

Digital mammography with PCR: Experience with 20 000 Patients

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PCR is vastly superior in terms of dynamic range and contrast.

Leeds General Infirmary, originally founded in 1771, has an impressive record of innovation in radiological imaging science and technology. It not only serves the city of Leeds, which is one of Britain's largest cities, but is also a referral center for a large surrounding area. The Breast Clinic at the General Infirmary is one of the most advanced in the country, with an advanced breast imaging service working in collaboration with two breast surgeons, and a team of dedicated pathologists and radiographers.

In recent years, the General Infirmary has been one of the institutions cooperating with Philips Medical Systems in the development and evaluation of new imaging techniques, in particular in digital X-ray imaging. It was therefore natural that clinicians and physicists at Leeds would play a major role in the development of computed mammography.

Since 1994, we have been using a combination of Philips Computed Radiography (PCR), which uses photostimulable phosphors, implemented on a conventional mammography system (Philips Mammo Diagnost UC), plus a dedicated image processing algorithm for optimizing contrast rendition, which is implemented on a Philips EasyVision RAD workstation. To date some 20 000 patients have been successfully examined with this system. In many cases, digital mammography has been able to provide essential diagnostic information where conventional film-screen mammography could not provide a satisfactory image.

It should be emphasized that the Mammography Department at the General Infirmary is a referral center for symptomatic patients, or patients at risk, and does not form part of the government screening program.

DIGITAL MAMMOGRAPHY WITH PCR

In principle, mammography should benefit greatly from the exploitation of digital imaging technologies. For example, computerized enhancement can be used to ensure optimum presentation of the images,

and to provide the input for image management and analysis systems. The vital prerequisite, however, is the availability of a digital image acquisition (capture) device for mammography, which should have the ability to visualize all diagnostic information, including subtle low contrast soft-tissue lesions and clusters of microcalcifications. When we began our study in 1990, the only practical digital image acquisition system was Philips Computed Radiography (PCR). Other digital acquisition technologies have subsequently begun to emerge.

In the past, the acceptance of digital mammography has been limited by concerns regarding spatial resolution of the imaging system as a whole. However, some of these limitations are based on preconceptions, rather than practical experience and objective analysis [1,2]. Although screen-film combinations may have a theoretical minimum detail resolution of 33 microns, this is measured using lead test gratings, with a very high subject contrast and a continuous rectilinear X-ray cross-section, rather than an individual three-dimensional structure such as a microcalcification. Because each microcalcification has this three-dimensional structure, the subject X-ray contrast reduces in proportion to its size. Consequently, subtle variations in contrast reproduction can play a very important role in visualizing such small features. This means that the measurement of spatial resolution with a test grating will not necessarily represent the real imaging situation found in clinical practice.

During 1991/2 we made a preliminary study of the possibilities of using PCR for mammography. PCR acquisition proved to be feasible, but the results were somewhat disappointing, because at that time the PCR digital image processing was not optimized for mammography. Consequently, we reformatted the image data from the PCR reader for use with the digital image enhancement algorithm successfully implemented with the Philips Digital Spot Imaging system, or DSI. During the development phase the digital mammography images were read using a

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Philips 7000 series PCR reader in the clinical department, and were enhanced and printed offline in the laboratory. Subsequently, to aid further progress with the project, Philips Medical Systems provided an EasyVision RAD workstation for the purpose of implementing the digital image enhancement and print formatting on-line in the clinical department. As a result we were able to develop an algorithm for use on the Philips EasyVision RAD, specifically designed to achieve maximum reproduction of details over the full grayscale range while retaining the artifact-free presentation of a film mammogram. This algorithm is now implemented on the EasyVision RAD as an option known as Dynamic Range Reconstruction (DRR). The DRR mode can handle a wide range of contrast, and unsharp masking is used to limit the contrast of large high contrast features, while enhancing subtle features. Using DRR, we found that we could detect objects down to about 130 microns in size .

The original research and development installation has now been replaced by a commercial PCR AC3 compact reader system combined with a dedicated EasyVision RAD workstation operating with the specially developed software.

We conducted two psychophysical studies [3] in which the detection of simulated microcalcifications with PCR was compared with that of screen-film mammography. It was found that, under clinical conditions, the difference in detail resolution between the two systems was insignificant: the minimum detectable size of microcalcifications was approximately 130 microns in both cases. However, PCR proved to be vastly superior in terms of dynamic range and contrast detectability (Figure 1).

The PCR-based digital mammography service has been in routine clinical use since 1994, and to date some 20 000 patients have been successfully examined. The mammography service at the General Infirmary is now exclusively digital, and continues to be based on PCR. PCR has one practical advantage over the new flat-panel digital mammography systems. It can be implemented on any conventional mammography X-ray unit without modification.

