**COMMISSIONING AND ROUTINE TESTING OF
SMALL FIELD DIGITAL MAMMOGRAPHY SYSTEMS**

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CONTENTS

PREFACE

This publication is an updated version of NHSBSP Report 01/09 (September 2001). It takes into account the experience that has been gained with testing small field digital mammography systems and developments in equipment design since the original report was published.

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1. INTRODUCTION

Recent developments in diagnostic imaging technology have resulted in the gradual replacement of screen-film imaging systems by digital devices. One area in which this new technology has been successfully implemented is small field mammography imaging. In the UK, nearly all mammography x-ray units purchased with a stereotactic attachment are now supplied with a digital imaging option (Table 1).

Clinical experience has suggested that the use of digital imaging can improve the performance of upright stereotactic core biopsy of microcalcifications giving a significantly increased success rate in accurately obtaining calcifications.[1]

This document introduces small field digital imaging systems for mammography and proposes suitable test protocols for commissioning and routine performance testing. It should be used in conjunction with IPEM 89,[2] which fully describes the testing of the mammography x-ray unit and stereotactic attachment.

The remedial levels given in this document are based on the current experience of testing small field digital systems and will be revised in line with performance data and advances in technology.

Terms in *italics* are explained in the Glossary.

Table 1 Small field digital imaging systems

Imaging system	Associated mammography x-ray unit	Design of detector	UK Supplier
Fischer Imaging MammoTest/ MammoVision*	MammoTest prone breast biopsy table	Detector unit replaces breast platform	Ethicon Endo-Surgery
GE SenoVision*	GE Senographe DMR+	Digital cassette	GE Healthcare
GE Delta 32 GE Delta 16*	GE Diamond	Detector unit replaces breast platform	GE Healthcare
Hologic LoRad DSM	Hologic LoRad MIV and StereoGuide* or MultiCare Platinum prone breast biopsy tables	Detector unit replaces breast platform	Medical Imaging Systems Ltd
Philips Digital Stereotactic Biopsy	MammoDiagnost	Digital cassette	Philips Medical Systems
Siemens MammoTest	MammoTest prone breast biopsy table	Detector unit replaces breast platform	Siemens Medical Solutions
Siemens Opdima	Siemens Mammomat 3000 Nova	Digital cassette	Siemens Medical Solutions
Planmed DigiGuide	Nuance Classic, Sophie and Sophie Classic	Digital cassette	Wolverson X-ray Ltd

*No longer in production but a number in use in the UK

2. DIGITAL IMAGING IN MAMMOGRAPHY

Small field digital imaging systems for mammography are designed primarily for stereotactic localisations but in certain cases may also be used for spot imaging and magnified views. They may also have applications in specimen radiography.

A small field digital imaging device comprises a detector assembly, which attaches to the mammography x-ray unit, and an associated workstation. The workstation provides many of the usual image processing facilities plus image storage and archive. Hard copy can be produced using an appropriate printing device. The detector may be an integral part of the stereotactic device.

A small field digital system is also available as part of dedicated breast biopsy systems. On these units the x-ray tube and detector assembly are mounted below a prone patient.

Dedicated specimen radiography systems are available with a small field digital imaging system to replace conventional film recording. However, due to their use and design, the test methods will differ to those for the clinical units and are outside the scope of this document.

Most of the available systems are provided with automatic exposure control (AEC) through the detector in addition to manual control. The GE SenoVision is provided with AES (automatic exposure setting) in addition to manual control, which automatically sets an mAs value based on the compressed breast thickness and compression force. The GE Delta 32 and Hologic DSM have manual control only with suggested exposure parameters given in the operator's manual.

Digital imaging techniques present a number of advantages when compared to screen-film systems. The dynamic range is increased and the low contrast sensitivity may be improved. However, with current technology, a reduction in spatial resolution is expected. Currently, most manufacturers suggest that digital imaging should result in a similar radiation dose to that of a modern mammographic screen-film combination. Developments in detector design may eventually allow a reduction in radiation dose.

Manufacturers have also suggested that digital imaging in mammography can result in a saving in examination time of 30% to 50% when performing stereotactic localisations. This could allow these investigations to be performed on an 'as required' basis without having to arrange a return visit for the patient. Additionally the patient remains under compression for a shorter period. Initial clinical experience with these systems has confirmed some of these advantages.[3]

2.1 The detector

All current small field systems employ detectors based on charge coupled device (*CCD*) camera technology. The imaging area varies between 50×50 mm and 85×49 mm. Two basic designs of digital detector are available in which the *CCD* is either directly or indirectly coupled to the imaging phosphor (usually caesium iodide or gadolinium oxysulphide) (Table 2).

