Evaluation of Kodak DirectView Mammography Computerised Radiography System

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1. INTRODUCTION

1.1 Image quality and dose standards for digital mammography

Breast screening was introduced into the UK because of successful clinical trials using film-screen mammography. The original procedures for testing image quality and the standards expected have been developed for film-screen imaging systems. More appropriate testing procedures for digital imaging systems are still being developed for the UK. At present, the most comprehensive published guidance on quality control of digital mammography systems is provided in a European protocol.[1,2] This report uses the testing methods and standards in the European protocol and it is expected that these will form the basis of the UK protocol. These standards are called the EUREF standards in this report. The method of measuring image quality was to use the contrast detail test object the CDMAM developed by Nijmegen University specifically for digital mammography systems. The performance standard required for a system to achieve results comparable to film/screen mammography is specified in the European protocol. The threshold contrast measured using the CDMAM may be different from those measured using other test objects and care should be exercised in comparing results derived using different designs of test object.

The standard and procedure for radiation dose measurement used here is essentially the same as that used for film-screen systems in the UK. The dose is important because of the strong relationship between the dose and the image quality, as well as the need to consider regulatory requirements. The contrast to noise ratio was also measured at different thicknesses of Perspex (PPMA), as required in the European protocol. This measurement is important because it indicates how image quality varies with breast thickness.

2. METHODS

2.1 Systems tested

Kodak recently introduced a new version of their computerised radiography (CR) equipment for mammography. This features improved phosphor plates and a smaller pixel size (50 micron). Such a system was installed at the Clementine Churchill Hospital, Harrow, Middlesex, for evaluation. Physical tests were carried out on 22nd July 2005. Some measurements were also made on a similar system at the Kodak factory in Rochester, New York, USA. Details of the systems tested are shown in Table 1.

Table 1: Kodak CR systems tested

Centre	Model of CR reader	X-ray set	Cassette	Screen	Pixel size (μm)	Printer	Film
Clementine Churchill Hospital	Kodak DirectView CR 850	GE DMR+	DirectView CR 850 Mammography	EHR-M	50	DryView 8900 with mammo upgrade	Mammo DryView M
Kodak Factory Rochester	Kodak DirectView CR 850	GE DMR+	DirectView CR 850 Mammography	EHR-M	50	n/a	n/a

2.2 Detector response and linearisation of pixel values

The detector response was established using a phantom comprising 18x24cm plates of PMMA with total thickness of 45mm. This phantom was exposed using a tube voltage of 28 kV and a Mo/Mo target/filter combination and a range of tube current-time products from the minimum to maximum possible. The images were saved as unprocessed files and transferred to another computer for analysis. A 10 mm square region of interest (ROI) was positioned on the mid-line and

6 cm from the chest wall edge of each image. The average pixel value and the standard deviation of pixel values within that region were measured for each image. The relationship between average pixel values and the mAs was determined. For CR systems the relationship is generally non-linear. These data were used to convert all the original pixel values measured in the CR images to a new pixel value which was linear with exposure (*p*), and therefore with energy absorbed in the detector.

2.3 Dose measurement

To assess the dose delivered by the system, the factors selected by the x-ray set when imaging a range of thicknesses of PMMA from 20 to 70mm were recorded. U-shaped expanded polystyrene spacers were added to adjust the total thickness to be equal to the equivalent breast thickness as shown in Table 2. The expanded polystyrene was positioned to avoid the area occupied by the AEC detector chamber which was positioned as close to the chest wall as possible. PMMA blocks with an area of 180 x 240 mm were used. To measure the contrast to noise ratio an aluminium square (10 mm x 10 mm) with a 0.2 mm thickness was placed on top of the 20 mm thick block, with one edge on the midline and 6cm from the chest wall edge. This position avoids the area above the AEC chamber of the x-ray set. Additional layers of PMMA were added on top to vary the total thickness. Exposures at Clementine Churchill were made using a compression force of 100N and the AEC in standard mode with a density setting of +3 as suggested by the Kodak engineers. The x-ray factors (kV, target material, filter material and mAs) were recorded for each exposure. The x-ray set output, HVL and the distance from the focus to table top were measured allowing the entrance surface air kerma at the top of the PMMA to be calculated. The method described by Dance et al (2000) was used to calculate the mean glandular dose to typical breasts with attenuation equivalent to PMMA with thicknesses shown in Table 2.[3] Also shown in Table 2 are the acceptable and achievable dose levels defined in the European protocol and likely to be adopted in a new UK protocol.[2] The current minimum standard for radiation dose in the UK is defined using only the 45mm thickness of PMMA, with the value as shown in the table ie <2.5 mGy.

Table 2: Acceptable dose levels for simulated breasts

Thickness of PMMA	Thickness of added expanded polystyrene	Thickness of equivalent breast	Mean glandular dose to equivalent breasts	
			acceptable level	achievable level
[mm]	[mm]	[mm]	[mGy]	[mGy]
20	-	21	< 1.0	< 0.6
30	-	32	< 1.5	< 1.0
40	5	45	< 2.0	< 1.6
45	8	53	< 2.5	< 2.0
50	10	60	< 3.0	< 2.4
60	15	75	< 4.5	< 3.6
70	20	90	< 6.5	< 5.1

2.4 Noise analysis

The standard deviations for the pixel values in the ROI for each image were used to investigate the relationship between dose to the detector and image noise. The noise was assumed to be strongly dependent on the total energy absorbed by the detector and therefore on the pixel value linearised with dose (*p*). For simplicity the noise is generally presented here as relative noise defined as in equation 2. In fact the relationship between noise and pixel values was found empirically to be approximated by a simple power relationship as shown in equation 1.