At Leeds we prefer to use a stand-alone PCR imaging system. Currently hardcopy laser film is preferred as the display medium, as soft-copy reporting

requires specialized high resolution displays, and softcopy images often take longer to view. Cost is also a major factor in this. PCR sets an economical standard for successful digital mammography. Image enhancement and printing are fully automated, and the processing settings have been standardized as reproducible default modes.

This provides excellent clinical results every time, so that there is no need to have a member of staff available to operate the workstation. The system consistently provides the same image quality, even in the case of large, dense breasts (Figure 2).

Clinical assessment

The breast represents a wide variation in radiographic density, both within the individual breasts and across the female population as a whole. Dense breasts pose a unique challenge for the detection of early-stage cancer, and are accountable for a large percentage of missed carcinomas [4]. The spatial resolution limit achievable with screen-film mammography is often quoted as 10 (or even 15) line pairs per mm [lp/mm]. This means that 10 (or 15) pairs of parallel lines (of lead and plastic) per mm can be distinguished in a suitable test grating. Transposing the higher spatial resolution limit of 15 lp/mm to the clinical situation would suggest that objects as small as 33 microns should be visible. However, high-resolution PCR imaging plates have a maximum spatial resolution of only 5 lp/mm, representing a minimum object size of about 100 microns. For this reason, there were doubts as to whether PCR could match screen-film mammography's ability to demonstrate microcalcifications. However this interpretation does not take account of the three-dimensional profile nature of real mammographic features, nor the implications of the noise in the image.

The real clinical situation is somewhat different. In spite of its theoretical superiority, screen-film mammography is, in fact, only able to detect microcalcifications of approximately 130 microns at currently acceptable dose levels. The reason for this apparent discrepancy is that the radiographic density and physical structure of a microcalcification

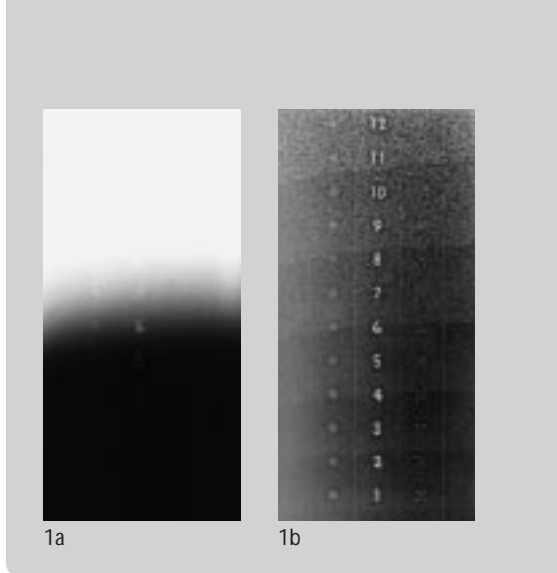


Figure 1. Screen-film and PCR images of a plexiglas wedge phantom showing the superior dynamic range and contrast detectability of digital mammography (Reproduced from Arnold Cowen et al., Phys Med Biol 42 (1997) by permission of IOP Publishing).

Figure 1a. Screen-film image. Film can only reproduce details over a limited dynamic range, corresponding to 3-4 cm breast tissue.

Figure 1b. Digital image. Digital mammography can reproduce details over the whole dynamic range. Contouring indicates that the system is operating under extreme conditions, unlikely to be encountered in practice.

PCR-based digital mammography has been in routine use since 1994.

The visibility of small microcalcifications is determined by signal-to-noise ratio rather than resolution.

is very different from that of a lead test grating. The three-dimensional structure of a microcalcification means that as its spatial size is reduced, the subject X-ray contrast is reduced simultaneously and proportionately. This reduction in subject contrast means that the visibility of small microcalcifications is ultimately limited by signal-to-noise ratio rather than purely spatial resolution considerations.

Microcalcifications represent individual specks of calcified material in the breast. In the image, such details represent wide-band spatial-frequency signals rather than narrow-band high-spatial frequency signals. It is therefore not the high spatial frequencies but the complete MTF(f) characteristic or, more correctly, the complete DQE spectrum, including the medium and low-frequency signal transfer which contribute to the visibility of the microcalcification. In this context, contrast, signal-to-noise ratio and dynamic range are at least as important imaging parameters as spatial resolution limit. In terms of radiation dose efficiency (DQE), PCR is slightly more efficient than screen-film mammography, but the difference is too small to allow significant dose savings.

The detectability of low-contrast features is far superior to that of screen-film mammography.

