EVALUATION OF THE FUJI PROFECT COMPUTERISED RADIOGRAPHY SYSTEM

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1. INTRODUCTION

Following the recommendations of the Forrest Report (1986), the NHS Breast Screening Programme (NHSBSP) was established in 1988. In the following six years, 95 breast screening services were established as well as a robust quality assurance structure.

The NHSBSP reports annually on the performance of each service against national standards. These standards are based on film-screen mammography. With the introduction of digital imaging in general radiography and more recently in symptomatic mammography, it is clear that analogue systems for mammography will be superseded by digital systems. The theoretical advantages of digital imaging are evident with regard to service redesign, outreach assessment, potential for dose reduction, image manipulation, archiving and links with other services. Computerised radiography (CR) technology can adapt to all current mammography systems and, indeed, CR imaging has long been established in general radiology.

Full CR may provide an affordable and immediate option for both small and large breast screening services in this transition.

2. SCOPE OF THE PROJECT

The West of Scotland Breast Screening Service evaluated the Fuji Profect computerised radiography system on behalf of the NHSBSP. The evaluation involved the use of the system at the assessment clinic on women recalled for further evaluation following their screening episode. The images obtained were then compared with the images obtained using film-screen mammography at the initial screening appointment.

The project aimed to evaluate the following:

1. image quality
2. CR softcopy reporting for assessment
3. the usability of the system for radiographers and radiologists.

3. IMAGE QUALITY

3.1 Technical parameters

The Fuji FCR Profect CS computerised radiography system was installed at the West of Scotland Breast Screening Centre, Glasgow, in April 2004. The unit was provided with HR-BD dual sided mammography cassettes in both 18 × 24 cm and 24 × 30 cm sizes, and images were produced with a pixel pitch of 50 μm.

The hardcopy device supplied was a Fuji Drypix 7000 laser printer.

The unit was initially supplied with Dome C3 3 mega pixel (MP) reporting workstation monitors, and the processing was initially optimised to the settings shown in Table 1 (Original settings). In October 2004, the monitors were upgraded to Totoku ME515L 5 MP reporting workstation monitors. At this point, further optimisation of the processing parameters took place, increasing the image contrast and edge enhancement. These are also shown in Table 1 as Optimised settings.

Table 1 Processing settings used

	Contrast (GA)	Density (GS)	Rotation centre (GC)	Characteristic curve (GT)	Enhancement (MRE)	Dynamic range (MDE)	Edge enhancement (PRE)
Original settings	2.3	0.3	0.6	H	0.7	0.7	1.0
Optimised settings	2.7	0.3	0.6	H	0.7	0.7	2.0

A range of tests were carried out on the system, including commissioning checks, image quality and dose evaluations. These are detailed in the following sections.

3.2 Commissioning and acceptance tests

Many of the tests described in the NHSBSP Equipment Report *Commissioning and Routine Testing of Full Field Digital Mammography Systems*[1] were carried out. A brief summary of the results is given in Table 2.

No pixel statistics (eg mean pixel value or signal to noise ratio in a region of interest) could be obtained from Fuji's own workstations. Therefore, the tests indicated with an asterisk in Table 2 could not be fully completed. It was also difficult to download images to take back to the physicists' own workstations, where pixel statistics could have been obtained.

Results for the tests were generally within tolerance, with the exception of automatic exposure control (AEC) variation with thickness. This was not adjusted because the x-ray unit is still used predominantly with film-screen but could be adjusted to be within tolerance for a dedicated CR unit.

Table 2 Summary of commissioning tests

Parameter	Results	Within tolerance
CR reader sensitivity	S value within 3% of manufacturer's target value*	✓
Uniformity	No non-uniformity was visible*	–
Artefacts	White band was visible along the chest wall edge of the image, but was later eliminated	✓
Linearity	Values of S-value × exposure were constant to within 5% over 10–400 mAs*	✓
Image quality	See sections 1.2 and 1.4	✓
AEC reproducibility	S-value and mAs variation < 5%*	✓
AEC variation in Opdose mode	Over 2–7cm, variation in S-value from mean 12–13%*	–
Contrast to noise ratio (CNR)	Could not be completed*	–
AEC variation with kV	In manual mode, over 2–7 cm, and for 25–30 kV, within 10%*	✓
AEC variation with thickness	In manual mode, over 2–7 cm, 16%*	×
Dose to the standard breast	Using new standard breast model, mean glandular dose 1.6 mGy	✓
Dose to sample of patients	See section 3.5 and Appendix 1	✓

3.3 Monitor tests

The results of tests carried out on the monitors were acceptable (Table 3).

Table 3 Reporting monitor test results for 3 MP and 5 MP monitors

Date	Monitor	5% steps visible?	Equally?	High contrast patterns?	Low contrast patterns?	100% (Cd/m^2)	0% (Cd/m^2)	Left and right matched?	Comments
Tolerance						> 240	< 1	100 ± 5%	
26/4/04	Left	Both OK	Yes	All OK	All OK	529	0.7	2.7%	Dome C3 monitors (3 MP)
26/4/04	Right					558	0.7	OK	
5/10/04	Left	Both OK	95/100 more visible	All OK but movement of smallest patterns	All OK	357	0.6	0.6%	Totoku ME515L monitors (5 MP)
5/10/04	Right					353	0.6	OK	

3.4 Image quality assessment

The TOR(MAX) and TOR(MAM) test objects were used primarily to assess image quality for hardcopy and softcopy images. The following settings were used.

TOR(MAX)
- Siemens Mammomat 3000 x-ray unit at 28 kV, Mo/Mo with AEC position 1–1.5
- TOR(MAX) test object on 4 cm Perspex
- normal density settings (ie + 1 for film and 0 for CR)
- for film images: Fuji AD-M film and fine screen (latest AD-M version)
- for CR images: Auto EDR mode (as for clinical films), L = 2.2.

TOR(MAM)
- Siemens Mammomat 3000 x-ray unit at 28 kV, Mo/Mo, AEC position 1
- TOR(MAM) test object on 3 cm Perspex
- normal density settings (ie + 1 for film and 0 for CR)
- for film images: Fuji AD-M film and screen (latest AD-M version); note that this film density is higher than would routinely be used
- for CR images: Auto EDR mode used (as for clinical films), L = 2.2–2.3.

The results are shown in Tables 4 and 5, with recent film-screen results for comparison. The resolution results are similar to those quoted in MHRA Report 04094[2] (8.9 lp/mm). The minimum detectable contrast is within NHSBSP minimum limits for film-screen for the larger 5–6 mm and 0.5 mm details. For the 0.25 mm details, the film and 5 MP monitor results are within this minimum standard (8%), but the hardcopy and 3 MP monitor results fall outside this limit (Figure 1). For both test objects, the film scores are superior to the hardcopy and 3 MP scores. The 5 MP monitor results show noticeable improvements, particularly with the optimised processing settings (Figure 2). The impact of these changes on clinical images was observed in order to decide whether further optimisation of processing parameters could be achieved.