Relative noise = $\frac{\sigma_p}{p} = kp^{-n}$ ……………………………………………….. (1)

where σ_p is the standard deviation in the pixel values in the ROI with a mean value *p*, and *k* is a constant. If the noise was purely quantum noise the value of *n* would be 0.5. However the presence of electronic and structural noise means that *n* can be slightly higher or lower than 0.5.

2.5 Image quality measurements

Contrast detail measurements were made using the CDMAM phantom (version 3.4, UMC St. Radboud, Nijmegen University, Netherlands). The phantom was positioned with a 20 mm thickness of PMMA blocks above and below, to give a total attenuation approximately equivalent to 50mm of PMMA or 60 mm thickness of typical breast tissue. This arrangement was imaged using the x-ray set's automatically selected factors normally set for clinical use for a breast of equivalent attenuation ie 60mm. The exposed image plates were read in the CR reader. This procedure was repeated seven times using a total of eight different imaging plates, to obtain a representative sample. Unprocessed images were transferred to disk for subsequent analysis off-site. The digital images had their contrast and density adjusted to optimally display the details in the test object, before printing or scoring on monitors.

For each image quality measurement three observers reviewed four of the digital images on soft copy displays and the test object manufacturer's correction scheme was then applied, before determining the threshold contrast for visibility of each detail diameter. The threshold contrast was converted from a gold thickness to a nominal contrast for an x-ray set with a tube voltage of 28 kV and molybdenum target and filter materials using published spectra (IPEM 1997)[4] as described in the European protocol.

The achievable and acceptable values for threshold contrast published in the European protocol for testing digital mammography systems are shown in Table 3. The 5 mm detail is regarded as optional and has not been evaluated here. (Note that all the threshold contrasts referred to are nominal values calculated from the threshold gold thickness using a 28 kV Mo/Mo spectra.) The average threshold contrast for each detail diameter for each system (an average for eight images and three experienced observers) was fitted with a curve of the form shown in Equation 2.

$$T_c = a + b \cdot x^{-1} + c \cdot x^{-2} + d \cdot x^{-3} \quad \text{…………………………………….. (2)}$$

where, *Tc* is the threshold contrast (%), *x* is the detail diameter (mm) and *a*, *b*, c and *d* are coefficients adjusted to achieve a least squares fit. The measured threshold contrasts were estimated to have 95% confidence limits of about 8%. The threshold contrasts quoted in the results are derived from the fitted curves, as this has been found to improve the accuracy by taking account of adjacent values.

Table 3: Acceptable and achievable levels for threshold contrast.

	Acceptable value	Achievable value
Diameter of detail [mm]	radiation contrast [%]	radiation contrast [%]
5	< 0.85	< 0.45
2	< 1.05	< 0.55
1	< 1.40	< 0.85
0.5	< 2.35	< 1.60
0.25	< 5.45	< 3.80
0.1	< 23.0	< 15.8

It is expected that there will be a strong relationship between the dose and the threshold contrast. This is because a higher detector dose leads to lower quantum noise. The expected relationship between threshold contrast and dose is plotted with the experimental data and is given by equation 3.

Threshold contrast = λD^{-n} ………………………….(3)

The appropriate value of *n* was determined from the analysis of the noise as a function of the pixel value. In practice this was done by finding the value of *n* that provided the best fit for equation 1 to the experimental data. D represents the mean glandular dose (MGD) for a 60mm thick standard breast equivalent (in terms of attenuation) to the test phantom configuration used for the image quality measurement. λ is a constant to be fitted.

2.6 Contrast to noise ratio

The images of the blocks of PMMA obtained during the dose measurement were also analysed to obtain the contrast-to-noise ratios (CNRs). For each image the average pixel values for ROIs in the centre of the aluminium square, *mean(Al),* and in the adjacent background area, *mean(bgd)*, were measured. The standard deviation of the pixel values in the background ROI, *sd(bgd),* and the aluminium ROI, *sd(Al)*, were also determined. These data were used to calculate the CNR for each image as described in equations 4 and 5 after linearisation of the pixel values.

$$Contrast = \frac{mean(bgd) - mean(Al)}{mean(bgd)} .100\% \quad \text{………(4)}$$

$$CNR = \frac{mean(bgd) - mean(Al)}{\sqrt{\frac{\left[sd(bgd)^2 + sd(Al)^2\right]}{2}}} \quad \text{……………………(5)}$$

To apply the standards in the European protocol the limiting value for CNR (using 50 mm PPMA) was determined according to equation 6. This equation determines the CNR value ($CNR_{limiting\ value}$) that is necessary to achieve the minimum threshold contrast for the 0.1 mm detail diameter (i.e. $threshold\ contrast_{limiting\ value}$ = 23.0%).