Table 2 Detector properties

Imaging system	CCD to phosphor coupling	Phosphor material	Detector cooling	Provision of AEC	Nominal imaging area (mm × mm)	Nominal *pixel size* (μm)
Fischer Imaging MammoTest/ MammoVision	Mirror/lens system	Kodak Min-R intensifying screen	Not required	AEC and manual	50 × 50	48
GE SenoVision	Direct	Kodak Min-R 2000 intensifying screen	Thermoelectric plus water	AES (semi-automatic) and manual	60 × 60	30
GE Delta 16 GE Delta 32	Fibre-optic taper	Kodak Min-R intensifying screen	Not required	Delta 16 – AEC and manual Delta 32 – manual only	50 × 50	48
Hologic LoRad DSM	Mirror/lens system	Kodak Lanex Regular intensifying screen	Thermoelectric plus fan	Manual only	55 × 55	Std – 110 High – 55
Philips Digital Stereotactic Biopsy	Direct	Caesium iodide	Not required	AEC and manual	85 × 49	Std – 48 High – 24
Siemens MammoTest	Mirror/lens system	Kodak Min-R intensifying screen	Not required	AEC and manual	50 × 50	48
Siemens Opdima	Direct	Caesium iodide	Not required	AEC and manual	85 × 49	Std – 48 High – 24
Planmed DigiGuide	Fibre-optic coupling		Not required		50 × 50	Std – 48 High – 24

2.1.1 Directly coupled devices

A large area *CCD* (nominally the same area as the imaging field) is bonded directly to the imaging phosphor via a thin fibre optic plate. With this design, the detector assembly is sufficiently thin to fit within the confines of a 'digital cassette'. This is similar in size to a conventional screen-film cassette and for stereotactic localisations is inserted into the cassette holder in the conventional stereotactic attachment. For spot imaging the detector normally slots into the existing bucky assembly but may also be used with a cassette holder without a grid (with a potential reduction in dose). With this type of detector, magnified views may be accomplished using the conventional magnification platform.

2.1.2 Indirectly coupled devices

Usually a small area *CCD* is used and is coupled to the phosphor via a fibre optic taper or lens/mirror system, which de-magnifies the image. This is housed within a sealed enclosure, which is larger and bulkier than the 'digital cassette' design. The detector unit completely replaces the bucky assembly/breast support platform. This design does not use an anti-scatter grid. On the GE Delta 16 and Delta 32 units, the stereotactic attachment is an integral part of the digital detector.

2.1.3 Detector cooling

The detector may be cooled in order to reduce *dark current* noise in the *CCD*. The Hologic DSM uses thermo-electric cooling in conjunction with a fan; the GE SenoVision employs liquid cooling in conjunction with a heat exchange unit.

2.1.4 Detector resolution

The Hologic DSM, Philips Digital Stereotactic Biopsy, Siemens Opdima and Planmed DigiGuide can be operated in either a standard or high resolution mode. A high resolution mode may require an increased radiation dose and image presentation will be slower. The measured range of *limiting spatial resolution* of current systems is approximately 5.0 to 15.0 line pairs per millimetre (lp.mm^{-1}).[4] This depends on the *CCD pixel* matrix, the type of phosphor and method of coupling and the resolution mode. A comparative value for screen-film imaging is 15.0 to > 20.0 lp.mm^{-1}.

2.2 The workstation

The computer workstation provides the operating system for image acquisition, processing and patient information. The exact facilities provided vary from manufacturer to manufacturer.

2.2.1 Image processing facilities

Two advantages of digital imaging systems when compared to screen-film imaging are the speed with which images are presented and the ability to manipulate and possibly enhance the displayed image.

Image presentation, after exposure, takes typically 5–10 seconds in standard resolution mode and 15–30 seconds in high resolution mode.

All current systems are provided with a selection of the following standard image processing tools. The exact functions provided vary from manufacturer to manufacturer.

- invert – inverts the image grey scale (black to white/white to black) which may assist visualisation of certain tissues
- window/level – alters the brightness/contrast of the image to optimise visualisation of the data displayed
- zoom – magnifies the complete image. Various degrees of magnification may be provided
- magnify and roam – magnifies a selected area of the image (magnifying glass effect). The magnified area can be moved about the image field
- edge enhancement – can improve edge differentiation. However, this may also have the effect of amplifying noise and reducing the visibility of low contrast objects. A range of levels of edge enhancement is normally provided
- region of interest (ROI) – allows a specific region of the image to be selected. Numerical data referring to the ROI may be provided
- measurement – provides measurement of distance in real space
- statistics – provides numerical data such as *pixel* count, histograms.

2.2.2 Image storage and archive

Digital images comprise a large amount of data (1–15 MB depending on the resolution mode), which need to be stored, both in the short and long term. Short term storage is generally provided on the computer hard disk. For long term storage, a separate archive facility is required.

Data compression may be used to improve the efficiency of storage.

All current systems claim a level of *DICOM* compatibility, which should be fully explained in the manufacturer's *DICOM* conformance statement.

2.3   Hardcopy device

The image from a digital system is initially displayed on the monitor. Consideration must be given as to whether reporting and diagnosis will be solely from the monitor (softcopy reporting) or if any form of hardcopy is required.

A high resolution device, such as a high resolution laser film printer, will be required if the hardcopy images are to be used for diagnosis. A lower specification device may be considered if images are only required for patient records.

3. TESTING PROCEDURES

This section outlines the testing procedures for small field digital mammography units, including those performed at commissioning and the routine tests summarised in Table 3.