A report on a comparative study of the 3 MP and 5 MP reporting workstation monitors with the Fuji FCR Profect CS computerised radiography system is given in Chapter 4.

Table 4 Image quality: TOR(MAX) results

			Softcopy		
	Film (mean of three images)	**Hardcopy**	**3 MP monitor, original processing setting**	**5 MP monitor, original processing setting (mean of three images)**	**5 MP monitor, optimised processing setting (mean of three images)**
Date	6/5/05	21/7/04	21/7/04	5/10/04	5/10/04
Exposure (mAs)	92.3	76.1	76.1	74.6	74.6
Density setting	+1	0	0	0	0
S value/optical density	1.97	74	74	75	75
Limiting resolution (lp/mm)					
Anode–cathode direction	14.3	7.5	7.5	7.3	Not scored
Lateral direction	14.3	7.5	7.5	7.7	Not scored
Low contrast: 5–6 mm circular details					
Number of details observed	7.7	7	7	7.8	8.3
Minimum detectable contrast (%)	0.8	1.0	1.0	0.8	0.7
Low contrast: 0.5 mm details					
Number of details observed	8.3	8.5	8.5	8.5	9.0
Minimum detectable contrast (%)	3.5	3.4	3.4	3.4	2.8
Low contrast: 0.25 mm details					
Number of details observed	6.7	6	6	6.7	7.3
Minimum detectable contrast (%)	6.8	8.3	8.3	6.5	5.2

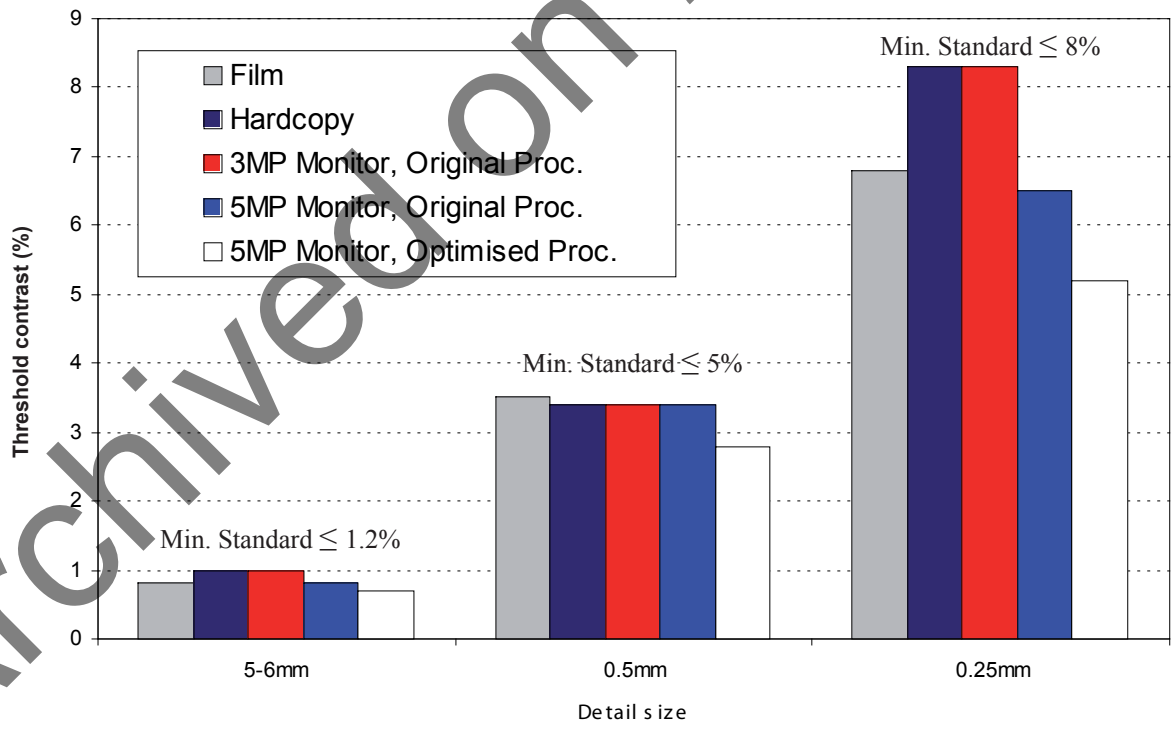

Figure 1 TOR(MAX) results.

Table 5 Image quality: TOR(MAM) results

			Softcopy		
	Film (mean of three images)	**Hardcopy**	**3 MP monitor, original processing settings**	**5 MP monitor, original processing setting (mean of three images)**	**5 MP monitor, optimised processing setting (mean of three images)**
Date	6/5/05	21/7/04	21/7/04	5/10/04	5/10/04
Exposure (mAs)	71	51.3	51.3	50.5	50.5
Density setting	+1	0	0	0	0
S value/optical density	2.28	74	74	75	75
Scores					
Filaments	41	30	32	36	40
Particles	13	13	13	13	14
Circular details	29	30	29	32	33
Total	83	73	74	81	87