$$Threshold\ contrast_{measured} * CNR_{measured} = Threshold\ contrast_{limiting\ value} * CNR_{limiting\ value} \quad \ldots\ldots\ldots\ldots(6)$$

The relative CNR was then calculated according to equation 7 and compared with the limiting values provided for relative CNR shown in Table 4.

$$Relative\ CNR = CNR_{measured} / CNR_{limiting\ value} \quad \ldots\ldots\ldots\ldots(7)$$

Table 4: Limiting values for relative CNR

Thickness of Perspex (mm)	Equivalent breast thickness (mm)	EUREF limiting values for relative CNR
20	21	>115
30	32	>110
40	45	>105
45	53	>103
50	60	>100
60	75	>95
70	90	>90

3. RESULTS

3.1 Detector response

The CR plates were found to have a logarithmic response as shown in Figure 1. The relationship was used to calculate new pixel values that were linear with the absorbed detector dose.

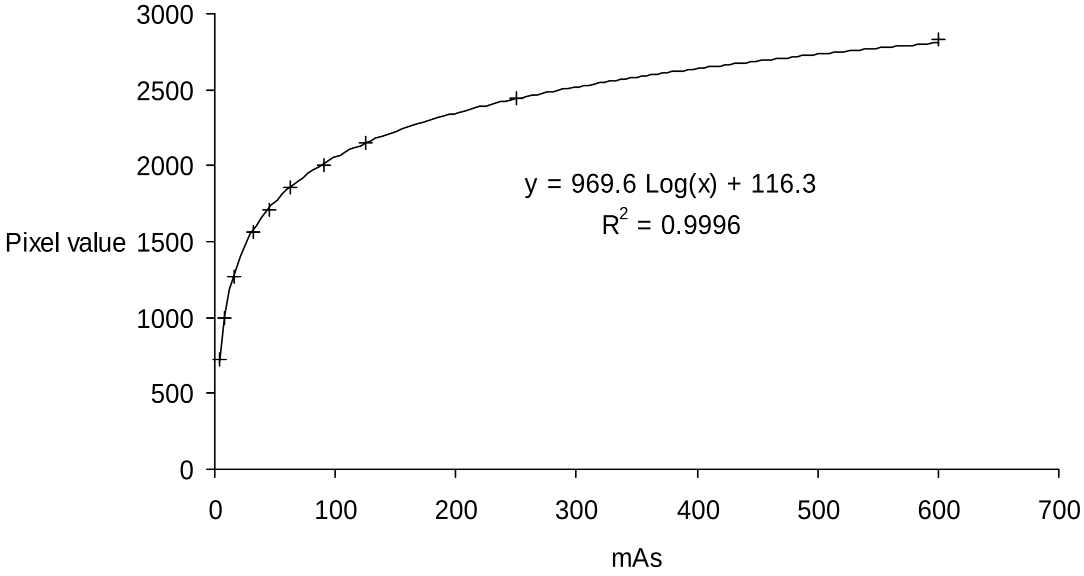

Figure 1 Detector response

3.2 Noise measurements

The relative noise for a range of beam qualities and doses are plotted in Figure 2. Equation 1 was fitted to the data in Figure 2 with n having a value of 0.391.

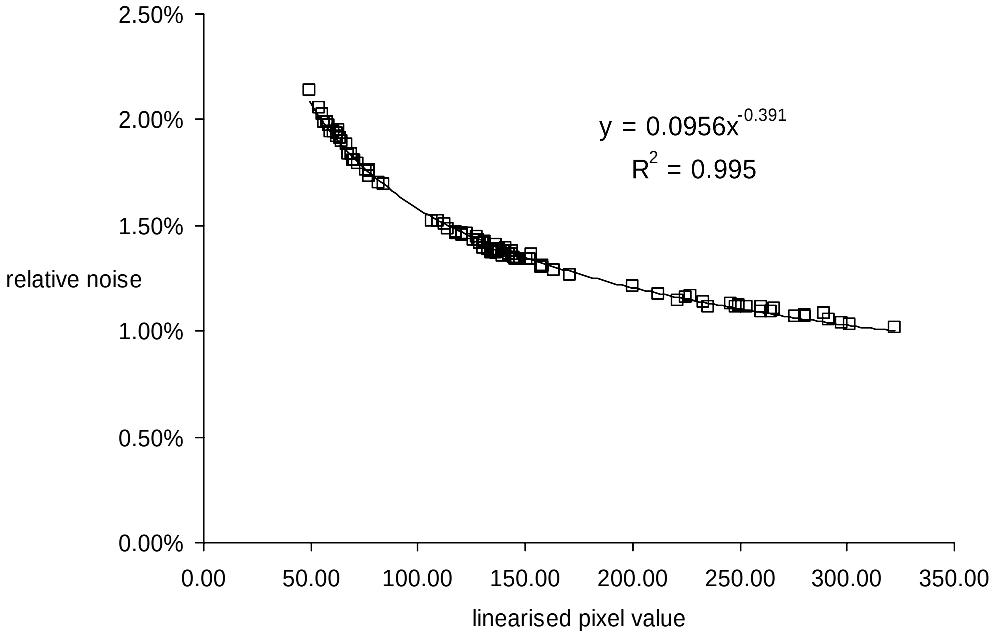

Figure 2: Relative noise as a function of detector dose (i.e. linearised pixel value)

3.3 Dose measurements

The mean glandular doses for breasts simulated with PMMA for the system at Clementine Churchill are shown in Table 4 and Figure 3. At all thicknesses the dose was below the limits set in the NHSBSP and the European protocol. For equivalent breast thicknesses of 75 and 90mm the dose was below the "achievable" level in the European protocol.