Table 3 Summary of routine tests

Section	Test	Frequency	Remedial level
Beam alignment	Alignment of the light field to the x-ray field	Annual	± 10 mm on all sides
	Alignment of the x-ray field to the imaged field	Annual	0 to + 10 mm on all sides
X-ray field non-uniformity	Variation in *pixel value* across the image	6 monthly	Variation in *pixel value* should not exceed 10% from the value measured in the centre of the image
Automatic exposure control	Overall repeatability	6 monthly	Maximum deviation in mAs should not exceed 5% from the mean
	Constancy with change in phantom thickness	6 monthly	Maximum deviation in *pixel values* should not exceed 10% of the mean
Display devices	Greyscale	6 monthly	Monitor – 5% steps from 0% and 100% grey levels equally visible Hardcopy – baseline greyscale step ± 0.15 OD (± 0.05 OD for minimum density step)
	Resolution	6 monthly	Frequency high contrast resolution pattern resolved
Image quality	Limiting spatial resolution	6 monthly	Should be at least 75% of the value determined at commissioning
	Low contrast detectability	6 monthly	5–6 mm details < 1.2% 0.5 mm details < 5% 0.25 mm details < 8%
Measurement of dose	Dose to the standard breast at the clinical setting	6 monthly	Variation within ± 25% of value determined at commissioning

Tests should be conducted in clinical modes, eg spot, stereo.

Some of these tests require the mean of the *pixel* values in a defined region of interest (ROI). Some systems do not allow an area to be selected; in this case two different methods can be employed:

- a single value can be taken at various points across this image
- if the system has a window and level facility, the window should be reduced to its minimum level (usually 1 or 2 greyscale levels) producing a binary image. The level control is then adjusted until the region of interest has approximately equal numbers of black and white *pixels*. The value of the level corresponds to the mean *pixel* value in the area of interest. A method for defining the region of interest is described in the Appendix.

When a standard sized region of interest (ROI) can be selected, it should typically be of dimensions 10 mm × 10 mm.

If the callipers are used in measurements, ensure that their accuracy is verified. The measurements must be done at the reference plane (eg 4 cm above the table for Lorad).

3.1 Beam alignment

The alignment tests required for a small field digital mammography system are as follows:

- alignment of the light field to the x-ray field
- alignment of the x-ray field to the visible image field/detector
- size of the imaged field.

For all tests ensure that the appropriate collimator is in place. In the case of dual track x-ray tubes, the tests may need to be repeated for the different target materials (Mo and Rh or W) if they are used clinically.

3.1.1 Alignment of the light field, x-ray field and visible image field

Test protocol
Place a loaded screen-film cassette on the breast support platform so that it overlaps the front edge. Position markers to delineate the edges of the light beam area on top of the cassette and acquire an image (use low values of kV and mAs). A fluorescent screen may be used in place of the screen-film cassette but this method will require a number of exposures. Although basic markers may be used for this test, it is simpler and more accurate to use radio-opaque markers at least 2 cm in length with subdivisions typically of 2 mm. Alternatively, a specially designed test object with radio-opaque scale markings to cover the full imaging area can be used.

Evaluation
The displacement between the x-ray field and the light field along the four sides is estimated by comparing the edges of the x-ray field to the position of the markers on the processed film or fluorescent screen.

The displacement between the imaged field and the light field is estimated by comparing the position of the markers and the edges of the visible image field as seen on the display monitor. Reference to the results of the displacement between the x-ray field and the light field can then be used to derive the alignment of the x-ray field to the imaged field.

The area of the x-ray beam at the breast table should be calculated for use in dosimetry (see section 3.6.1).

Remedial levels
Alignment of light field to x-ray field = ± 10 mm on all sides
Alignment of x-ray field to imaged field = 0 to + 10 mm on all sides

Frequency
Annually

3.1.2 Size of imaged field

This test is carried out to verify the nominal/specified size of the imaged field.

Test protocol
Align the markers with the four edges of the light beam on the major axes. Ideally, the markers should be at least 2 cm in length with subdivisions typically of 2 mm. Note the distance between opposite pairs of markers.

Alternatively use a specially designed test object with scale markings to cover the full imaged area. Acquire an image (use low values of kV and mAs) and view the image on the display monitor.

Evaluation
By noting the positions of the markers and knowing their separation, derive the size of the visible image field. The image of the specially designed test object will give a direct indication.

In addition to checking the softcopy image on the display monitor, the hardcopy image should, if provided, be tested independently.

Remedial level
Each dimension should be within 5% of the nominal/specified value

Frequency
Commissioning

3.2   X-ray field non-uniformity

All systems have flat field calibration which should be checked routinely. The presence of artefacts should be evaluated. Note that the uniformity of the image may be temperature dependent.

The uniformity of a digital image can be measured by assessing the *pixel values* resulting from an exposure of a uniform test object, such as Perspex or aluminium.