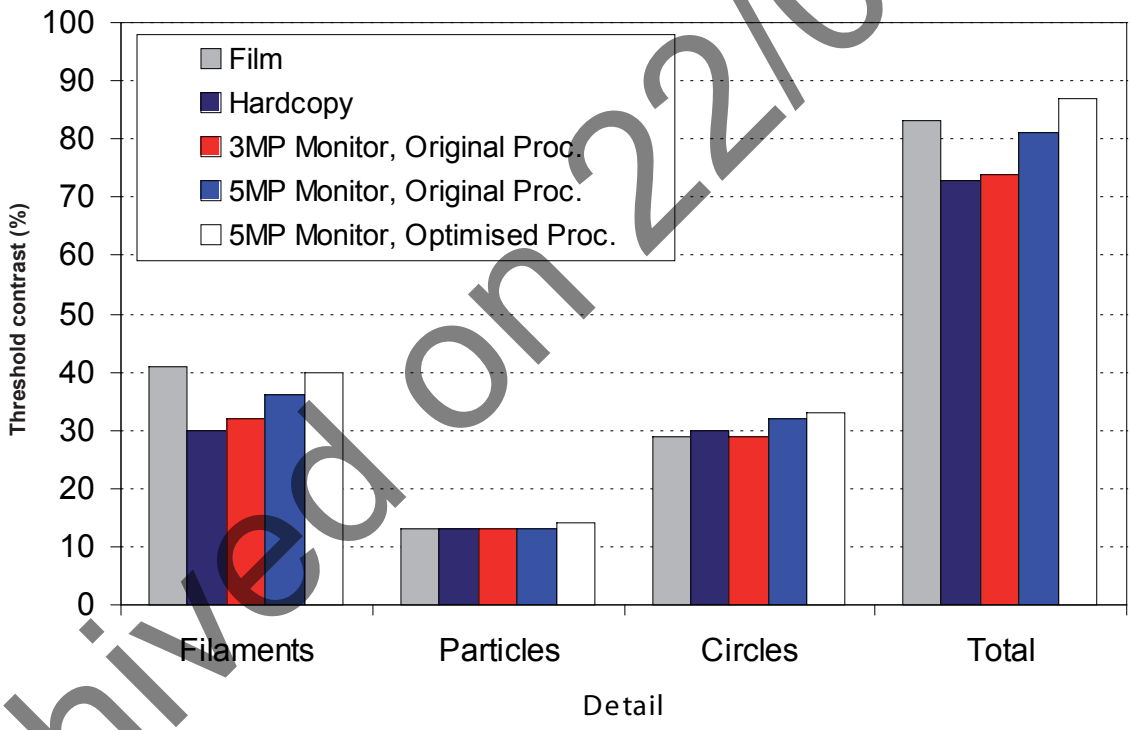

Figure 2 TOR(MAM) results.

The CDMAM test object was used to assess the contrast detection threshold in more detail. Eight images were acquired under AEC control with the x-ray set operating at 28 kV with a molybdenum anode and filter. The images were scored visually using one of the 5 MP monitors. Images were also read automatically using the CDCOM software, and both sets of results were analysed following the procedure described by Young et al.[3]

Both visual assessment and automatic reading showed that the system met the 'acceptable' standard for all detail sizes from 0.1 mm to 1.0 mm. The results are shown in Figure 3.

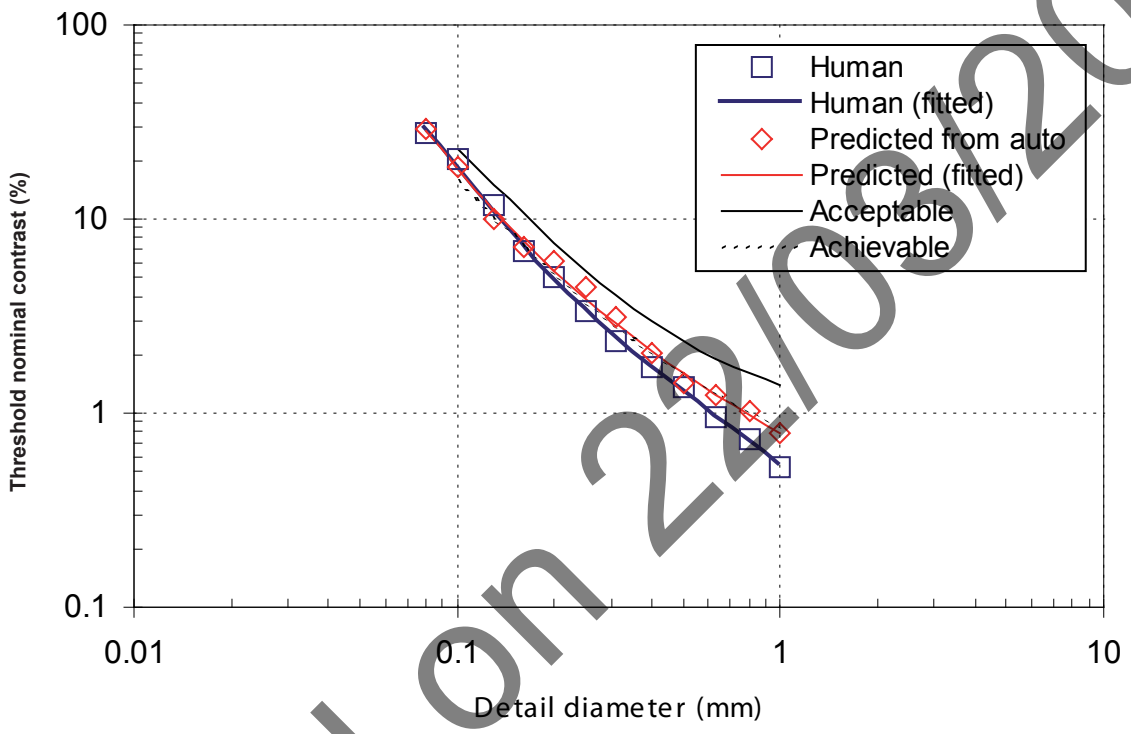

Figure 3 CDMAM results.

3.5 Dose assessment

The dose was initially assessed using the standard breast model (4.5 cm Perspex to simulate a 5.3 cm breast). As expected, the film dose was higher than the CR dose because a higher density setting was used (+ 1 compared with 0). The results are shown below in Table 6, together with a summary of two patient dose surveys (Jan–Mar 2005 for film and Apr–Jun 2004 for CR). The average oblique view mean glandular doses for breasts with thickness between 50 mm and 60 mm are within the national diagnostic reference level[4] of 3.5 mGy for both film and CR.

Further details of the dose survey data are in Appendix 1.

Table 6 Summary of dose assessment

	Standard breast		Craniocaudal view		Oblique view	
	Film	**CR**	**Film**	**CR**	**Film**	**CR**
Mean dose (mGy)	1.72	1.61	1.55	1.60	1.88	2.24
Mean thickness (mm)	53	53	52	50	51	55
Mean S value	–	136	–	66	–	62
Number of images	–	–	31	245	97	22
Mean dose for 50–60 mm	–	–	–	–	2.02	2.11
Mean thickness for 50–60 mm	–	–	–	–	55	55

4. COMPARISON OF 3 MP AND 5 MP REPORTING WORKSTATION MONITORS

The Fuji FCR Profect CS computerised radiography system was installed at the West of Scotland Breast Screening Centre, Glasgow, in April 2004. At this time, Dome C3 monitors were supplied as reporting monitors, having 3 MP resolution. Commissioning and on-going tests included assessment of the image quality, using the TOR(MAX) and TOR(MAM) test objects.

On arrival of the new Totoku ME515L 5 MP reporting workstation monitors in October 2004, repeat image quality tests were carried out. These ensured that the image quality was still within NHSBSP recommended limits for CR systems, but also sought to detect any differences between the two types of monitor.

At the same time, adjustments were made to the pattern enhancement for mammography (PEM) coefficient and GA (contrast) settings. These parameters were set up at installation as:

GA = 2.3 PEM coefficient = 1

Experience with the system and feedback from other UK users led the Glasgow users to make adjustments in order to increase the contrast and enhancement coefficient values to:

GA = 2.7 PEM coefficient = 2

Before this GA adjustment, users were already manually increasing the GA value from 2.3 to 2.5.

The PEM coefficient increase would be expected to enhance the visibility of microcalcifications. The effect of these adjustments was also assessed.

4.1 Measurements

All films were taken using a Siemens Mammomat 3000 x-ray unit, at density setting 0 under AEC control.

