

# Digital mammography: from planar imaging to tomosynthesis

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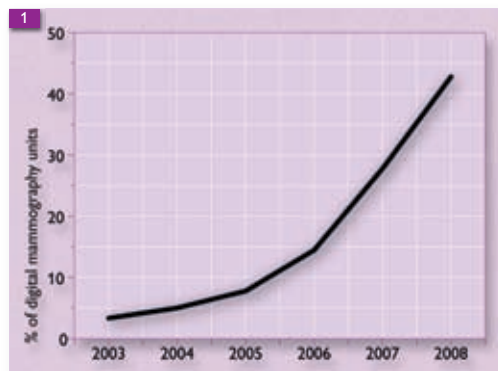
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Mammography has been used for breast cancer detection and work-up of suspected findings in the breast for more than fifty years [1]. After several large clinical trials, mammography has established itself as the primary method for general screening for breast cancer [2-6].

Breast magnetic resonance imaging (MRI) [7, 8] is now recommended as an additional imaging tool for high-risk women. This role is likely to increase. However, at this time, mammography is the only method for which a reduction in breast cancer mortality has been shown in randomized trials [6, 9].

Digital mammography can now deliver better soft tissue contrast than screen-film techniques, better X-ray penetration through dense breasts, and more consistent image quality. Various forms of digital mammography have been commercially available in Europe and the United States for almost a decade. Recent technological trends and results from clinical trials have catalyzed its wider acceptance.

According to the US Food and Drug Administration (FDA), more than 50% of all mammographic units in the United States are digital (6,577 digital out of a total 13,052 mammographic units) [10]. Figure 1 shows the growth of digital mammography in the United States over the past five years, demonstrating a clear acceleration of the trend in recent years.



► Figure 1. Growth of digital mammography in the United States from 2003 to 2008.

## The rationale for digital mammography

Early investigations on the physical properties of digital mammography provided the impetus for further research [11-15]. These studies suggested that the image noise characteristics of digital systems could be better than for screen-film mammography. Therefore, the high-resolution advantage of screen film might not be as important for detection of microcalcifications in the breast as it was originally assumed.

Moreover, visualization of subtle anatomic detail, such as microcalcifications or soft tissue spiculations, may not be as dependent on spatial resolution as on image contrast and proper exposure: two parameters that present a challenge to screen film but are the strengths of digital imaging techniques.

The ability of digital imaging systems to accommodate a large range of exposure (dynamic range) and the ability to manipulate the contrast of the images after acquisition are important factors that make digital mammography highly desirable. Because of these abilities, digital mammography can alleviate the problems that dense fibroglandular tissue and wide variations in X-ray attenuation often cause in screen-film mammography.

Results from the American College of Radiology Imaging Network – Digital Mammography Imaging Screening Trial concluded that while the overall diagnostic accuracy of digital and screen-film mammography were similar, digital mammography was more accurate in younger women, women with dense breasts, and pre- or peri-menopausal women [16, 17].

Physicians have always viewed digital imaging, including mammography, not only as a technology that may enable better care through improved image quality but also as an important tool for increased productivity. For example,

► **Digital mammography can now deliver better soft tissue contrast than screen film.**

images acquired at a screening site can easily be transmitted and interpreted at a central location. They can be transmitted to another site for additional consultation. In addition, they can be readily available to the breast surgeons and oncologists.

## The technology

The development of X-ray detectors that would match or surpass the physical characteristics of mammographic screen-film has been a formidable task. Such detectors must have a pixel size no larger than 100 microns, for an approximate matrix of about 2000 x 2500 pixels or higher.

Moreover, the intrinsic sensitivity of the detector should be high to detect very weak X-ray fluence through dense tissue. At the same time the detector must be able to tolerate very high X-ray fluence in the region of lower X-ray attenuation near the periphery. The electronic noise characteristics should be low so that very low signals through dense breast tissue are not masked.

Two technological approaches have emerged to meet this challenge: amorphous silicon flat-panel detectors used with a scintillator (indirect conversion) and amorphous selenium (direct conversion). The indirect approach uses a thin structured thallium-doped cesium iodide scintillator as the primary detector that is in contact with a pixelated amorphous silicon thin film transistor (TFT) array [18, 19]. Although the scintillator is prone to some light diffusion that can degrade the spatial resolution, this approach has worked well with careful design of the structured scintillator and post processing to preserve high spatial resolution.

The second approach uses amorphous selenium as the primary detector with a TFT readout pixelated array [20, 21]. Selenium is a nearly ideal X-ray detector in the mammographic X-ray energy range. Unlike the indirect conversion approach, X-rays interacting with the amorphous selenium layer in contact with the TFT array are converted directly to electrons, without the intermediate step of scintillation.

Due to the minimal deviation of the electrons from their path in this process (compared to light diffusion in indirect conversion), direct conversion is characterized by high spatial resolution that can be helpful in the detection and characterization of breast microcalcifications. Figure 2 shows a digital mammography system that uses a direct conversion flat-panel detector.



