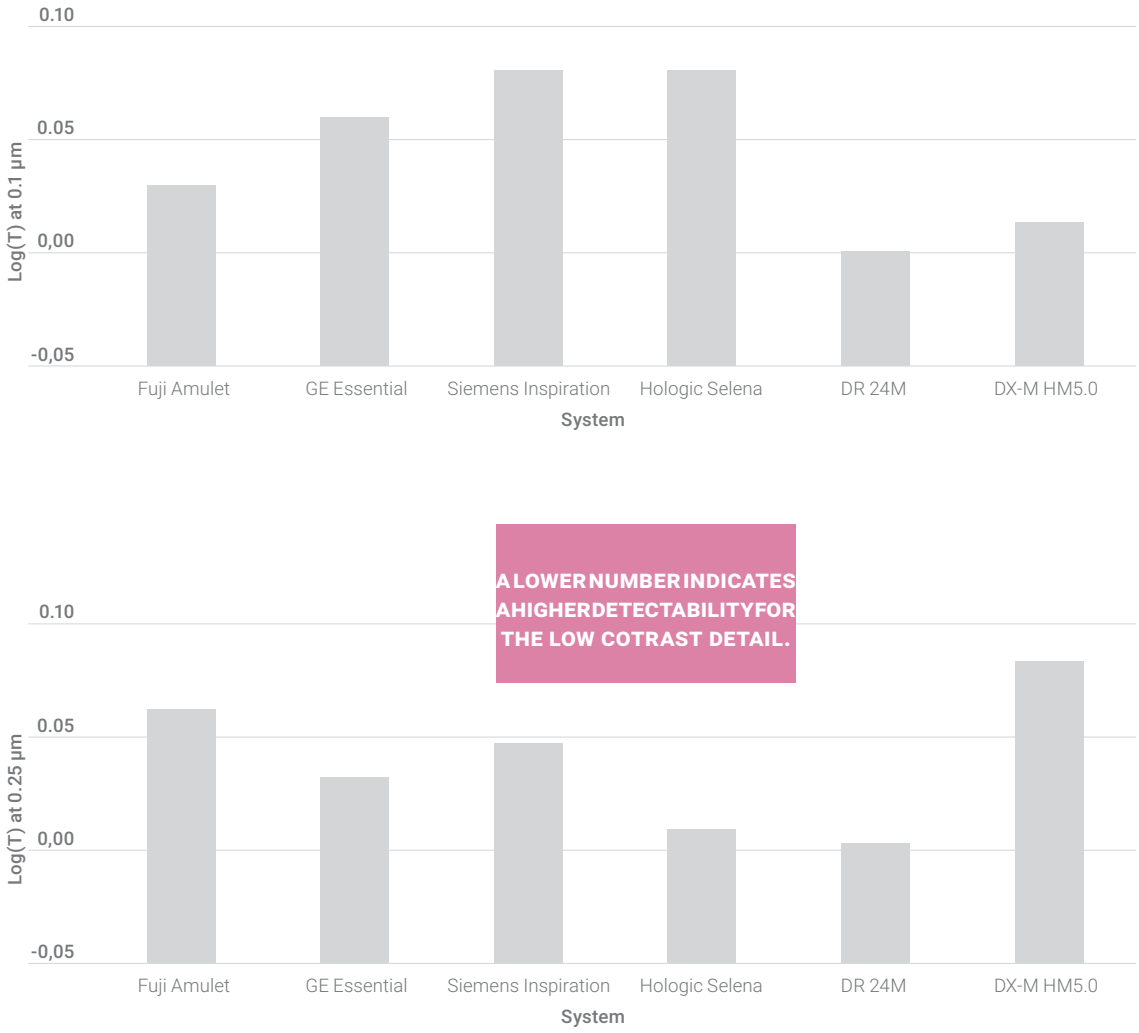
Exposure conditions are typically the clinically used exposure parameters for a 60 mm compressed breast.

**TABLE 3**
Overview of exposure conditions according to the respective AEC calibrations and threshold detection for 0.1 and 0.25 mm disk in the CDMAM phantom 3.4

| System | kV | A/F | Air Kerma (µGy) | Log(T) (0.1) | Log(T) (0.25) |
|---|---|---|---|---|---|
| **Agfa DR 24M** | 30 | MO/RH | 80 | 0.00 | -0.63 |
| **Agfa DX-M HM 5.0** | 29 | MO/RH | 104 | 0.013 | -0.52 |
| **Fuji Amulet** | 29 | MO/RH | 88 | 0.03 | -0.55 |
| **GE Essential** | 29 | RH/RH | 83 | 0.06 | -0.59 |
| **Hologic Selenia** | 29 | W/RH | 100 | 0.08 | -0.62 |
| **Siemens Inspiration** | 28 | W/RH | 98 | 0.08 | -0.57 |

The contrast detail thresholds for the 0.1 mm and 0.25 mm discs are the most relevant, as these diameters represent the dimensions of micro-calcifications in mammograms. The smaller the threshold value for these diameters, the better the capability of a given system to image small and low-contrast details.