Initially, a comparison of the exposure parameters for 4 cm Perspex was made to ensure that the x-ray unit and CR system performance were similar for the two sets of measurements. The results (using Opdose Programme 2, 28 kV Mo/Mo, SemiFix processing, position 2) are shown in Table 7.

Table 7 Comparison of exposure parameters

Monitors	Date	mAs	S value
3 MP	21/07/04	51.7	139
5 MP	05/10/04	51.9	129

When it was clear that there were no significant changes in these parameters, the image quality test objects were exposed at 28 kV, Mo/Mo, AEC position 1–1.5. The results are shown in Tables 8–10 and Figures 1 and 2.

Table 8 TOR(MAX) + 4 cm Perspex (results on 5/10/04 are the mean of three exposures)

		Settings					Resolution (lp/mm)		Threshold contrast (%)		
Date	Monitor	GA	PEM	mAs	S	L	Anode to cathode	Lateral	5–6 mm	0.5 mm	0.25 mm
21/07/04	3 MP	2.5	1	76.1	74	2.2	7.5	7.5	1.0	3.4	8.3
05/10/04	5 MP	2.5	1	74.6	73	2.2	7.3	7.7	0.8	3.4	6.4
05/10/04	5 MP	2.7	2	74.6	73	2.2	Not re-scored		0.6	2.8	5.1

Table 9 CIRS resolution pattern (at 28 kV, Mo/Mo, using old PEM/GA settings only)

Date	Monitor	mAs	Resolution with no Perspex (lp/mm)		Resolution with 4 cm Perspex (lp/mm)	
21/07/04	Old	10/60	8.5	8.5	8	8
05/10/04	New	10/63	8.5	8	9	8.5

Table 10 TOR(MAM) + 3 cm Perspex (results on 5/10/04 are the mean of three exposures)

		Settings					Filament	Particle	Circle	
Date	Monitor	GA	PEM	mAs	S	L	score	score	score	Total score
21/07/04	3 MP	2.5	1	51.3	74	2.2	32	13	29	74
05/10/04	5 MP	2.5	2	50.5	75	2.3	36	13	32	81
05/10/04	5 MP	2.7	2	50.5	75	2.3	40	14	33	87

4.2 Results

As expected, the change to the higher resolution monitors and new settings resulted in some improvement in the image quality scores.

For the TOR(MAX) test object, a lower threshold contrast was observed for all three detail sizes (Figure 4). Both changes led to an improvement in threshold contrast, with an overall reduction of 20–50%. There was no significant improvement in high contrast spatial resolution (measured at maximum zoom). This was to be expected because the monitor was not the limiting factor; the resolution is primarily limited by the x-ray conversion process.

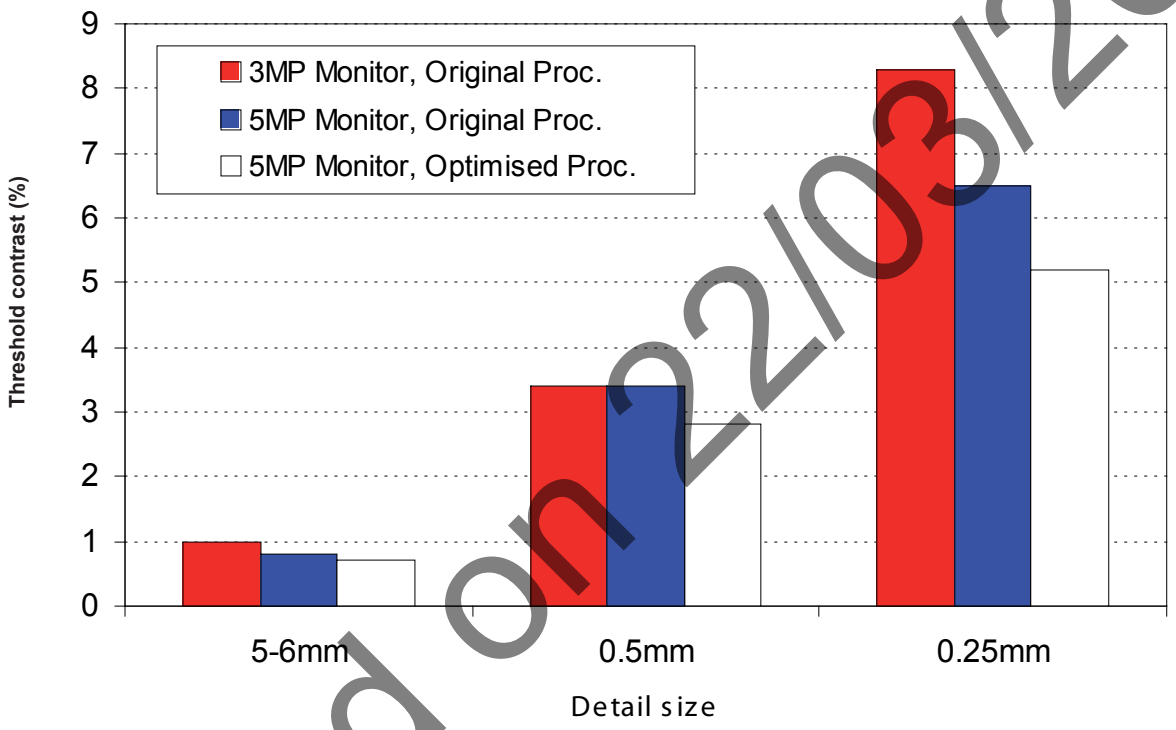

Figure 4 Comparison of monitors using TOR(MAX).

For the TOR(MAM) test object, both the monitor and setting changes resulted in improvements in the scores. All three detail types (filaments, particles and circles) show some increased visibility, and overall the score has increased by 16% (Figure 5).

From these results, we are satisfied that the image quality of the new 5 MP monitors is at least as good as the original 3 MP monitors. With the changes made to the contrast and enhancement settings also, the clinical images should be improved, particularly in the visibility of microcalcifications.