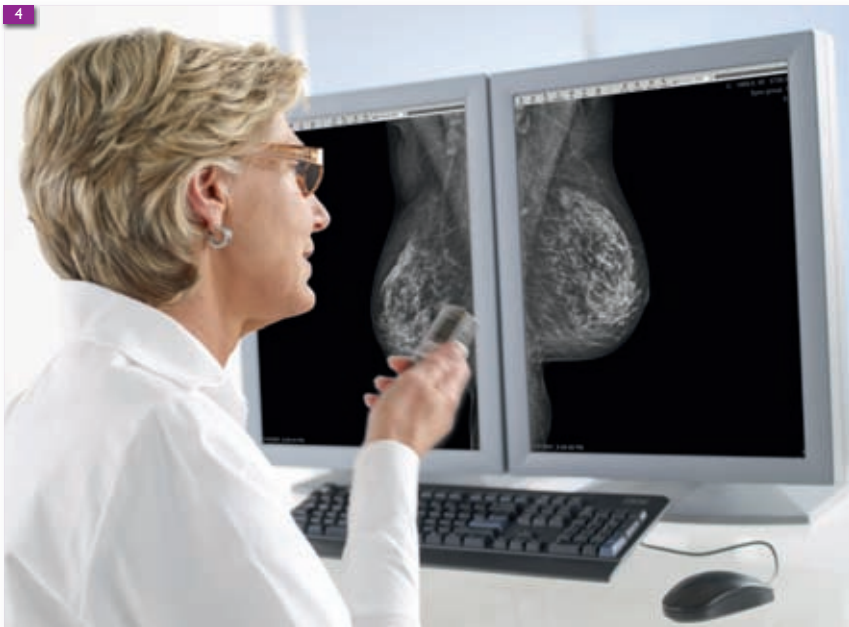
Figure 2. A full-field digital mammography system with direct conversion flat-panel detector (Philips MammoDiagnost DR).



Figure 3. A digital mammography plate reading station.

Photo-stimulable phosphor technology, also called computed radiography (CR), has been available for mammography for some time [22-24]. The main advantages of CR mammography are its relatively easy adaptation, which does not require replacing existing mammography units, and the resulting lower initial cost for the transition to digital. CR mammography uses cassettes containing stimulable phosphor plates that replace the screen-film cassettes. Digital images are obtained by electro-optical processing at a plate readout station (Figure 3).

With some digital systems, the X-ray dose to the breast may be lower than that with screen-film systems. This is due to a more efficient X-ray detection and the use of a slightly higher kVp with rhodium or silver filtration. Recent research based on computational simulations suggests that



▲ Figure 4. A digital mammography workstation.

a slight reduction in breast compression during digital mammography may also be feasible. However, this needs to be further investigated and confirmed in clinical studies [25].

### Mammography reading

The large volume of image data and the high image quality requirements of screening mammography necessitate special attention to the image reading environment. Digital mammography images are occasionally printed on high-quality digital film printers, but this deprives radiologists of the opportunity to adjust image display parameters, and is clearly an uneconomical and environmentally undesirable practice.

Specialized softcopy reading workstations have been developed for this purpose. Two high-resolution flat-panel displays are now the standard in digital mammography workstations, typically with an image matrix of about 2048 x 2560 pixels, a pixel pitch in the order of 0.16 mm, and luminance exceeding 600 cd/m<sup>2</sup> (Figure 4). Contrast ratios exceeding 700:1 are attainable and greater than 8-bit resolution at the output is recommended [26].

Some digital mammography systems generate an image matrix that is larger than the native matrix of current image displays, and in such cases the entire breast cannot be viewed in full resolution. However, the zoom mode can be used for easy and fast interaction to view image details in full resolution.

In breast cancer screening, experienced radiologists may read more than 100 cases per

hour [27]. Mammography workstations must be able to support this workflow with high data transfer rates, the possibility to define appropriate image hanging and reading protocols, including computer aided detection (CAD) and double reading, as well as integrated reporting facilities. The transition to multimodality imaging of the breast makes it imperative for the radiologist to be able to review images from various modalities such as digital mammography, ultrasound, and MRI.

This has created both ergonomic and workflow needs that are critical for effective diagnosis. In addition, there is a need for vendor-neutral workstation solutions that can communicate with an imaging modality from any manufacturer. Such solutions are available today that allow visualization of images from multiple imaging modalities. Tools in such systems may include hanging protocols, interactive display or hiding of mammography CAD results, advanced zoom and magnification tools, magnification “lens”, actual size display and measurement, and programmable functions to suit each radiologist’s preference.

However, there are opportunities to enhance workstation solutions to incorporate breast MRI and ultrasound image analysis applications. Emerging imaging technologies such as tomosynthesis and dedicated breast computed tomography (CT) will create the need for additional workstation facilities. Any workstation solution should be capable of full integration with picture archiving and communication systems (PACS) and patient information systems to maximize workflow efficiency and to improve care delivery.