Measure the mean *pixel value* for an ROI at a position in the centre and at each of the four corners of the image. The exact placement of the ROIs is not important but the positions should be recorded so that the same setup may be used on subsequent routine visits.
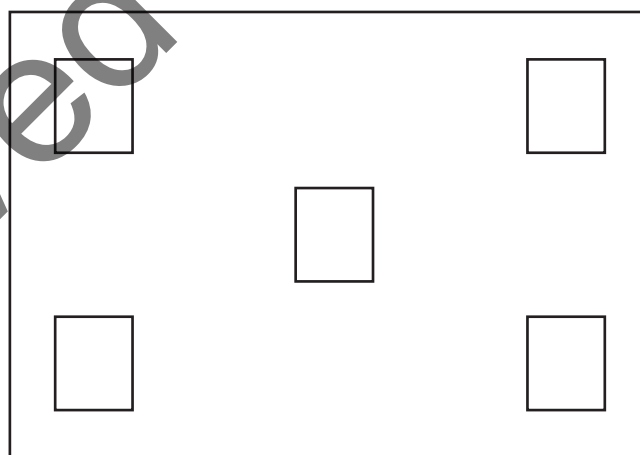

Chest wall edge

Figure 1 ROI locations.

Test protocol

Place a 40 mm thickness of Perspex or 2 mm thickness of aluminium (large enough to cover the full field of view) on the breast support platform. Expose at 28 kV, Mo/Mo using automatic exposure control and normal resolution. Visually inspect the image. Record the *pixel value* in the centre of the image and at the four corners (see Figure 1) for the unit being tested. Calculate the percentage deviation of the corner means from the central ROI mean value:

$$Deviation\ from\ centre\ mean = \frac{(Corner\ ROI\ mean - Centre\ ROI\ mean\ )}{Centre\ ROI\ mean} \times 100$$

Repeat with a 70 mm thickness of Perspex, or 3–4 mm aluminium, to assess the uniformity for a longer exposure time. Visually inspect the image.

Remedial level

> The variation in *pixel value* should not exceed 10% from the value measured in the centre of the image

Frequency

> 6 monthly

3.2.1 Artefacts

Artefacts are signals generated in the imaging system which are not related to the structure of the object being imaged. Artefacts can only be assessed subjectively and judgement will be required as to whether they may significantly affect the clinical image quality. Artefacts are normally assessed from uniformly exposed images. In such cases, they may be easily visible because of the lack of anatomical background structure which would be present in a normal clinical image. Also, with a digital imaging system, the reduced *pixel value* range associated with a uniformly exposed image means that the image can be presented with higher display contrast which may make the artefacts more visible.

In most systems, fixed pattern artefacts should be removed by flat fielding correction techniques. This process is usually carried out without the need for user input, so that the displayed image will have already been corrected. If significant artefacts are present, the flat fielding procedure should be checked to ensure that it is being carried out by the method and at the frequency specified by the manufacturer. Some types of artefacts which have been observed on *CCD* based small field digital systems are described as follows:

Dead pixels usually appear as white dots on the image when it is viewed in the inverted contrast grey-scale mode (ie presented in the same rendition as film). They can occur either individually, in clusters or as dead columns or rows. Some systems use software algorithms to correct for dead pixels (interpolate a new value depending on neighbouring pixel values). The manufacturer should be able to quote a specification for the maximum number of dead pixels acceptable on the device and possibly the maximum acceptable cluster size.

Some *CCD* devices allow the data to be read out through more than one channel. Thus several areas of the *CCD* may be read out simultaneously. This is particularly valuable for large area *CCDs* and allows image readout and display in a shorter time. Differences in the gains or offset levels for each electronic channel can result in differences in the background signal level in different areas of the image. This has been observed in some systems, for example as quadranting, where four distinctly different background levels are observed in the image. Quadranting can be reduced by keeping the room temperature constant.

Remedial level

   No disturbing artefacts should be seen on clinical images

3.3   Automatic exposure control

The automatic exposure control system uses the detector to monitor the radiation and terminates the exposure at a predetermined level.

As well as controlling the duration of an exposure, some of the AEC systems select the appropriate kV and target/filter combination.

At commissioning, measurements are made at various set exposure parameters and breast phantom thicknesses, as well as at clinical settings. It should be noted that since Perspex is generally denser than breast tissue any automatic selection of kV, target or filter may be slightly different from real breasts. This can be corrected by adding expanded polystyrene blocks to the PMMA as a spacer to make up a total thickness equal to the equivalent breast. A standard compression force should be applied (eg 100 N).

3.3.1   Overall repeatability

Test protocol (commissioning)
Place a 45 mm thickness of Perspex (large enough to cover the full imaged field) on the breast support platform. Make six exposures at 28 kV, Mo/Mo using automatic exposure control and normal resolution mode. For each exposure, record the delivered mAs and the mean *pixel value* in a ROI at the centre of the image.

Remedial level

   The maximum deviation in both mAs and *pixel value* should not exceed 5% of the mean value

   Typical *pixel values*:

      Fischer: 1500/800
      GE SenoVision: 250
      Delta 16: 2.3
      Delta 32: –
      LoRad: 5400 @ 50 mAs for 40 mm PMMA
      Philips: –
      Siemens Opdima: 800

Test protocol (routine)
Place a 45 mm thickness of Perspex (large enough to cover the full field of view) on the breast support platform. Make six exposures at 28 kV, Mo/Mo using automatic exposure control and normal resolution mode. For each exposure, record the delivered mAs and the *pixel value* at the centre of the image.