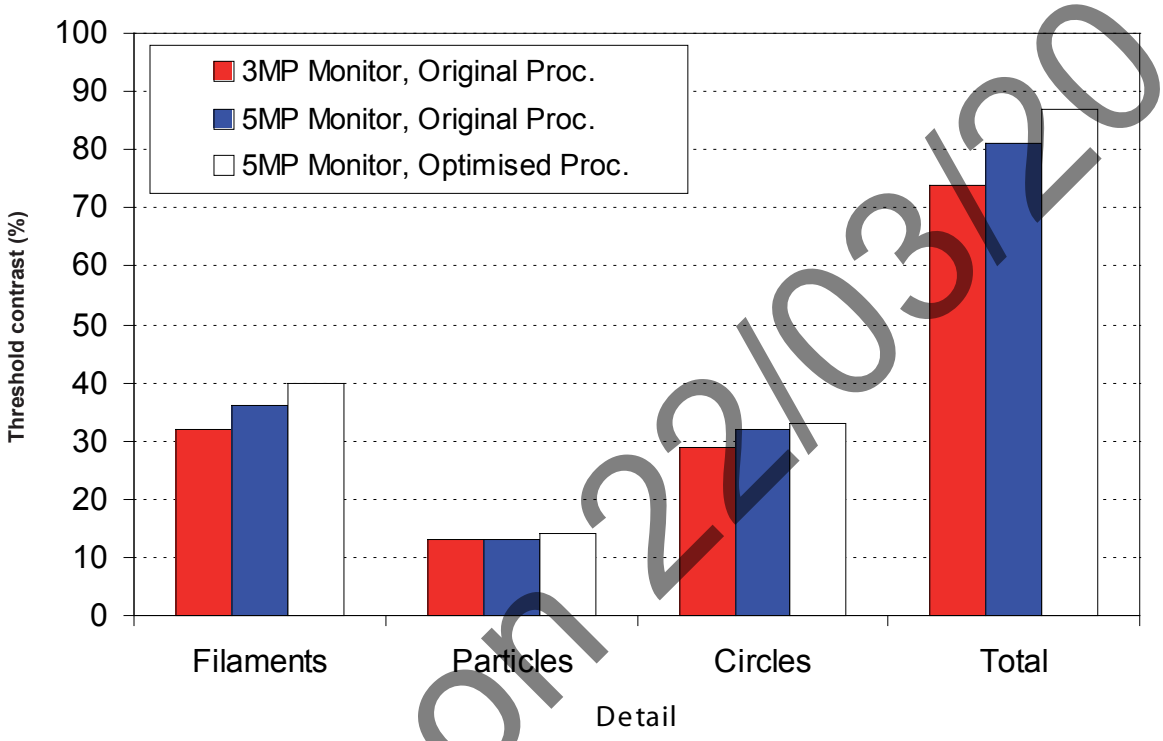

Figure 5 Comparison of monitors using TOR(MAM).

4.3 SMPTE test pattern

The quality of both sets of monitors was checked using the SMPTE test pattern. Both scored acceptably (Table 11). Note that the 100% brightness of the 5 MP monitors is reduced, but is still within limits.

Table 11 SMPTE results

Date	Monitor	5% steps visible?	Equally?	High contrast patterns?	Low contrast patterns?	100% (Cd/m²)	0% (Cd/m²)	Left and right matched?	Comments
Tolerance						> 240	< 1	100 ± 5%	
26/4/04	Left	Both OK	Yes	All OK	All OK	529	0.7	2.7%	Dome C3
26/4/04	Right					558	0.7	OK	Monitors (3 MP)
5/10/04	Left	Both OK	95/100 more visible	All OK but movement of smallest patterns	All OK	357	0.6	0.6% OK	Totoku ME515L monitors (5 MP)
5/10/04	Right					353	0.6		

4.4 Conclusions

- For both monitor sets, image quality was within NHSBSP recommended limits for CR systems.
- Improvements in the detection of low contrast details were observed because of the new 5 MP monitors and because of the adjustments in processing parameters (GA and PEM coefficient). Both changes resulted in similar levels of improvement. Overall, the TOR(MAM) score increased by 16% and the threshold contrast decreased by 20–50%.
- These changes should now be assessed clinically.
- Further image quality improvement may be possible by continued optimisation of the processing parameters.

4.5 Recommendations

Phantom images demonstrate the necessity of using 5 MP monitors for softcopy reporting. A variation in image quality was also demonstrated with differing processing settings. It is therefore essential that the image processing parameters are optimised.

5. CR SOFTCOPY REPORTING AT ASSESSMENT

During the evaluation period, there were intermittent problems with delays in sending images directly to the reporting monitors. This was an issue because the system was being evaluated in the assessment clinic and, therefore, radiologists were waiting for the images to arrive on the workstation. However, this problem seems to have been rectified by the installation of a gigabyte switch which has improved the speed of transfer of the images from the quality assurance (QA) workstation to the reporting monitor.

During the assessment clinics, the previous films were mounted on a Planilux viewer, which was adjacent to the reporting monitors. Initially, this created a problem with ambient light, but this was resolved by shielding the monitors from the light from the viewers or by switching off the viewers when the monitors were being used.

6. USABILITY OF THE SYSTEM

6.1 Training

Two trainers attended the Fuji training course and then disseminated the training to other members of staff. This training is essential to ensure the efficient use of the system as quickly as possible. Some difficulties with training were experienced initially because a number of radiographers work part time in the screening programme. However, once staff were experienced, there were no serious issues with the use of the equipment. The training was very well delivered by Fuji, although possibly there could have been more in depth training for film readers.

6.2 Ergonomic issues

Using the Fuji CR system involves the use of cassettes that are inserted into a bucky then into the reader for scanning. However, these plates are lighter than conventional film cassettes and, with the turbo release systems on the mammography units, the risk of repetitive strain injury should be less than with conventional film systems. The cassettes can be easily pushed into the reader with two hands.

Further ergonomic problems arose with the use of a computer with a keyboard and mouse. A risk assessment should be carried out when the QA workstations and reporting monitors are installed to ensure that adequate consideration is given to the position of the monitors and also to the position of the radiographers and radiologists when viewing the monitors.

6.3 Archiving

Cases were archived to DVD. The use of a DVD has caused many problems and it is not recommended as a permanent archiving process. The problems have included loss of images, difficulty in archiving images in the correct format and the usability of formatting and changing DVDs when they are full.

6.4 Recommendations

- The training course delivered by Fuji to a number of key trainers is essential in order to ensure the smooth introduction of the CR system. Consideration should be given to delivering an intensive training programme involving all radiographers using the system.
- A risk assessment should be carried out prior to the siting of the QA workstations and reporting monitors to ensure that viewing conditions are optimum and that the risk of repetitive strain injuries using a mouse is minimised.
- The use of DVDs is not recommended as a permanent archiving system. A picture archiving and communication system (PACS) should be integrated with the CR system.

7. IMAGE EVALUATION

A total of 132 images were evaluated (75 before the installation of 5 MP monitors and 57 after the installation of 5 MP monitors) out of a total of 300 cases. The evaluation compared the softcopy images with the conventional film-screen images obtained at the screening appointment. Hardcopy images were not assessed at this stage. The criteria used were:

- breast background pattern
- radiological classification of the lesion (see Appendix 2)
- the comparative score of the zoom image vs magnification image.

The results are shown in Figures 6–10. Results are presented for the 5 MP monitors only because the image quality was better than with the 3 MP monitors.