Table 4: Mean glandular does for simulated breasts

PMMA thickness (mm)	Equivalent breast thickness (mm)	kV	target	filter	mAs	MGD (mGy)	EUREF std acceptable	EUREF std achievable
20	21	26	Mo	Mo	33	0.86	< 1.0	< 0.6
30	32	27	Mo	Mo	61	1.39	< 1.5	< 1.0
40	45	27	Mo	Rh	100	1.73	< 2.0	< 1.6
45	53	29	Mo	Rh	96	2.02	< 2.5	< 2.0
50	60	29	Mo	Rh	136	2.64	< 3.0	< 2.4
60	75	30	Rh	Rh	153	2.99	< 4.5	< 3.6
70	90	32	Rh	Rh	186	4.03	< 6.5	< 5.1

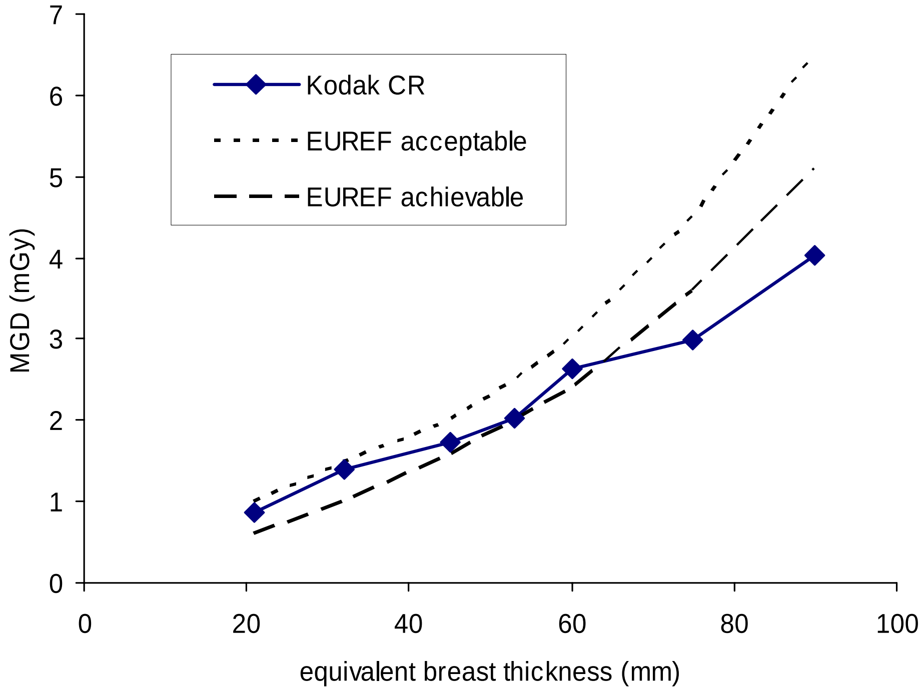

Figure 3 : MGD for simulated breasts

3.4 Threshold contrast measurements

The average threshold contrast values for different diameters and three different dose levels are shown in Table 4, with the minimum and achievable threshold contrast values from the European standard. The contrast detail curve for an MGD of 2.59 mGy is shown in Figure 4. The system meets the minimum standard for all diameters except the smallest (0.1 mm). The measured threshold contrasts are plotted against the dose for the 0.1 mm detail size in Figures 5. This illustrates that when the dose was increased the threshold contrast at 0.1mm diameter did reduce as expected by the theory but did not come within the acceptable range defined by the EUREF standards. The measured threshold contrasts are plotted against the dose for the 0.25 mm detail size in Figures 6. At this detail size the system does come within the acceptable range.

Table 4: Average threshold contrasts for different detail diameters for the Kodak CR system at Clementine Churchill for three different doses using 29 kV Mo/Rh.

Diameter (mm)	Average threshold contrast for each detail diameter (%) (Figures in bold where the minimum standard is exceeded.)				
	EUREF Min. std	EUREF Achievable	Kodak CR at Clementine Churchill		
			MGD = 2.59 mGy	MGD = 3.88 mGy	MGD = 5.44 mGy
0.10	< 23.0	< 15.8	**25.5 ± 1.6**	22.7 ± 2.0	18.7 ± 1.5
0.25	< 5.45	< 3.80	4.79 ± .27	4.22± .31	3.96 ± .31
0.50	< 2.35	< 1.60	1.70 ± .11	1.55± .13	1.52 ± .12
1.00	< 1.40	< 0.85	0.87 ± .06	0.87 ± .07	0.77 ± .06
2.00	< 1.05	< 0.55	0.63 ± .04	0.70 ± .05	0.50 ± .04