**FIGURE 3**
CDMAM threshold gold thickness for 0.1 (top) and 0.25 mm (bottom) disks in CDMAM 3.4




For typical digital mammography systems, the pixel size in the high-resolution range between 50 and 100 µm is irrelevant with regard to contrast detail visibility measured with the CDMAM phantom.

# 4 Diagnostic image quality: additional parameters

## 4.1 IMAGE PROCESSING AND FRACTIONAL MULTISCALE PROCESSING

Agfa's image processing for digital mammography is based on MUSICA image processing technology. With this image processing technique, a multiscale decomposition is computed using a series of spatial filters. Typically, these filters compute a weighted average of pixels in a local neighborhood surrounding each pixel in the image, called the filter kernel.

With Agfa's patented Fractional Multiscale Processing (FMP), the filtered kernels are decomposed into smaller fractions at each scale; thus, the individual kernel fractions are enhanced instead of the weighted sum. This results in significantly better detail. A dedicated MUSICA version, based on FMP technology, was developed with specific adjustments to enhance features such as micro-calcifications in mammograms.

**FIGURE 4**
Suboptimal (top) and optimal (bottom) resolution of low contrast objects

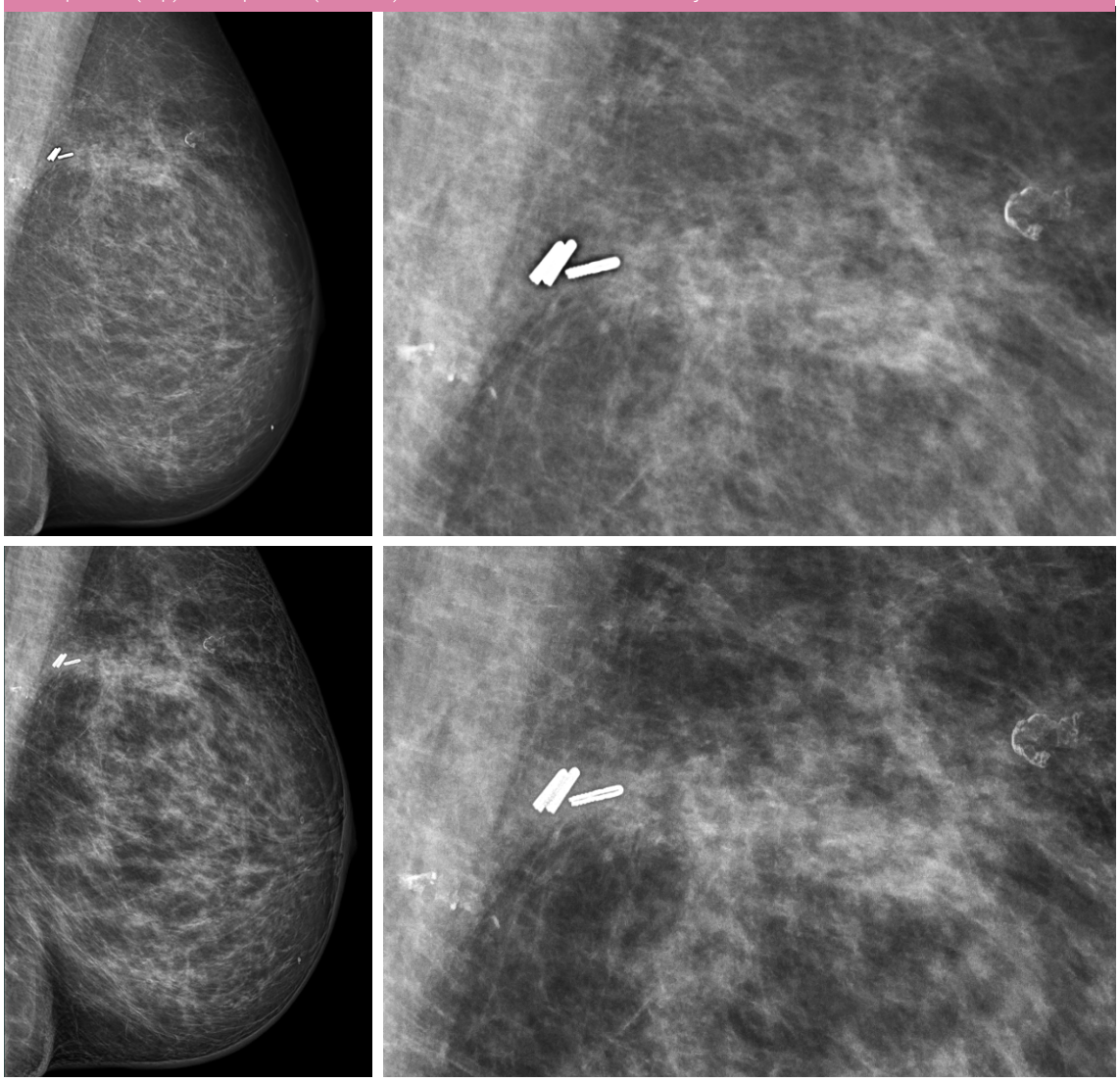


**FIGURE 5**
Examples (both MUSICA with FMP) for optimal rendering of a small object in digital mammograms

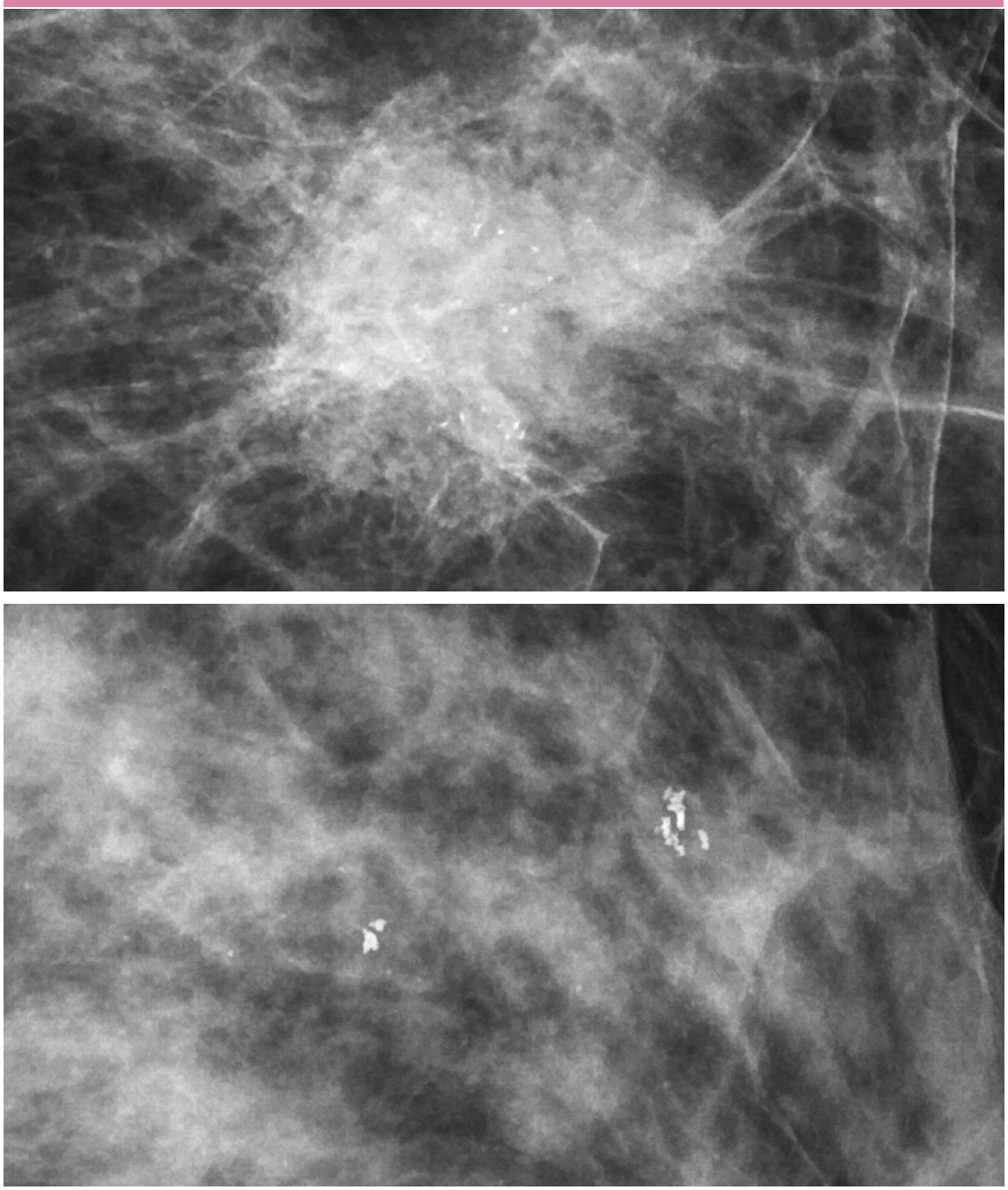


Image processing does enhance the diagnostic image quality of mammograms. Agfa's patented Fractional Multiscale Processing (FMP) can improve the diagnostic image quality of images from various FFDM systems to the highest level, independent of the technical design parameters of the FFDM system, such as the pixel size of the digital detector.