Figure 6 demonstrates that, in 57% of the 57 cases evaluated, the information obtained from using the zoom facility equated to the conventional magnification image using film-screen; 32% of the 57 cases demonstrated that the magnification view provided more information than the zoom; and 11% of the 57 cases demonstrated that the zoom view provided more information than the magnification view. The type of background breast tissue was also assessed in relation to the comparison of zoom and magnification. Figure 7 shows the distribution of cases in which zoom equalled the magnification. It can be seen that 37% of the cases were in fatty tissue compared with 33% in mixed and 30% in dense tissue. Figure 8 shows that, where magnification was better than zoom, the distribution was slightly different in that 11% of cases were in fatty tissue but 50% were in mixed and 39% were in dense tissue. Figure 9 demonstrates that 64% of the cases in which zoom equalled magnification were well defined opacities, 15% were microcalcifications and 15% were ill-defined opacities. Figure 10 shows that, where the magnification view has provided more information, 39% of the cases were well defined opacities, 28% were microcalcifications and 22% were microcalcifications with a well defined opacity.

In summary, the zoom facility equates to the conventional magnification view in slightly more than half of the cases assessed. The lesions predominantly demonstrated more clearly were well defined opacities.

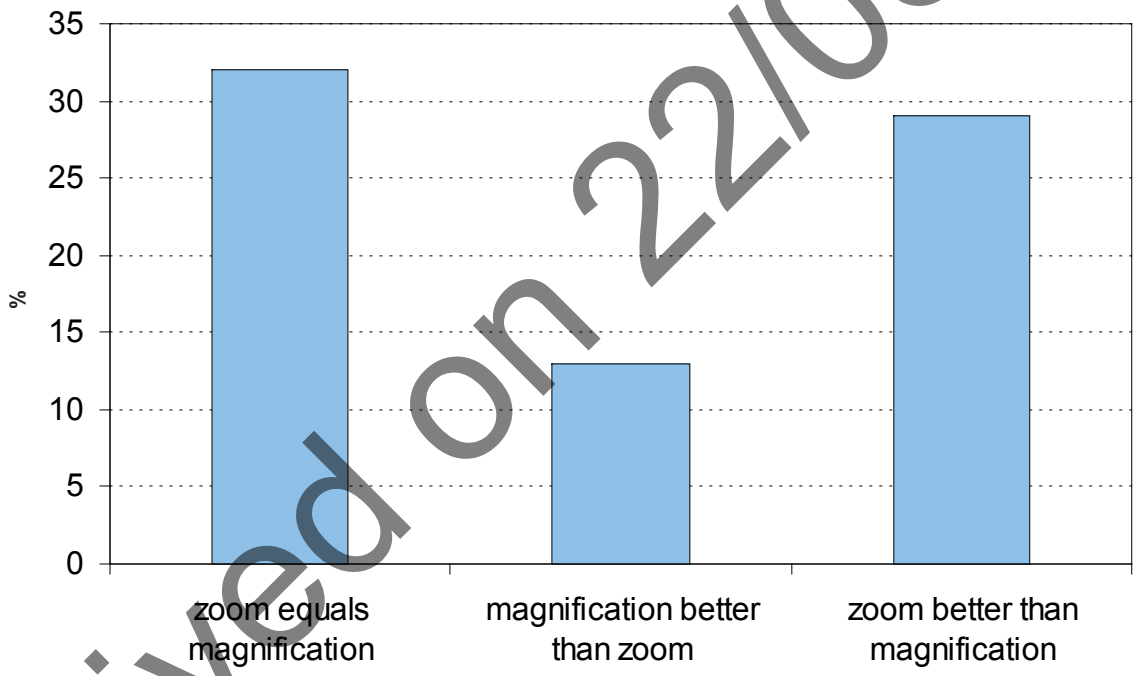

Figure 6 Fifty-seven cases with 5 MP monitors.

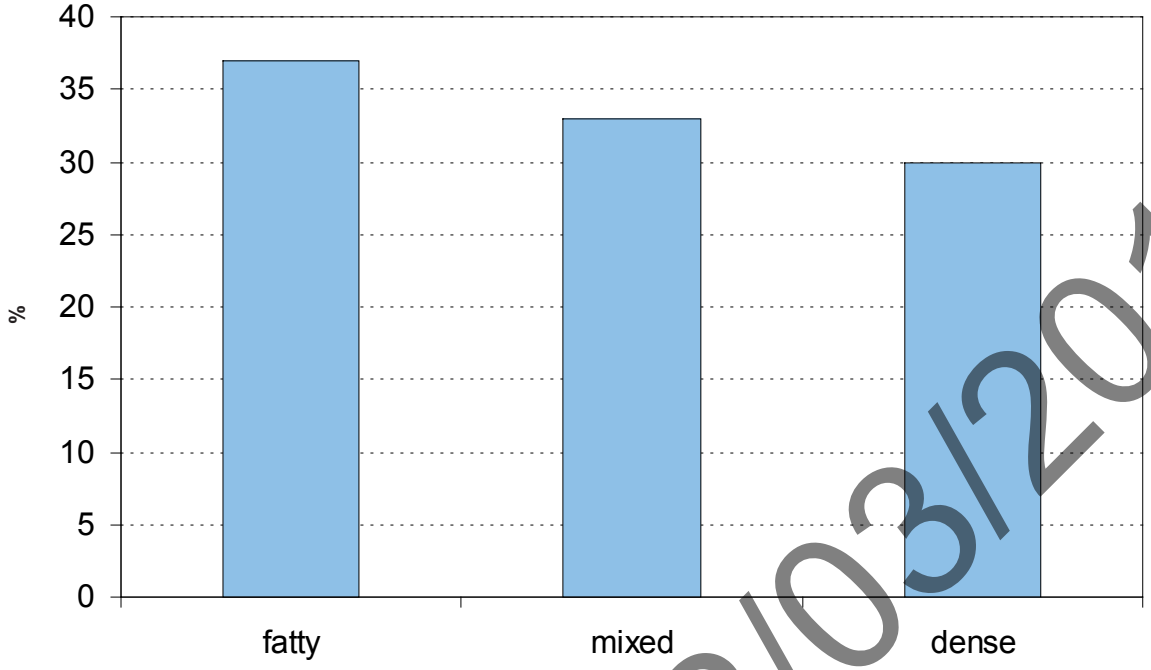

Figure 7 Zoom equal to magnification.