Remedial level

   The maximum deviation in mAs should not exceed 5% of the mean value
   The mean *pixel value* should be within 10% of the commissioning value

Frequency
> 6 monthly

3.3.2   Constancy with change in phantom thickness

Test protocol (commissioning)
Use blocks of Perspex with thicknesses 20, 30, 40, 45, 50, 60 and 70 mm to simulate breasts of different thicknesses. For each thickness make one exposure at 28 kV, Mo/Mo using automatic exposure control and normal resolution. Record the delivered mAs and the mean *pixel value* in a ROI in the centre of the image.

Remedial level
> The maximum deviation in *pixel value* from the mean should not exceed 10%

Test protocol (commissioning and routine)
Use thicknesses of 20, 40, 45, 60 and 70 mm of Perspex to simulate breasts of different thicknesses. For each thickness make one exposure using the settings used clinically for the equivalent breast thickness (including any auto selections of kV, filter, target).[2] Record the delivered exposure factors and the *pixel value* in the centre of the image.

Remedial level
> The maximum deviation in *pixel values* should not exceed 10% of the mean value

Frequency
> 6 monthly

3.3.3   Constancy with change in tube voltage

Test protocol (commissioning)
Using AEC and normal resolution, expose 45 mm of Perspex at tube voltages of 25, 26, 28, 30, 32 and 35 kV, using a Mo/Mo target/filter combination. Record the delivered mAs and the mean *pixel value* in a ROI in the centre of the image.

Remedial level
> The maximum deviation in *pixel value* should not exceed 10% of the mean value

3.4   Display devices

An important component in a digital imaging system is the display system. This component should be tested independently of the whole imaging system. This may allow the separation and identification of image quality problems related specifically to the display system rather than the image acquisition system. Tests are necessary to ensure the proper visual adjustment of the display device and that the performance of the display device remains acceptable.

Quality control and adjustment of display devices may be undertaken using a display test pattern. The test pattern should be capable of allowing the assessment of the resolution and the greyscale setup of the image display system. A suitable test pattern is that proposed by the Society of Motion Picture and Television Engineers (SMPTE)[7] or one that conforms to this specification. Such test patterns may be available from external video signal generators or may be internally generated as a digital pattern on the imaging modality.

3.4.1 Viewing monitor

Test protocol
These tests should be conducted with low ambient light.

Ensure that the window and level (or other digital contrast and brightness controls) are set appropriately. Display an appropriate test pattern (eg SMPTE).

Ensure that the 5% greyscale step in the 0% field and the 95% greyscale step in the 100% field are equally visible.

If the steps are not equally visible the monitor may require adjustment as follows:

> Set the monitor brightness and contrast controls to their minimum values. Adjust the brightness so that the line structure just becomes visible. Display the SMPTE test pattern and adjust the contrast control such that the 100% level gives the required luminance. The luminance level may be checked if a photometer is available. Typically the maximum luminance may be in the range 100–200 candelas/metre^2, although this may be higher for some high output monitors (the monitor luminance specification should be checked with the manufacturer). When adjusted the 5% steps from the 0% and 100% grey levels should be equally visible.

The high and low contrast resolution test patterns should be assessed at each position on the monitor. The high contrast resolution patterns (100% modulation) should be resolved up to the maximum frequency. A note should also be made of the low contrast resolution limits.

Ideally the display luminance should conform to the *DICOM* GSDF.

Remedial level
> Greyscale – the 5% steps from the 0% and 100% grey levels should be equally visible
> Resolution – maximum frequency in the high contrast patterns should be resolved

Frequency
> 6 monthly

3.4.2 Hardcopy film printer

Test protocol
These tests should be performed at commissioning and routinely if films are printed for diagnosis.

The greyscale rendition of the image printed on hardcopy film should match that displayed on the viewing monitor. An appropriate minimum and maximum density for the hardcopy device should be set. Setup procedures will vary depending on the hardcopy device make and model and will not be dealt with in detail here,

although it is likely that the maximum density should not be less than 2.5 and the minimum density should not be greater than 0.20. Devices usually have a range of available lookup tables to ensure that the appropriate greyscale rendition can be achieved.

An appropriate test pattern (eg SMPTE) should be printed onto hardcopy film. Once it has been ensured that the hardcopy film greyscale rendition matches that of the monitor display, a number of greyscale steps on the pattern should be sampled to provide baseline density measurements for subsequent constancy tests. The density of the following greyscale steps should be measured:

1 100% greyscale step – this should correspond to the minimum density and should be close to base + fog level of the film
2 the step closest to an optical density of 1.0 above base + fog level (approximately 1.15 OD)
3 the step closest to a gross optical density of 2.0.

The high and low contrast resolution test patterns should be assessed at each position on the hardcopy film. The high contrast resolution patterns (100% modulation) should be resolved up to the maximum frequency. A note should also be made of the low contrast resolution limits.