Early clinical assessments of CR-based mammography at other research centers proved disappointing, but we believe that this was mainly because the standard processing was not optimized for mammography. In mammographic examinations, the laser-stimulated readout signal is now digitized on a high-resolution (2370 x 1770) matrix array over a 24 x 18 cm field with 10 bits (1024 levels) of grayscale discrimination per pixel. If the clinical standard of detectability is used, PCR is at least equal to screen-film mammography, and has the advantages of better contrast and image reproducibility.

Any new digital detection device would have to yield an image quality equivalent or superior to that of PCR.

Image presentation

On-line (soft copy) imaging typically takes 50% more time than conventional film reporting, which is why we have preferred the latter approach to date. Furthermore, display image quality (including spatial resolution) is very important. Acceptable image quality can be achieved on high-resolution monitors, but one monitor is needed for

Standardized default settings consistently produce excellent image quality.

each image displayed, which typically means that at least four monitors will be required to read a study. Another important consideration is correct formatting on the hardcopy film. In screen-film mammography, the images are conventionally displayed back-to-back in pairs, with the mediolateral oblique (MLO) and cranio-caudal (CC) images one above the other, or side-by-side. As direct comparison of the two sides is essential, in order to detect subtle asymmetries, the hard or soft copies in the digital viewing environment should provide similar display modes.

The laser film produced by the EasyVision RAD workstation presents the images back-to-back and one above the other on a single sheet of 35 x 43 cm laser film (Figure 2).

As the pixel size of the laser imager is smaller than that of the PCR system, the images are presented at full resolution, but at approximately 85 % of actual size. A scale can be included on the hard copies for ease of measurement. This type of presentation has been found to be convenient for display, and is also economically viable, as the cost of one sheet of laser film is approximately equal to the cost of four mammography films.

Contrast resolution

Contrast resolution is a factor that has been widely ignored, because film has a fixed and relatively limited contrast. A digital system provides far more flexibility. The detectability of low-contrast features such as subtle masses and stromal deformities with digital mammography is far superior to that of screen-film mammography.

Standardized settings

Neither the radiologists nor the radiographers have to sit at the workstation manipulating the image data. Standardized default settings consistently produce excellent image quality. Consistency is very important, because it allows subtle changes over time to be detected. Very small or subtle changes in tissue form or content can be easily detected two years later in follow-up patients. There are also fewer retakes, which reduces costs and minimizes stress for the patients.

Due to the very narrow exposure latitude of a typical mammography screen-film system, slight under- or overexposure can produce a dramatic loss of detail caused by increases or decreases in density