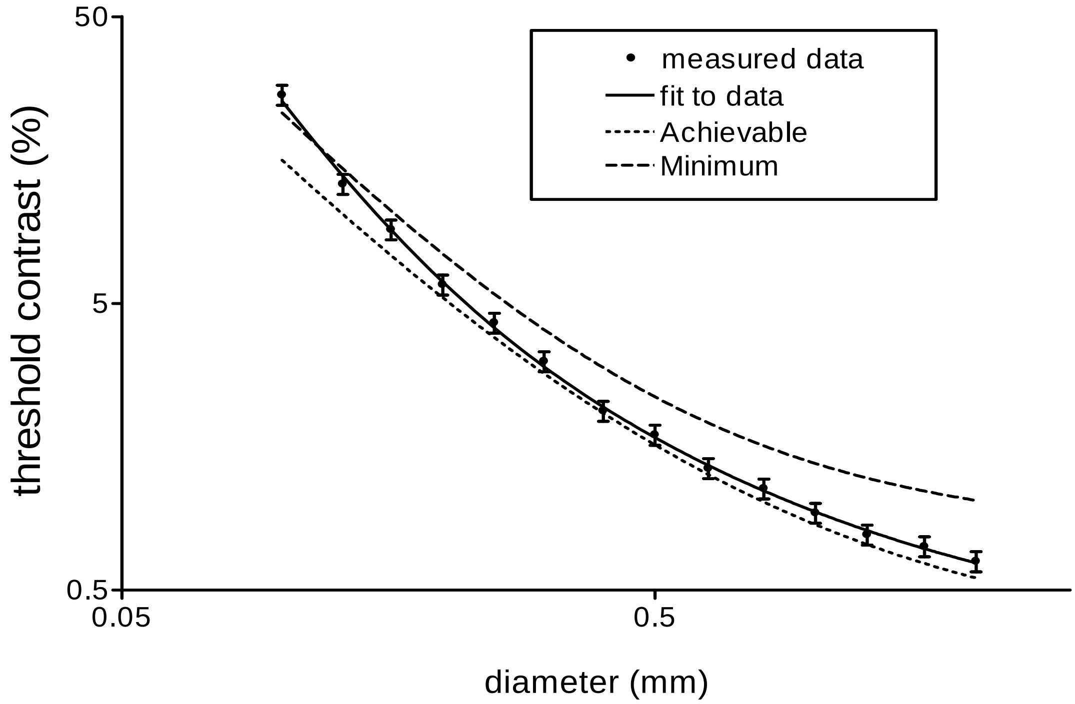

Figure 4 Contrast-detail curve for Kodak CR system (MGD=2.59 mGy).

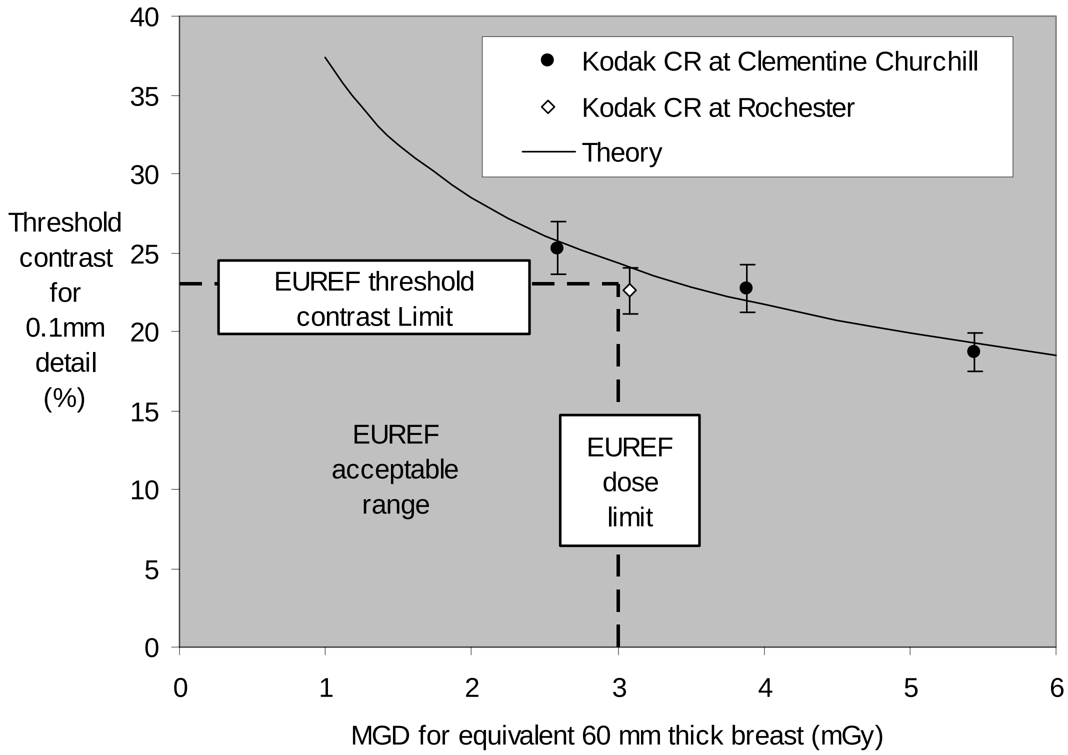

Figure 5 : Threshold contrast for 0.1mm detail at different doses using 29 kV Mo/Rh