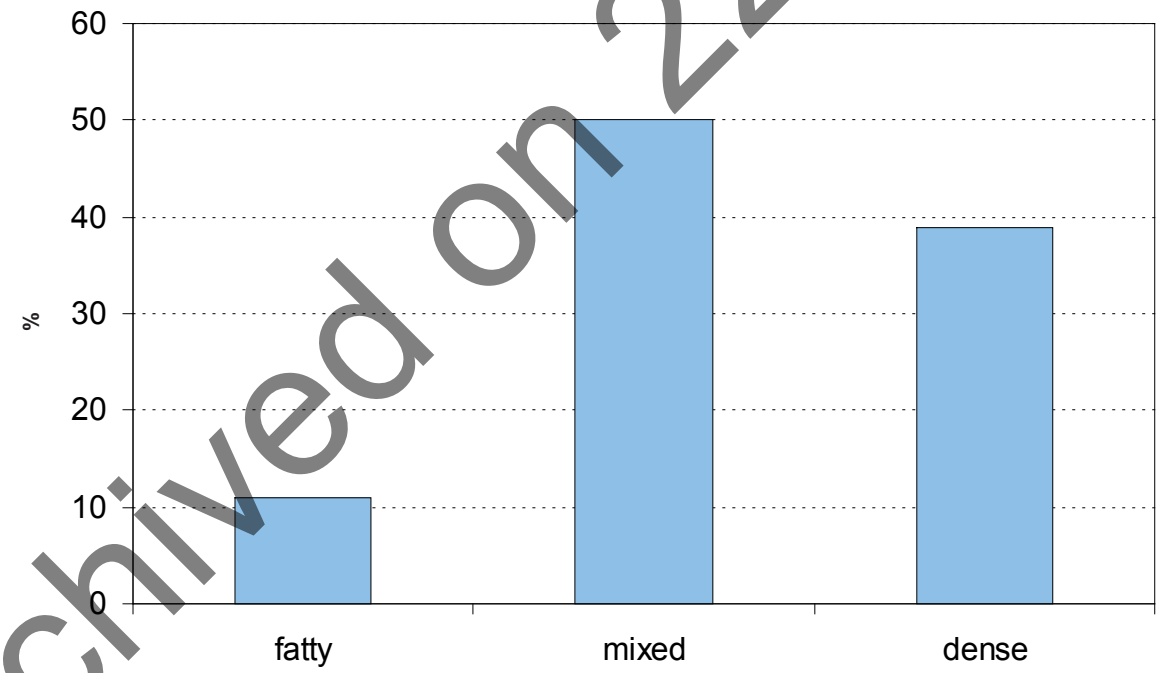

Figure 8 Magnification better than zoom.

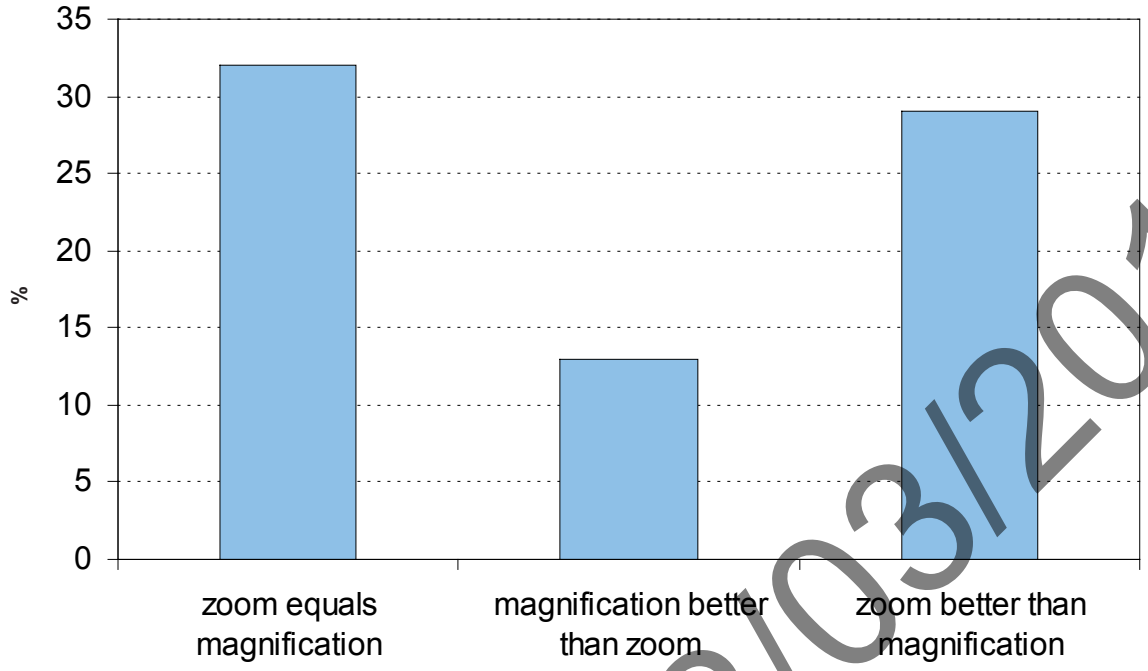

Figure 9 Zoom equal to magnification (5 MP).

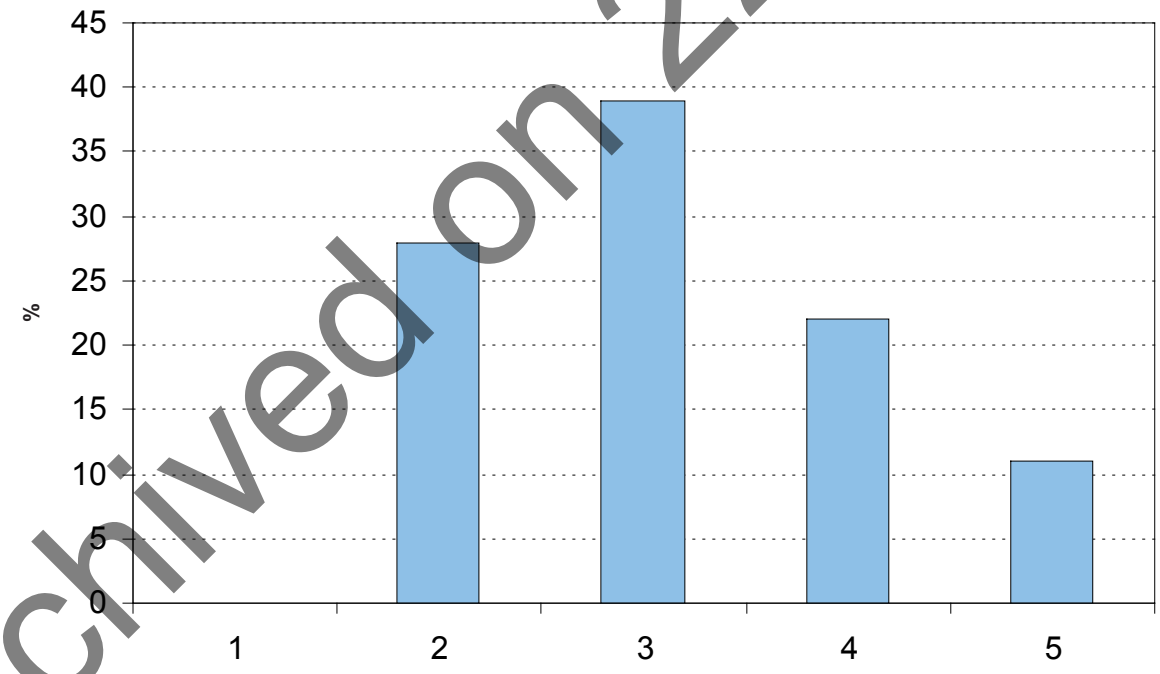

Figure 10 Magnification better than zoom (5MP).