Remedial level
  Greyscale – the greyscale rendition should match that of the image display monitor. Also the greyscale steps selected for monitoring should be within the following tolerances:

  Step 1: ± 0.05
  Step 2: ± 0.15
  Step 3: ± 0.15

  Resolution – maximum frequency in the high contrast patterns should be resolved.

Frequency
  6 monthly, if used routinely for diagnosis

3.5 Image quality tests

Image quality data can be obtained using conventional mammography test objects. However, with small field systems this is made difficult by the limited field size and requires multiple views plus a means of navigating about the test object. Thus it may be advantageous to use test objects designed specifically for small field systems that can be imaged using a single exposure. A possible layout is a contrast detail format.

Image quality tests for digital mammography systems are categorised into two main types of test:

• spatial resolution
• contrast sensitivity.

Image quality test objects should contain suitable test details in order to measure the above parameters. A high contrast resolution grating is suitable for the measurement of spatial resolution. This may be used as a separate test piece or as part of a test object (eg TORMAS or TORMAX). The test detail plate of such a test object should be separable from any scattering material to allow contact exposures to take place. For contrast sensitivity measurements, the test object should contain contrasts of a suitable range for a number of detail sizes, eg 5–6 mm and 0.1–0.5 mm diameter details. The contrast is specified in terms of the primary subject

contrast (which excludes the effects of scatter). Contrast of details should be specified for a given x-ray beam quality in terms of energy fluence. If I is the background transmitted energy fluence and ΔI is the difference in energy fluence transmitted by the signal detail and background then the contrast is given by $\Delta I/I$.

3.5.1 Limiting spatial resolution

The resolution properties of an imaging system may be most conveniently quantified by measuring the *limiting spatial resolution*. However, such a measure is just a single figure descriptor of a more complex parameter (ie it represents the high spatial frequency limit of the Modulation Transfer Function of the imaging system) and while meaningful comparisons may be made for imaging systems of the same type, such as screen-film systems, such comparisons may not be appropriate for different types of imaging systems. For digital imaging systems, the *limiting spatial resolution* may be determined by the sampling rate at which the signal is digitised, rather than the inherent resolution limit of the analogue component of the system. Thus it may be possible that two systems, while having similar inherent sharpness properties, may have quite different *limiting spatial resolution*.

However, the *limiting spatial resolution* is useful as a commissioning test on the detector and for routine testing of the system.

Test protocol
Detector The *limiting spatial resolution* of the detector system may be measured by contact exposure where a high contrast resolution test grating is placed as close as possible to the detector input plane (usually on the breast platform).

System The *limiting spatial resolution* of the system, which includes the effect of geometric unsharpness due to the finite size of the focal spot, should be measured with either the test grating placed on top of a 45 mm Perspex stack or with TORMAS or TORMAX on top of 40 mm Perspex stack and centred in the field.

Evaluation
System resolution may be limited by either the spatial resolution characteristics of the detector (either analogue or digitisation effects) or by the effect of the focal spot size. For some detector systems the limiting resolution will be lower than the corresponding *Nyquist frequency*. This may be due to the resolution of the phosphor, optical coupling arrangement or the presence of bandlimiting anti-*aliasing* filters in the electronic processing of the *CCD* camera signal.

The evaluation of the *limiting spatial resolution* for digital imaging systems needs to be carried out carefully to ensure that *aliased* patterns are not included. The appropriate number of bars and spaces should be visible across the group (eg with a Type 18 Huttner pattern, as found in the TORMAX test object, 4 bars and 5 spaces). A lower number of bars or spaces than expected in the group may indicate the presence of *aliased* components and such a group should be discounted from the evaluation. This may be checked against the *Nyquist frequency* of the system.

The display system and display conditions will also affect resolution and the results obtained. Sufficient display magnification and contrast will be required to ensure proper evaluation of the *limiting spatial resolution* of the imaging system.

Note that display monitors, especially those which are colour, may have limited resolution capabilities.

Remedial levels

The present standards for *limiting spatial resolution* for the performance of mammographic systems in the breast screening programme were derived from surveys of the performance of screen-film systems. Comparison of the performance of different types of detector system on the basis of *limiting spatial resolution* alone is misleading, especially in the case of digital detectors where the digitisation process may determine the limiting resolution. For this reason, the adoption of an absolute level of minimum performance in terms of *limiting spatial resolution* for digital imaging systems is thought to be inappropriate.

Commissioning The limiting spatial resolution of the detector should meet the manufacturer's specification (if given) and be greater than 70% of the Nyquist frequency of the detector. A value for the limiting spatial resolution of the system is not given as it depends on a number of factors including focal spot size.

Routine The *limiting spatial resolution* for the detector should be at least 75% of the value determined at commissioning.

Frequency

Commissioning Measure the resolution of the system and the detector. The resolution of the detector should be measured in the directions perpendicular and parallel to the anode-cathode axis of the x-ray tube and at 45°.

Routine 6 monthly – measure the detector resolution at 45°.