### Research studies

Digital mammography provides the technological platform for a number of research imaging techniques, ranging from contrast injection mammography and subtraction techniques to tomographic imaging of the breast by digital tomosynthesis or dedicated computed tomography of the breast. While none of these technologies are presently approved for use in screening mammography, they hold the promise of improving the sensitivity and specificity of mammography for detecting early breast cancer.

### Contrast injection mammography

It is well established that the progression of breast tumors is associated with angiogenesis [28]. Intravenously injected X-ray contrast agents may therefore prove efficacious in early detection of breast tumors. In the early angiogenesis stage,

tumors may exhibit very small uptake of contrast agent that is already diluted by the intravenous path. Two methods for increasing the visibility of an iodinated contrast agent have been explored in pilot studies so far: temporal subtraction [29, 30] and dual-energy subtraction [31].

### **Temporal subtraction**

In temporal subtraction, the breast is placed in light compression so that the flow of contrast into breast tissues is not impeded. A pre-contrast mask image is obtained followed by one or more post-contrast images. Post-processing is used before subtraction to correct for the inevitable patient motion during the injection.

### **Dual-energy subtraction**

Dual-energy techniques that require acquisition of an image pair, one each at low and high X-ray energies, seems particularly well suited to distinguishing materials that have vastly different atomic numbers and density from that of breast tissue, as in the case of iodine contrast in tissue. In dual-energy subtraction, the intravenous iodinated contrast agent is administered before any breast compression.

After about 90 seconds, the breast is compressed and one or more dual-energy image pairs are acquired. The advantage of the dual-energy technique is that bilateral and multiple views of breast can be obtained, while in temporal subtraction imaging is limited to the one view in which the mask was obtained. However, temporal subtraction has the advantage of achieving more complete subtraction than with dual-energy, which depends on the energy separation between the two beams. In addition to diagnostic evaluations, these techniques may have potential for screening of high-risk women.

### **Digital breast tomosynthesis**

Digital mammography does not provide tomographic information and it may fail to image tumors that are masked by superimposed normal anatomy. The concept of digital tomosynthesis, a limited-angle X-ray tomographic technique, has been explored as a possible solution to this problem.

Digital breast tomosynthesis (DBT) evolved from digital mammography. It consists of acquiring multiple projections of the breast and using them to reconstruct a quasi-tomographic image [32-34]. This requires about six to fifteen projections in an arc, typically up to 60°.

DBT can produce mammogram-like images at different depths. The slice thickness (and spatial resolution) in the z-plane is about 1 mm, but the

spatial resolution in the x-y plane is about the same as in standard digital mammography. With improved imaging detectors and techniques, it is now feasible to acquire DBT images with the same radiation dose to the breast as a two-view mammogram. What is uncertain at this time is whether DBT alone is adequate for routine screening, or whether additional mammographic (planar) views will be required for screening.

DBT performs well in visualizing soft tissue abnormalities, but the visualization of very subtle amorphous microcalcifications seems to present a greater challenge than in standard mammography. Therefore, studies indicate that at this time it is difficult to rely solely on tomosynthesis (without any planar views) for the entire examination but this may change as the technology improves.

DBT is well developed and several clinical trials are under way; however, it will have to clear the regulatory process in the USA, Europe and in other countries before it can be used in routine clinical applications.

### **Dedicated CT of the breast**

Dedicated CT of the breast is another alternative that was initially attempted more than thirty years ago, but technological constraints have prevented the application of CT technology for routine imaging of the breast [35]. In recent years, with the advent of new X-ray detectors and reconstructions for cone beam geometry, the concept of dedicated breast CT has been revisited.

In a typical implementation of dedicated breast CT, the patient lies in the prone position with the breast pendant through an aperture on a specially designed table [36]. The X-ray source rotates below the table for a tomographic acquisition in cone beam geometry. Dedicated breast CT generates tomographic images with isotropic resolution in three dimensions. The main challenges in breast CT are associated with attaining adequate visualization of microcalcifications, tissue coverage of the axilla and medial aspect of the breast, and in minimizing the radiation dose. This approach is experimental and research into the technological aspects of dedicated breast CT, as well as limited clinical trials, is in progress.

### **The future of digital mammography**

High-resolution mammographic imaging detectors and displays that seemed technologically impossible and financially unaffordable a few years ago are increasingly becoming within reach

► **X-ray contrast agents may prove efficacious in the early detection of breast tumors.**

► **High-resolution imaging detectors and displays are now within reach of even smaller clinics.**

of even the smaller clinics. Integration of digital mammography workstations with CAD is now commonplace. At some point, we are likely to see image displays with larger pixel matrices, capable of accommodating the entire breast at full resolution. Imaging workstations that integrate multimodality imaging such as mammography, MRI and positron emission tomography (PET) are also likely to become commonplace. X-ray detectors that use photon counting approaches are emerging for digital mammography and potentially for tomosynthesis and dedicated breast CT [37].

Digital breast tomosynthesis has become the next frontier in transformation from planar to tomographic imaging. More research is needed to establish the role of advanced techniques such as dedicated breast CT and contrast-injected mammography.

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