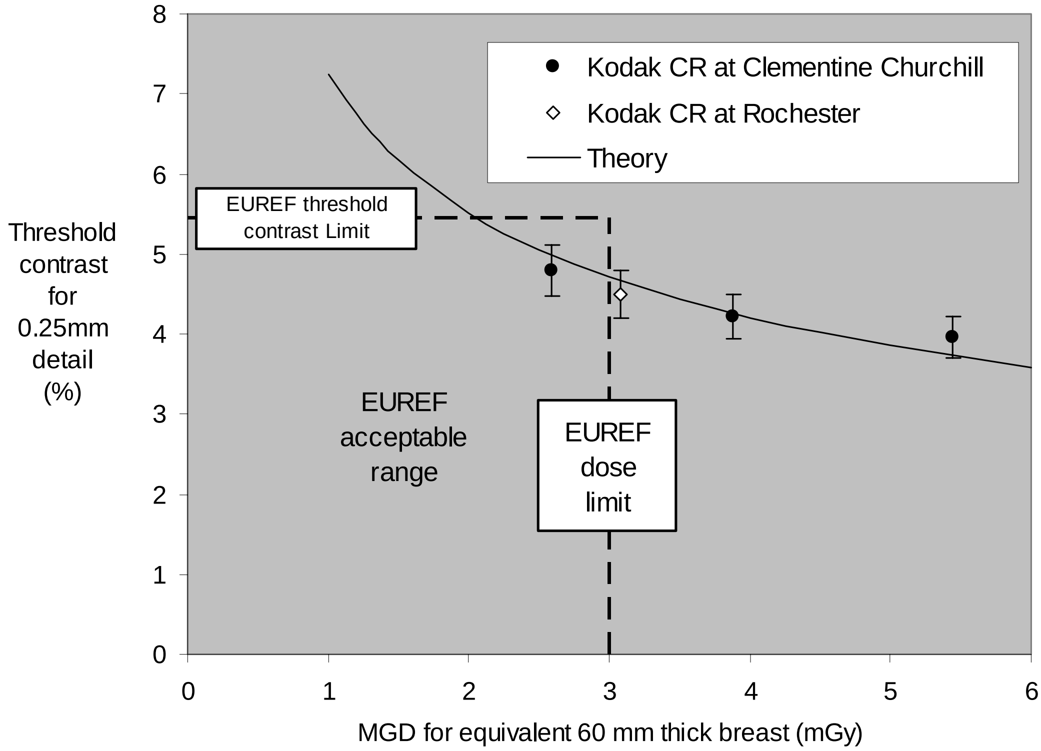

Figure 6: Threshold contrast for 0.25mm diameter detail at different doses using 29 kV Mo/Rh

3.5 CNR Results

The results of the contrast and CNR measurements are shown in Table 6. The CNR relative to that required to pass the image quality standard at the 60mm breast thickness has also been calculated for comparison against the EUREF limiting values and is shown in Figure 7. The system does not meet the European standard for CNR for breast thicknesses of 53mm and greater at the automatic settings used. However there is scope to increase the detector dose for larger breasts by adjusting the AEC to give doses closer to the limiting values.

Table 6: Contrast and CNR measurements

Equivalent breast thickness (mm)	kV T/F	mAs	Original pixel value	% contrast for 0.2 mm Al square	Measured CNR	CNR limiting value	CNR relative to limiting value at 60mm	EUREF limiting values for relative CNR
21	26 Mo/Mo	33	1039	21.5%	11.51	-	137	>115
32	27 Mo/Mo	61	1026	19.4%	10.48	-	125	>110
45	27 Mo/Rh	100	1032	16.4%	8.60	-	103	>105
53	29 Mo/Rh	96	1038	15.2%	7.84	-	94	>103
60	29 Mo/Rh	136	1026	14.5%	7.61	8.37	91	>100
75	30 Rh/Rh	153	987	11.9%	6.78	-	81	>95
90	32 Rh/Rh	186	976	10.5%	6.01	-	72	>90