3.5.2 Low contrast detectability

The ability of an imaging system to demonstrate low contrast signals depends on the noise, unsharpness and contrast loss processes within the imaging system. The effect of these processes is best demonstrated by determining the lowest contrast which can be detected by an observer for a range of detail sizes using a contrast detail test object. Contrast detectability is usually determined for details which have sizes of dimension similar to clinically significant details eg in mammography, small masses and micro-calcifications.

With a digital imaging system, it is possible to obtain an image over a wide range of receptor exposures. The image quality (contrast sensitivity) will depend on the dose level at the image receptor. It is therefore important that contrast sensitivity is assessed at a standard receptor dose level, which is representative of that used in clinical practice. For this reason, image quality tests should be carried out, where possible, using the AEC setting normally used in clinical practice.

Test protocol

Place the low contrast test object (an example of a test object with suitable low contrast details is TORMAS or TORMAX) on top of 40 mm Perspex stack. For routine testing it is suggested that the test object image should be acquired under a standardised exposure condition eg 28 kV Mo/Mo. For determining absolute threshold contrasts it will be necessary to use the test object under conditions for which there are calibrated contrast values. Acquire the image under AEC control using the normally used AEC sensitivity setting. For systems where the exposure is under manual control, use an mAs which would be appropriate for a 45–50 mm thick compressed breast.

Evaluation

Careful attention should be paid to viewing conditions in evaluating contrast detail test images. For small sized details it may be necessary to magnify the image to ensure that the detectability of small details is not limited by the capabilities of the display device.

Sufficient display contrast should be used to ensure that low contrast detectability is not limited by internal noise of the observer. Usually the display will have sufficient presentation contrast if noise can be perceived in the image background.

For larger sized details, where the detail is much larger than the unsharpness of the imaging system, the use of display magnification is of less importance and may even be detrimental. For such details, different approaches may be used which may yield different low contrast threshold results. One approach is to use a fixed viewing distance. Another approach is to optimise the viewing distance for each detail size so that contrast detectability is maximised. Evaluators should be aware of the effects of sample variability and intra and inter observer variability on the precision of threshold contrast determined using such tests.

Remedial levels

Contrast detectability should at least meet the targets for screen-film systems in the breast screening programme[6]

5–6 mm details < 1.2%
0.5 mm details < 5%
0.25 mm details < 8%

Frequency

6 monthly

3.6   Measurement of dose

The two dose issues of concern are the risk and image quality implications of each exposure. The risk can be related to the mean glandular dose, while the dose to the receptor has image quality implications. The following three procedures are described for dose measurement.

3.6.1 Dose to the standard breast

Test protocol

The mean glandular dose (MGD) for the standard breast can be estimated from measurements with a 45 mm thickness of Perspex. The standard breast is defined in IPEM 89[2] and is equivalent to a 53 mm thick breast with a glandularity of 29% in the central region. The model has 5 mm thick adipose surface layers. The dose should be determined using the usual clinically selected exposure factors including any automatic selection of kV and target/filter combination. This should be done using the AEC where available. It should be noted that since Perspex is generally denser than breast tissue any automatic selection of kV, target or filter may be slightly different from real breasts. This can be corrected by adding expanded polystyrene blocks to the PMMA as a spacer to make up a total thickness equal to the equivalent breast. A standard compression force should be applied (eg 100 N).

The mean glandular dose (*D*) to the standard breast is calculated[2,5] by applying the following formula:

$D = K_{45}.g_{53}.c_{53}.s.a$

where K is the incident air kerma (without backscatter) measured at the upper surface of a 45 mm thickness of Perspex. The g factor converts incident air kerma to mean glandular dose. The c factor corrects for the glandularity of the standard breast. The s factor corrects for any differences between the x-ray spectrum used and Mo/Mo. The a factor corrects for the reduced area of the compressed breast that is exposed, calculated as in equation 1.

a = area of breast irradiated/area of standard breast

$$a = \frac{area\ irradiated\ at\ breast\ table.\left(\dfrac{FTD - 26.5}{FTD}\right)^2}{area\ of\ standard\ breast} \tag{1}$$

where FTD is the focus-to-table distance in mm.

Due to beam divergence the irradiated area of the breast depends on the plane of the breast chosen. Taking the area at the mid plane of the breast provides a reasonable compromise between extremes. The area irradiated at the breast table may be determined using the results obtained in section 3.1. The area of the standard breast is 100 cm^2. (Note that this is a standard assumption and does not reflect average breast area, but does allow for a simple and approximate correction for the reduced area exposed by small field systems.)

(Note that for estimating the dose in stereo mode, the value used for the HVL should not include the effect of beam hardening by a compression paddle.)

The dose should be determined using clinical settings, including any automatic selection of kV and target/filter combination in stereo and/or spot mode (as used clinically).