8. CONCLUSIONS

The evaluation of the Fuji Profect computerised radiography system has demonstrated that it meets the image quality standards in the NHSBSP[1] and EUREF[5] protocols.

There are demonstrable benefits in the breast screening assessment process for women.

There was a noticeable improvement in the image quality when the 3 MP reporting monitor was replaced by a 5 MP monitor.

The image quality of the Fuji Profect CR system meets NHSBSP standards. However, processing parameters affect image quality and these settings must be optimised.

Softcopy reporting generally worked satisfactorily in the assessment clinic. The siting of the monitor is important, particularly when using a viewing box for comparison with film-screen images.

The CR system integrated well with a Siemens 3000 and a GE DMR unit. No additional calibration of the AEC was required. It may also be possible to reduce the dose, but this was not fully evaluated. The dose remained the same as using film-screen combinations.

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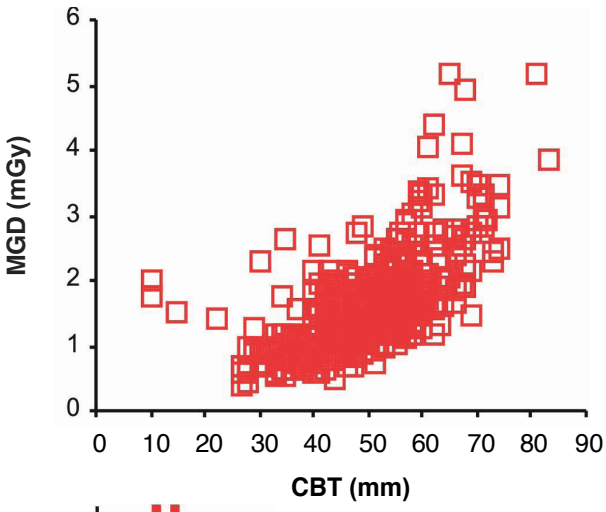
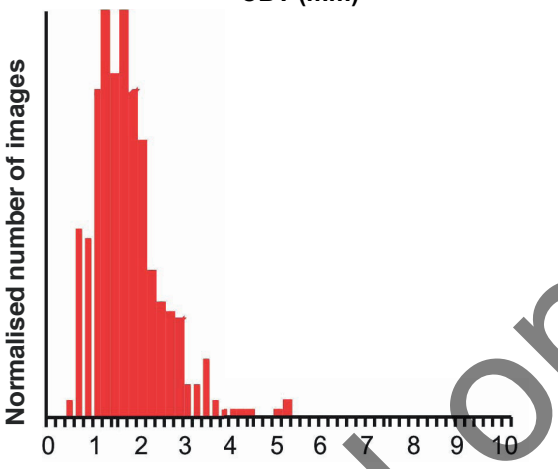
APPENDIX 1: COMPARISON OF PATIENT DOSES FOR FUJI CR WITH FUJI AD ADVANCED FILM-SCREEN

Computerised radiography





View	Number of exposures	Minimum MGD (mGy)	Maximum MGD (mGy)	Mean MGD (mGy)	Mean CBT (mm)
Craniocaudal	245	0.40	4.40	1.60	50
Oblique	22	0.86	4.91	2.24	55

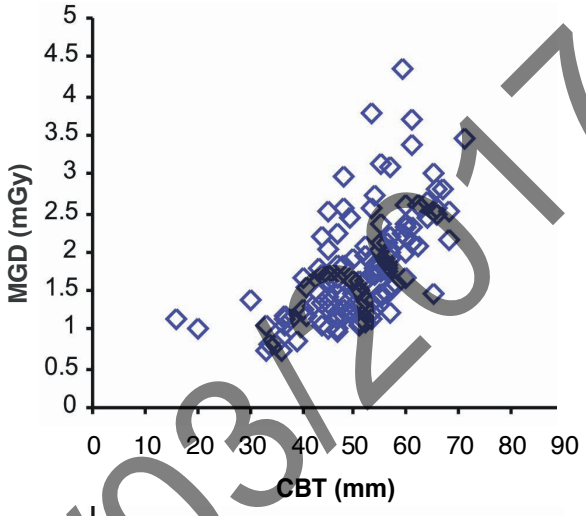
Average MGD for 50–60 mm thick breasts

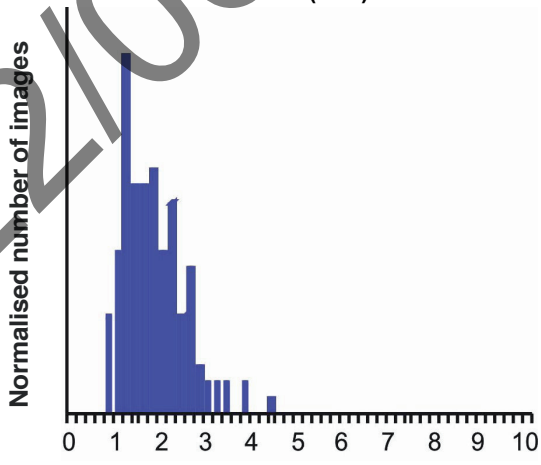
View	Number of exposures	Mean MGD (mGy)	Two sem	Mean CBT (mm)
Oblique	10	2.11	0.30	55

Summary of x-ray factors selected

Anode	Filter	kV	Number
Mo	Mo	27	26
Mo	Mo	28	160
Mo	Mo	29	3
Mo	Mo	30	1
Mo	Rh	28	151
Mo	Rh	29	18
Mo	Rh	30	25

Film-screen





View	Number of exposures	Minimum MGD (mGy)	Maximum MGD (mGy)	Mean MGD (mGy)	Mean CBT (mm)
Craniocaudal	31	0.75	2.56	1.55	52
Oblique	97	0.74	4.35	1.88	51

Average MGD for 50–60 mm thick breasts

View	Number of exposures	Mean MGD (mGy)	Two sem	Mean CBT (mm)
OB	42	2.02	0.20	55

Summary of x-ray factors selected

Anode	Filter	kV	Number
Mo	Mo	27	3
Mo	Mo	28	36
Mo	Rh	28	78
Mo	Rh	29	2
Mo	Rh	30	12

APPENDIX 2: RADIOLOGICAL CLASSIFICATION

1. Normal
2. Microcalcification
   a. casting
   b. non-casting
3. Well defined opacity
4. Mainly well defined opacity with calcification
5. Mainly ill-defined opacity
6. Mainly ill-defined opacity with calcification
7. Parenchymal distortion, no centre
8. Parenchymal distortion, no centre and microcalcification
9. Asymmetry
10. Asymmetry and microcalcification
11. Parenchymal distortion, with centre
12. Parenchymal distortion, with centre and calcification