## 4.2 OPTIMIZING THE X-RAY SPECTRUM: AEC CALIBRATION

The attenuation of materials for X-rays depends on the chemical composition of the material and the average energy of the X-rays. Contrast reproduction also depends on the spectral sensitivity of the detector system.

Breasts include only soft tissues and small calcifications; the latter have a higher attenuation for X-rays, but are difficult to detect due to their small size. One way to increase their visibility is the optimization of the X-ray spectrum, which is usually done by changing the $KV_p$ and anode/filter combination. This must always be linked to the detector system used, since the spectral sensitivity of the detection system depends on the technology of the detector. Changing the exposure conditions will have an impact on the patient dose, and is thus critical. The calibration of the AEC, and therefore the selection of the $KV_p$ and A/F combination per breast thickness, is the responsibility of the medical physicist in charge in the screening center, and is preferably recommended by the manufacturer.

## 4.3 HOW DOES THE USER IMPACT DIAGNOSTIC IMAGE QUALITY?

Although manufacturers have pushed the technology of digital mammography systems to a rather high level of performance, and although hospitals, driven by various local and international guidelines and standards, have installed screening procedures that benefit from these evolutions in technology, the final diagnostic image quality obtained with such high-performing FFDM system also depends on the optimal use by the operators.

Acceptance tests for newly installed or updated systems, together with regular quality control tests, can guarantee the system's optimal performance of over a longer period of time. It is highly recommended to give medical physicists control over the correct implementation of these procedures.

Finally, correct positioning of the breast, applying the correct compression, following the recommended exposure conditions (A/F combination, exposure level) as well as applying the optimal viewing conditions when reading the mammograms, all contribute to the performance of a FFDM system in a mammography unit in terms of detecting early cancers or making the right diagnosis.

Correct use of a high-performance digital mammography system (positioning, anode/filter combination, dose, etc.) is important to reach its optimal diagnostic image quality.

# 5 Conclusion: small object detection versus diagnostic image quality

Many technical parameters have a direct or indirect influence on the diagnostic image quality of a FFDM system. These are related to the detector technology, but also to the exposure conditions and image processing software. The diagnostic image quality further depends on correct positioning, compression and viewing conditions, all of which are fully under the responsibility of the user.

The pixel dimension of a detector is only one of these parameters, but as illustrated by the technical image quality data and by the threshold thickness for small details in the CDMAM phantom, in the range of 50 to 100 µm pixel size, acceptable diagnostic image quality is realized with only small differences in patient dose.

Pixel size is an important factor for determining the minimum size of small objects that can be reproduced in an image, but it is not a precondition for good diagnostic image quality.

In fact, for pixel sizes ≤ 100 µm, digital mammography systems reach superior image quality at reasonably low dose through the overall detector design (e.g. Agfa DR 24M) and state-of-the-art image processing (e.g. MUSICA with FMP technology).

# 6 References

(Bunch, 1999): P. Bunch, Advances in high-speed mammographic image quality. Medical Imaging 1999: *Physics of Medical Imaging*, Proc. SPIE. (pp. 120-130).

(Pisano, 2005): D. Pisano, C. Gatsonis, E. Hendrick, M. Yaffe, J. Baum, S. Acharyya, E. Conant, L. Fajardo, L. Bassett, C. D'Orsi, R. Jong, M. Rebner. Diagnostic Performance of Digital versus Film Mammography for Breast-Cancer Screening. *N. Engl. J. Med., 353,* (2005), 1773 - 1783.

(N.W. Marshall, 2011): N.W. Marshall, P. M. Image quality assessment in digital mammography: part 1 Technical characterization of the systems. *Phys. Med. Biol. 56*, (2011), 4201 - 4220.

(P. Monnin, 2011): P. Monnin, N. H. Image quality assessment in digital mammography: part 2. NPWE as a validated alternative for contrast detail analysis. *Phys. Med. Biol. 56,* (2011), 4221 - 4238.

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* Agfa does not offer any of its mammography solutions in the US/Canada.


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