Frequency
    6 monthly

Remedial level
    ± 25% of the value at commissioning

    Typical MGD for 45 mm PMMA at clinical settings:

        Fischer: 0.3–0.6 mGy
        GE SenoVision: 1.1–1.6 mGy
        Delta 16 and 32: 1.1–1.3 mGy
        LoRad: 0.4–0.9 mGy
        Philips: –
        Siemens Opdima: 0.9–1.3 mGy

3.6.2 Clinical breast doses

If the mean glandular doses for individual breasts need to be calculated, it is suggested that the doses be calculated as for full field views of the breast but multiplied by the appropriate area factor as in equation 1 (modified for the actual breast thickness). The entrance air kerma in this case is estimated from the exposure

factors used and the output characteristics of the x-ray set. Exposures for stereotactic localisation will involve a degree of angulation of the x-ray tube. However, since the angles are relatively small it is assumed that this can be neglected for practical purposes. A more precise approach to dose estimation is beyond the scope of this protocol.

Frequency

When required for purposes of dose optimisation

3.6.3 Standards for dose

Currently, there is no guidance on appropriate doses. Since these techniques are only used where there is an increased suspicion of disease the radiation risk involved is likely to be of less concern than it would be in screening. Nonetheless, there is a requirement to keep doses as low as reasonably practicable. Only when sufficient dose data have been collated nationally on these systems will it be possible to establish acceptable limits.

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GLOSSARY

Aliasing

Aliasing is a phenomenon which arises in sampling when the signal to be sampled has higher frequencies present than can be represented by the sampling process (ie higher than the *Nyquist frequency*). Such frequencies will be undersampled and would be erroneously represented as lower frequencies (aliases) in the sampled signal. If the original frequency to be sampled is f and this is greater than the *Nyquist frequency*, f_N, then this would be aliased in the sampled signal to a frequency $(2f_N - f)$.

Charge coupled device (CCD)

A CCD is an integrated circuit which acts as an array of photodiodes converting light to electrical charge. The charge is collected in a series of storage wells, which can be read out sequentially after an exposure.

Dark current

Even in the absence of light, electrons will be generated in the *CCD* elements due to thermal energy. This generation of charge gives rise to a dark current whose magnitude will depend on the integration time of the *CCD* and also, critically, on the temperature. Dark current can be compensated for by removing its offset signal. However, the noise or random variability associated with this signal cannot be removed. Dark current and hence dark noise may be reduced by means such as cooling the sensor device.

DICOM

Digital Imaging and Communications in Medicine standard is a set of protocols that enables a piece of medical equipment or software produced by one manufacturer to communicate with software or equipment produced by another. *DICOM* v3.0 is the third version of the standard.

Limiting spatial resolution

This is the highest spatial frequency which can be resolved from the image of a high contrast bar pattern test piece. In an analogue imaging system the *limiting spatial resolution* is usually determined by the MTF of the imaging system and is determined as the point where the MTF value has fallen to some low modulation figure (usually in the range 3–5%). For a digital imaging system the *limiting spatial resolution* may also be affected by the sampling interval (*pixel size*) used when digitising the analogue image data. Sampling theory imposes a maximum spatial frequency which can be represented in a sampled image and this is determined by the sampling interval and called the *Nyquist frequency*. If the MTF value at the *Nyquist frequency* is still significant then the system will be undersampled and the limiting spatial frequency will be limited by the sampling process ie equal to the highest sampled frequency.

Nyquist frequency

In a sampled system the Nyquist frequency represents the highest frequency component which can be represented by the sampled data. It is given by $1/2\Delta x$ where Δx is the distance between samples.

Pixel

This is an abbreviation for 'picture element' and is the smallest discrete element which makes up a digital image. It has a spatial dimension and is assigned a discrete intensity value.

Pixel binning	Some *CCDs* have the facility to shift multiple *pixel* charges in both the horizontal and vertical directions into a single larger charge. Typically a 2×2 binning may be used where the charge from four adjacent pixels will be combined to form a larger charge packet. This technique increases the sensitivity of the *CCD* but reduces its spatial resolution capabilities.
Pixel size	The *pixel size* for a detector refers to the distance between sampling points. This is distinct from the active area of the detector, which is the size of the light sensitive element. For a *CCD* the active area may be smaller than the distance between the element centres (sampling points).
Pixel value	This refers to a digital value which represents the greyscale level assigned to a *pixel*.

APPENDIX: PSEUDO ROI ANALYSIS USING A MASK

Pseudo ROI analysis can be carried out on systems which do not have ROI analysis software (eg Opdima) using a physical mask. This technique is more reproducible than using individual pixel values to provide an estimate of the mean.

Select a piece of light-opaque card or an over-exposed film. The card should be about 10×10 cm so that it is easy to position on a display monitor. Cut out a circle in the centre with a diameter of approximately 10 mm. This is the mask. To measure mean pixel value at the centre of a uniform image, display the required image using a standard, consistent format which yields images that are life-size or close to it. Place the mask at the centre of the image. Set the window width to 1 and vary the window level from minimum to maximum, stopping at the point where there are visually equal numbers of white and black pixels within the mask (mid-grey universal colour). The window level at this point corresponds to the mean grey level at the centre of the image.

The mask can also be used to measure image uniformity by moving the mask over the appropriate image to suitable corner positions and repeating the windowing technique described above to obtain an estimate of the mean grey level at that position.

When the image is displayed on a CRT monitor, and pixel values are changing rapidly over distance, parallax can introduce errors into the technique and must therefore be avoided.