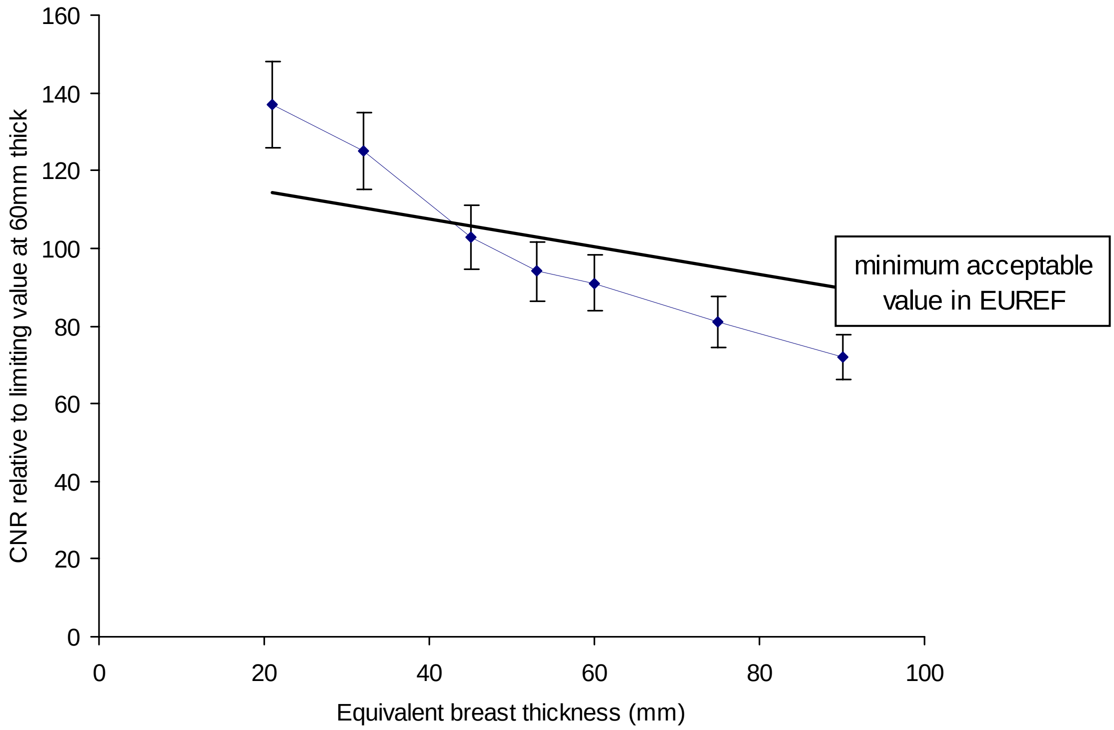

Figure 7: Measured CNR compared to the limiting values in the EUREF standards (Error bars indicate 95% confidence limits)

3.6 Artefacts and overall image quality

Some artefacts were observed in an image of a uniform block of PMMA. Figure 8 shows two clear dark horizontal lines across the image, as well as numerous less obvious lighter ones.

The images were noisy when viewed at 1:1 pixel size, making it difficult to impossible to see the 0.1 mm size details of the CDMAM test object. Some evidence of the noisy "dappled" pattern is seen in Figure 8.

The unprocessed images used for analysis had a very narrow range of original pixel values (approximately 980-1200); for systems with such a narrow range it is generally more difficult to image and read the CDMAM.