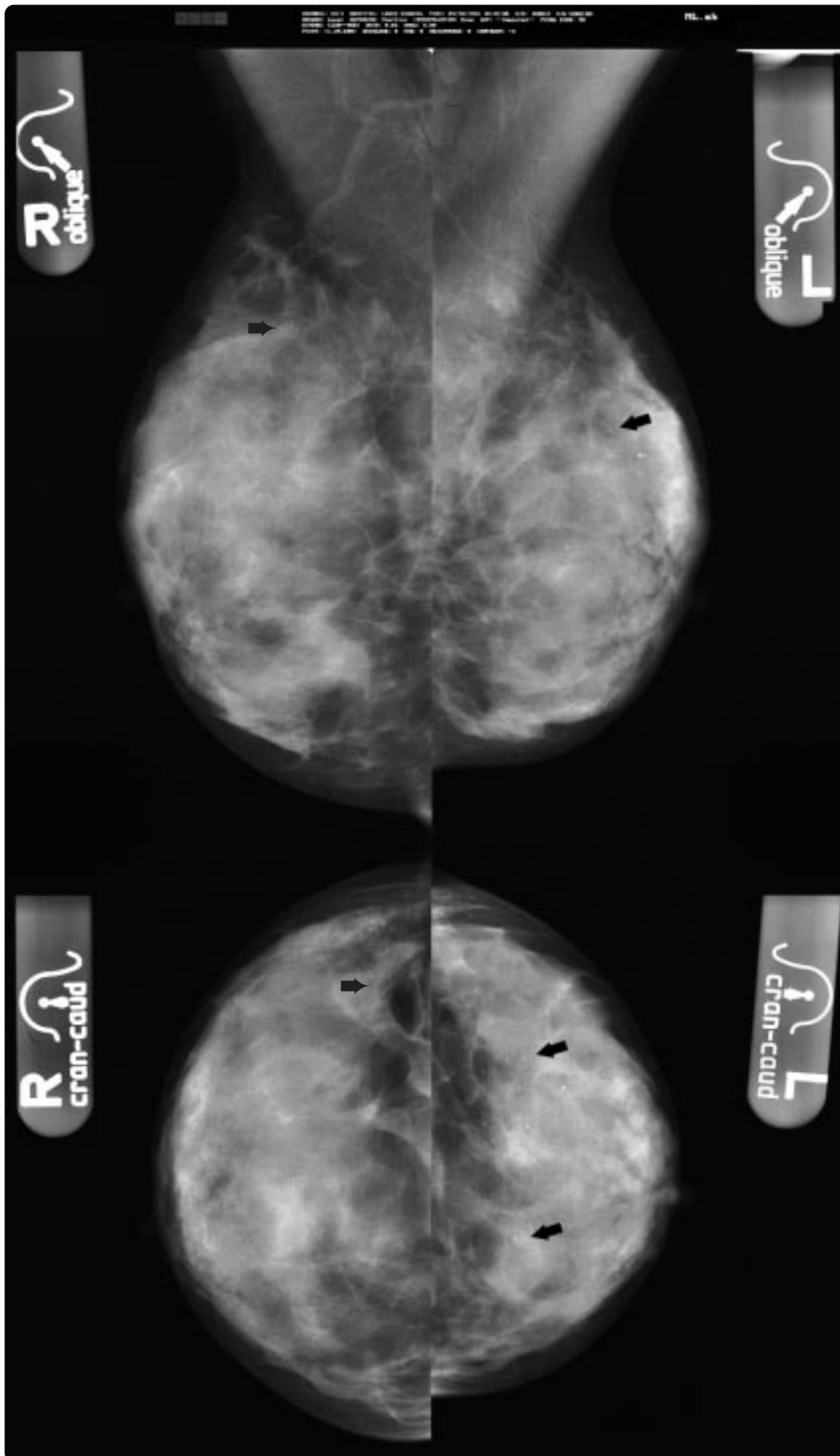


Figure 2. Digital mammogram of very dense breasts. The patient was referred to the General Infirmary because conventional screen-film mammography was unable to show any detail. The digital mammogram clearly shows the microcalcifications (arrows). The laser film of the EasyVision workstation presents the images back-to-back and one above the other on a single sheet of 35 x 43 cm laser film.

Presentation on a single sheet of laser film is convenient and economically viable.

and contrast. Digital mammography optimizes the image presentation so that each image is displayed at a predetermined level of density and contrast, independent of dose.

Dynamic Range Reconstruction provides more information in dense areas.

DRR clearly enhances the detail visibility in radiographically dense areas, providing significantly more information than a conventional mammogram.

The clinical advantages of digital mammography have been clearly demonstrated. Images do not look any different from a conventional mammogram: they just look like a very high quality conventional mammogram.

DISCUSSION

In our hospital, digital mammography has been in routine use since January 1994. To date, some 20 000 patients have been successfully examined. The whole mammography service is currently run on PCR, but could easily be adapted to other digital inputs, provided that they meet the required quality standards. It should be noted that the department is a referral center for symptomatic or at risk patients, but does not form part of the British National Health Service screening program.

The decision as to whether a digital mammography service should be centralized, or be served by a dedicated unit, is essentially a political and organizational one. We prefer to have a dedicated unit, separate from the main radiology department, which is a PACS environment.

The mammography system is the Philips Mammo Diagnost UC. It is used with the high-resolution PCR image plates (series HRVN). The radiographic procedure is virtually identical to that of a conventional film-screen examination. The main difference lies in the digital image processing, which ensures superb image quality.

The original performance specification demanded that it should not be necessary to change the image processing settings, and this has been achieved in practically every case. Another advantage of the use of standardized settings is that the images are reproducible and comparable, even over comparatively long periods.

In spite of the excellent results achieved, many hospitals are still reluctant to implement CR-based

digital mammography. The reason is probably due to the generally held opinion regarding the inferior spatial resolution of digital acquisition techniques. However, as we have demonstrated, digital mammography is at least equal to conventional mammography in detecting small microcalcifications. The ultimate limitation features of small size is not spatial resolution, but noise: i.e. achieving an acceptable signal-to-noise ratio at a responsible dose per image. It is expected that, in the near future, this problem will be alleviated by the use of high-resolution flat panels with superior DQE performance.

Some publications on digital techniques quote a dose that is higher than that of conventional systems. In our experience, PCR shows everything that can be seen on conventional screen-film mammograms at a comparable dose, and indeed is sometimes better, particularly in the case of dense breasts. Because the technique is rapid, convenient and standardized, an identical high-quality imaging service is assured for all patients. In our opinion screen-film mammography no longer represents the best quality of diagnostic imaging service for patients requiring mammography.

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The procedure is virtually identical to a conventional screen-film examination.

The fast and standardized technique ensures identical high-quality imaging for all.