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A comparison of digital mammography detectors and emerging technology

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ABSTRACT

The overall diagnostic accuracy of digital mammography in the context of screening has been shown to be similar or slightly better than screen-film mammography. However, digital mammography encompasses both Computed Radiography (CR) and integrated Digital Radiography (DR) and there is increasing evidence to suggest that differences in detector technology are associated with variations in cancer detection rate, dose and image quality. These differences are examined in detail.

Although digital mammography offers many advantages compared to screen-film, there are still some limitations with its use as a screening tool and reduced cancer detection in dense breasts remains an issue. Digital mammography detectors have paved the way for emerging technologies which may offer improvements. Taking the definition of mammography to only include X-ray imaging of the breast, this article focuses on tomosynthesis, contrast-enhanced digital mammography, stereoscopic mammography and dedicated breast computed tomography. Advanced software applications such as Computed Aided Detection (CAD) and quantitative breast density assessment are also presented. The benefits and limitations of each technique are discussed.

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Introduction

Breast cancer is a major health burden on a global scale, with over 1.6 million new cases being diagnosed worldwide each year.[1] As the population ages, risk and consequently incidence are expected to rise, making breast screening as important now as when it was introduced. A national breast screening programme commenced in Australia in 1991[2] and screening is now carried out exclusively using digital mammography.

The term *digital mammography* (DM) encompasses both Computed Radiography (CR) and integrated Digital Radiography (DR), with DR incorporating a range of detector technologies, shown in Fig. 1.

There are a number of advantages to DM compared to screen-film. Film was both the detector and the display; in DM these are separate devices, enabling each stage of imaging (acquisition, pre-processing, post-processing and display), to be optimised independently of the others.

The major strength of digital detectors is their wide dynamic range. The relationship between grey level and exposure is linear, as opposed to film which follows an S-shaped characteristic curve. Image contrast is generated when grey level changes with exposure. For film, this only occurs over a narrow range of exposures; for digital detectors the exposure range, or dynamic range, is much wider. Optimisation is therefore essential because the correct exposure is no longer limited purely by contrast, but also by noise. If the dose is too low, the image will have unacceptably high quantum mottle. If the dose is too high, the patient will receive unnecessary radiation dose, which could go unnoticed because unlike film, digital image processing prevents image saturation. This phenomenon is known as *dose creep* in digital imaging. Fortunately, the stringent quality control in mammography and the introduction of a new parameter, known as Signal Difference to Noise Ratio (SDNR) to achieve the optimum balance between dose and image quality,[3] means that dose creep has not been an issue. Several clinical dose audits have shown that patient doses are actually lower for DR systems than for film.[4–7] This is partially attributed to the use of harder beam qualities and most digital systems now employ a tungsten target instead of, or in addition to, molybdenum and rhodium. A heavily filtered tungsten spectrum (to remove the undesirable L-characteristic radiation) results in more efficient X-ray

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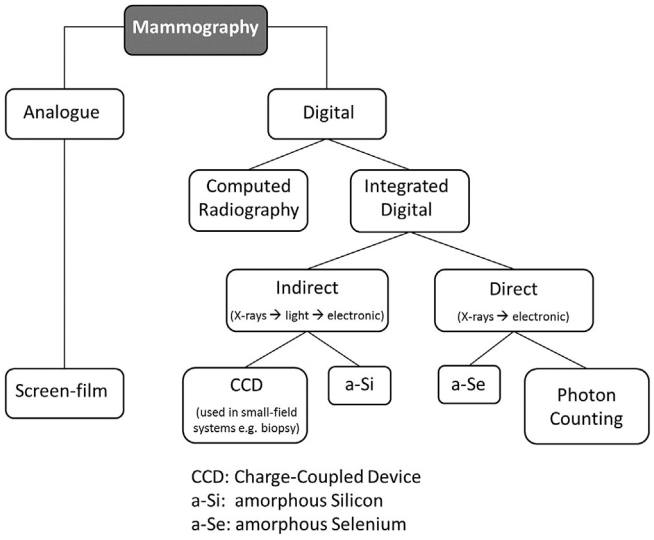

Figure 1. Detector technologies employed in analogue and digital mammography.

production and a higher effective energy.[8,9] The loss in physical contrast associated with higher energy X-rays can be compensated for by increasing the detector dose, which reduces quantum noise in the image.[3]

DM has greater contrast resolution than film, which in principle should lead to improved diagnostic accuracy, particularly in women with dense breasts. This has been found to be true in practice; studies have shown that the overall diagnostic accuracy of DM and screen-film mammography in the context of screening is comparable,[10–13] or slightly better.[14,15] Analysis of particular subgroups found that DM was more sensitive in women with radiologically dense breasts and in younger women.[10,14,16] Image processing may also be credited with improved sensitivity in dense breasts, as radiologists have reported that breasts appear to be less dense on digital mammography images compared to film.[17]