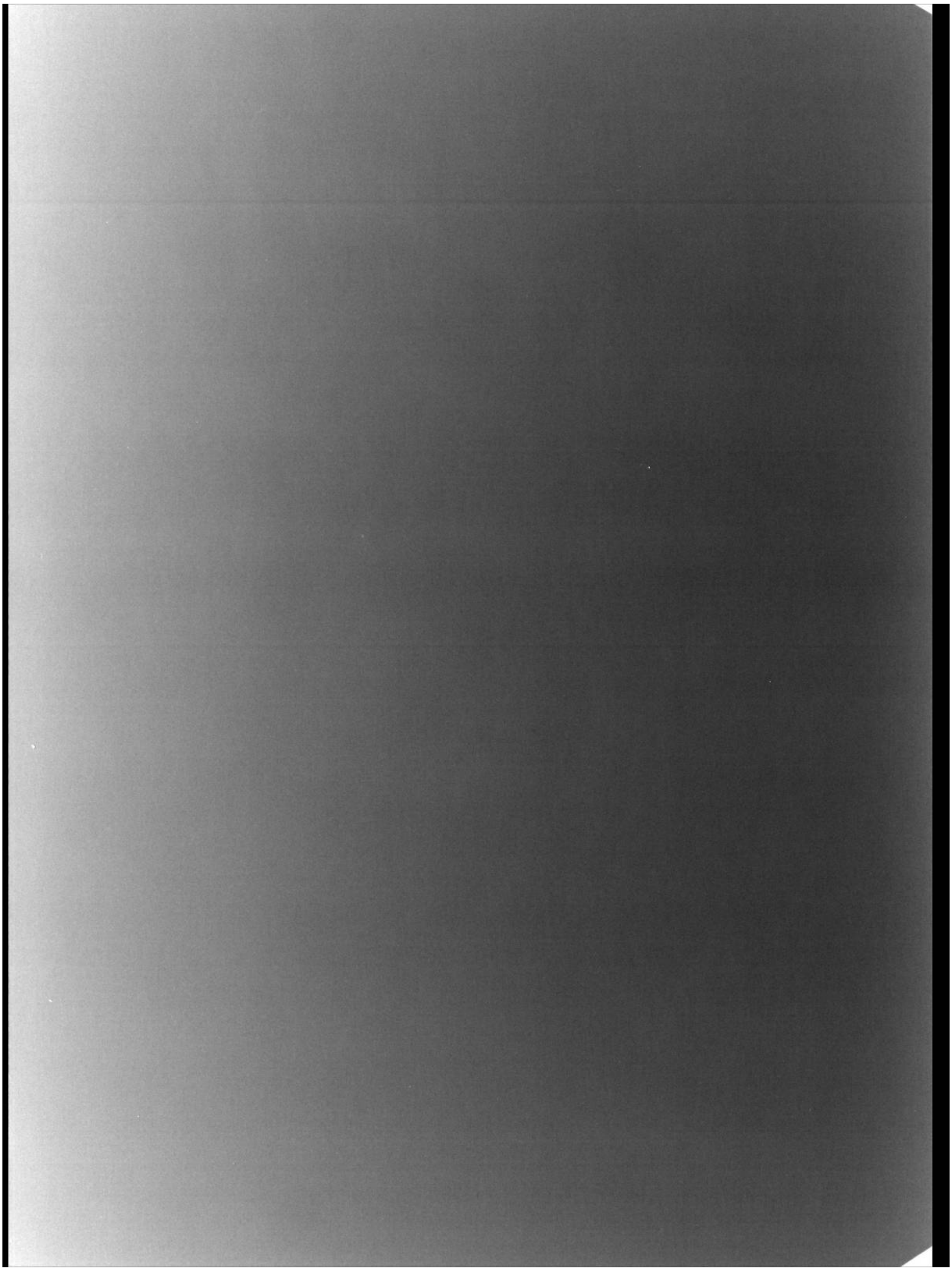

Figure 8: Example of artefacts on an image of a uniform block of PMMA

4 DISCUSSION

The logarithmic response of the CR system was as expected from the manufacturer's literature. The relationship between the noise in the images and the detector dose was well fitted by the power relationship described by equation 1. It should be noted that this relationship may not be so well fitted at much higher or lower doses where structural noise and electronic noise would be expected to dominate. However within the mid-range of doses that may be used clinically quantum noise is the main noise source. The fact that the index, n, was less than 0.5 may be explained by the presence of some structural noise.

The doses measured for the different breast thicknesses were within the limits set by the NHSBSP and the European protocol. As regards image quality the Kodak CR system meets the minimum standards set in the European protocol for all sizes except for the smallest detail size (0.1 mm). However, the margin by which the system fails is small. It was noted that the presence of some structural noise in the images made it difficult to see the 0.1mm details. Increasing the dose did improve the threshold contrast as expected from the theory but the dose required to meet the image quality limit would exceed the dose limit of 3 mGy as shown in Figure 5. The theoretical relationship between the dose and the threshold contrast (equation 5) fitted the measured data within experimental error. The image quality and dose limits are specified for breasts equivalent to a 5cm thickness of Perspex. To evaluate the performance at other thicknesses one needs to consider the CNR results. These showed that the CNR declined relatively steeply with increasing thickness and fell below the standard in the European protocol at all thicknesses above 45 mm. This implies that while the image quality standard is almost met at the standard thickness it is somewhat poorer at greater breast thicknesses.

The image quality results indicate that this Kodak CR system is poorer at detecting very small details than current film screen systems. This might prove a problem when attempting to visualise and characterise microcalcifications, but a clinical view needs to be taken on this. For the larger detail sizes (0.5 to 2.0 mm) the performance met the acceptable values for threshold contrast in the European protocol.

It may be possible to improve the image quality within the existing dose limits by changing the beam quality selection to higher energies eg 32 kV Rh/Rh for all thickness above about 50mm. Provided sufficient detector dose was used the system may just come inside the dose and image quality standards in the European protocol. Even if this works the system would still require higher doses to achieve acceptable image quality than other digital mammography systems.

5 CONCLUSIONS

As presently configured the system fails to meet the image quality standards in the EUREF protocol. However, it may be possible to alter it to do this by adjusting the AEC to use more optimal parameters. With these adjustments it would be reasonable to consider further clinical evaluation.

6 COMMENTS FROM KODAK

Kodak were invited to comment on this report and provided the following statement.

"Kodak continues to refine and optimise its CR mammography solutions. We have begun the submission process to the U.S. Food and Drug Administration (FDA) for approval of its computed radiography system for mammography to demonstrate that Kodak's CR technology is clinically proven. Further system developments are underway both in CR screen technology and in the software & hardware solution to further improve CR system visualisation. These enhancements are foreseen during 2006 and will be part of a full Kodak digital mammography solution. As new digital mammography quality guidelines evolve, Kodak is committed to ensuring its CR systems are clinically proven."

7 REFERENCES

1. Young KC, Johnson B, Bosmans H, Van Engen R. Development of minimum standards for image quality and dose in digital mammography. In Digital Mammography IWDM 2004, Proceedings of the Workshop in Durham NC, USA, June 2004. (2005)
2. Van Engen R, Young KC, Bosmans H, and Thijssen, M. "*Addendum on digital mammography*", version 1.0, November 2003, addendum to chapter 3 of the *European guidelines for quality assurance in mammography screening*, Third edition, 2001 (available at www.euref.org)
3. Dance DR, Skinner CL, Young KC, Beckett JR and Kotre CJ. *Additional factors for the estimation of mean glandular breast dose using the UK mammography dosimetry protocol.* Phys. Med. Biol. 45;3225-3240 (2000)
4. Institute of Physics and Engineering in Medicine. 1997. *Catalogue of diagnostic spectra and other data*. York: IPEM Publications, 1997 (IPEM Report 78).