The limiting spatial resolution of DM (5–10 lp/mm) is lower than that of screen-film (15–20 lp/mm). However, despite initial concerns that this may lower microcalcification detection rates, the opposite has been found for DR detectors, which exhibit significantly greater sensitivity than screen-film.[14,16,18–22,26,27] Neal et al. found that the detection rate of high-risk lesions, which often manifest as calcifications, was three times higher for DM compared to film.[19] Although this might facilitate risk-reduction strategies, it may contribute to over-surveillance and over-treatment, both of which are common criticisms of mammographic screening.[23]

Practical advantages of digital mammography include easier archival, retrieval and transmission of electronic images and potentially higher patient workflow for DR, but possibly not for CR.

Comparison of digital mammography detectors

A CR image plate is a layer of photostimulable phosphor on a transparent plastic substrate, contained within a cassette which slots into the Bucky in the same manner as a screen-film cassette. CR can therefore be used with existing mammography X-ray units and is considered a cost-effective solution into DM. CR plates must be read in order to view the image, but are reusable. The effective detector element (del) size is typically 50 μm and spatial resolution of 10 lp/mm is theoretically possible.[24]

With indirect conversion detectors, X-rays are first converted to light photons in a scintillation layer (usually Caesium Iodide). Light photons are then converted to an electronic charge signal using a flat panel of amorphous silicon (a-Si) that incorporates an array of photodiodes. The effective del size is typically 100 μm, corresponding to a maximum achievable spatial resolution of 5 lp/mm.[24]

Direct conversion flat panel detectors utilise a semiconductor material known as amorphous selenium (a-Se) to convert X-rays directly to electronic charge. Nominal del sizes are 50–85 μm, which equates to a limiting spatial resolution of 6–10 lp/mm. This is the technology employed by most digital mammography vendors. An alternative method developed by one vendor employs single x-ray photon counting with energy discrimination thresholds to reject scattered photons and electronic noise. X-ray photons are then converted directly to electronic signal in a crystal silicon detector.[24]

Since the publication of the Digital Mammography Imaging Screening Trial (DMIST)[10] ten years ago, research has shifted from a comparison of DM with screen-film, to the variation in performance of different digital detector technologies. Recently published studies have compared cancer detection rates,[16,21,22,25–27] patient dose[4–7,28] and image quality.[7,27,29,30]

Keavey et al. reported no significant difference in overall cancer detection rates between digital mammography systems employing three different detector technologies.[24] However, all of these were DR detectors. Chiarelli et al. found that overall cancer detection rates were lower with CR (3.4 per 1000 women screened) compared to film (4.8 per 1000) or DR (4.9 per 1000) with CR significantly less likely to help detect invasive cancers.[26] Although a similar trend in overall cancer detection rates was reported by Seradour et al. (CR: 5.5 per 1,000, film: 6.6 per 1000 and DR: 7.1 per 1000), there was no significant difference in invasive cancer detection.[16] Investigations in Australia also showed no significant difference in invasive and small invasive cancer detection rates between CR and DR; these studies also concluded that CR was at least as good as film, based on overall cancer detection rates.[21,22] The only common finding between all studies was that DR was significantly better at detecting ductal carcinoma in situ (DCIS).[16,21,22,26] All of these studies[16,21,22,26] examined concurrent cohorts of a screening population (aged 50–74) and all mammograms were double-read, except for those in the study by Chiarelli et al.[26] which were single-read; however, this would have been the case for film, CR and DR images. Differences in the study results may be due to differences in the CR systems and it would be interesting to see not just a comparison of CR and DR, but a comparison by system manufacturer. 79% of the CR systems used in the study by Chiarelli et al.[26] were from a vendor, which initially failed to comply with European image quality standards[31] and was deemed unsuitable for use in the UK breast screening programme,[32] although a later model by the same vendor was considered acceptable following optimal adjustment of the Automatic Exposure Control.[33]

The lower cancer detection rates for CR compared to DR, particularly for DCIS, are somewhat expected, based on assessment of physical image quality measures.[7,27,29,30] The parameters of interest are spatial resolution, contrast and noise (which has quantum, structural and electronic components).[8,29,34] Each parameter exhibits a dependence on the others, so overall performance is commonly evaluated using metrics such as the modulation transfer function (MTF), signal to noise ratio (SNR) and detective quantum efficiency (DQE)[8,27,29] Yaffe et al. found that, despite their smaller nominal del size, the MTF was actually lower for CR than DR systems.[29] Explanations for this include a degradation in spatial resolution caused by scattering of laser light in the phosphor layer and inefficient conversion of X-ray photons to electronic signal within the photostimulable phosphor and readout processes.[29] The lower DQE of CR compared to DR is associated with a lower SNR, which is

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