TECHNICAL EVALUATION OF PROFILE AUTOMATIC EXPOSURE CONTROL SOFTWARE ON GE ESSENTIAL FULL FIELD DIGITAL MAMMOGRAPHY SYSTEMS

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K C Young, J M Oduko, O Gundogdu and M Asad
National Coordinating Centre for the Physics of Mammography

Enquiries
Enquiries about this report should be addressed to:
Professor KC Young
National Coordinating Centre for the Physics of Mammography
Medical Physics Department
Royal Surrey County Hospital
Guildford
GU2 7XX

Tel: 01483 406738
Fax: 01483 406742
Email: ken.young@nhs.net

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NHS Cancer Screening Programmes
Fulwood House
Old Fulwood Road
Sheffield
S4 7UQ
Tel: 0114 271 1060
Fax: 0114 271 1089
Email: info@cancerscreening.nhs.uk
Website: www.cancerscreening.nhs.uk

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1. INTRODUCTION

1.1 Testing procedures and performance standards for digital mammography

This report is one of a series evaluating commercially available digital mammography systems on behalf of the NHS Breast Screening Programme (NHSBSP). The testing methods and standards applied are mainly derived from NHSBSP Equipment Report 0604.[1] This is referred to in this document as the NHSBSP protocol and it has the same image quality and dose standards as those provided in the European protocol.[2,3] The European protocol was followed where there is a more detailed performance standard, eg for the automatic exposure control (AEC) system.

1.2 Objectives

The purpose of these tests was to supplement those already published in a previous technical evaluation of the GE Essential digital mammography system.[4] They include the results of tests on an optional new AEC design described as 'Profile'. The original design of AEC is now termed 'Classic' and will be available as an alternative setup on GE Essential and DS models.

2. METHODS

2.1 System tested

The tests were conducted at the Princess Grace Hospital, London, on the system tested in the original report and shown in Figure 1.

The manufacturer has extended the automatic optimisation of parameters (AOP) tables from a single set (contrast, standard and dose) to two sets of tables. The first set, now named 'Classic', is the one tested in the original technical evaluation. The second set of tables, named 'Profile', was derived from the 'Classic' in the following way:

- In contrast mode, the mean glandular dose (MGD) has been moderately reduced for thin breasts, in order to have more margin than the maximum acceptable level in the European protocol.
- For all modes, the manufacturer has refined the management of thick/dense breasts, so that the 70 mm thickness of polymethylmethacrylate (PMMA) is no longer penalised by constraints for the thickest breasts
- For all modes, the contrast-to-noise ratio (CNR) versus thickness curve has been flattened; this was done for the contrast mode through a moderate reduction in the CNR and MGD at 50 mm, and a moderate CNR improvement at 60 and 70 mm; for the standard and dose mode, this was done by a significant increase in CNR at 60 and 70 mm. Obviously, the price to pay for that is an increase in MGD for thick breasts.
- These tables are part of a new software revision from the manufacturer that is generally installed in all new models and can be retrofitted to existing systems; the Classic table will continue to be offered to users.

For this report a new set of measurements were performed on both the Classic and Profile versions of the AOP tables.

Figure 1 Photo of GE Essential.

2.2 Dose measurement

Doses were measured by using the AEC in each of its three Classic AOP modes to expose different thicknesses of PMMA, with an area of 18 × 24 cm. Small PMMA spacers were added at the edges of the test object to adjust the total thickness to be equal to the equivalent breast thickness. Mean glandular doses (MGDs) were calculated for the equivalent breast thicknesses and the displayed doses recorded. To measure the contrast-to-noise ratio (CNR), an aluminium square, 10 mm × 10 mm, and 0.2 mm thick, was placed on top of a 20 mm thick block, with one edge on the midline and 6 cm from the chest wall edge. Additional layers of PMMA were added on top to vary the total thickness.

The measurements were repeated using the Profile AOP mode.

2.3 Contrast-to-noise ratio

The images of the blocks of PMMA obtained during the dose measurement were analysed to obtain the CNRs. Twenty small square regions of interest (ROIs) (approximately 2.5 mm × 2.5 mm) were used to determine the average signal and the standard deviations in the signal within the image of the aluminium square (four ROIs) and the surrounding background (16 ROIs), as shown in Figure 2. Small ROIs are used to minimise distortions due to the heel effect.[5] However, this is less important for this system because flat field correction is applied. The CNR was calculated for each image as defined in the NHSBSP and European protocols.

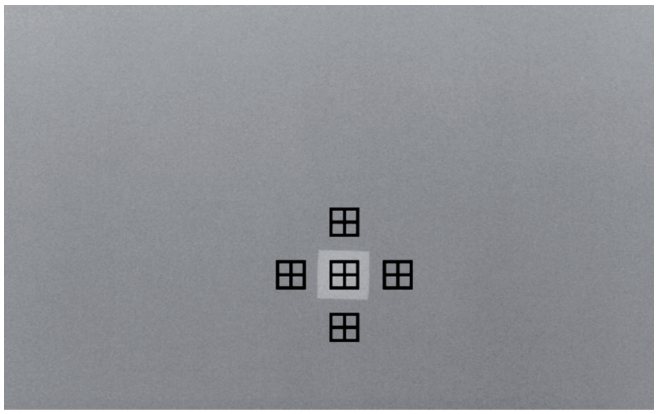

Figure 2 Location and size of ROI used to determine the CNR.

To apply the standards in the European protocol the limiting value for CNR (using 50 mm PMMA) was determined according to equation 1. This equation determines the CNR value ($CNR_{limiting\ value}$) that is necessary to achieve the minimum threshold gold thickness for the 0.1 mm detail (ie $threshold\ gold_{limiting\ value}$ = 1.68 µm, which is equivalent to $threshold\ contrast_{limiting\ value}$ = 23.0% using 28 kV Mo/Mo). Threshold contrasts were taken from the original technical evaluation and used in equation 1.[4]

$$CNR_{limiting\ value} = CNR_{measured} \quad \frac{TC_{measured}}{TC_{limiting\ value}} \tag{1}$$

The relative CNR was then calculated according to equation 2 and compared with the limiting values provided for relative CNR shown in Table 1. The minimum CNR required to meet this criterion was then calculated.

$$Relative\ CNR = CNR_{measured}/CNR_{limiting\ value} \tag{2}$$

Table 1 Limiting values for relative CNR

Thickness of PMMA (mm)	Equivalent breast thickness (mm)	Limiting values for relative CNR (%) in European protocol
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 AEC performance: Classic

3.1.1 Dose

The mean glandular doses for breasts simulated with PMMA exposed under AEC control are shown in Table 2 and Figure 3 for the three AEC modes available. The equipment does its own internal calculation of dose and the displayed values are shown in Table 2. At all thicknesses the calculated dose was below the remedial level in the NHSBSP protocol, which is the same as the maximum acceptable level in the European protocol.

Table 2a Mean glandular dose for simulated breasts (Classic AOP in standard mode)

PMMA thickness (mm)	Equivalent breast thickness (mm)	kV	Target	Filter	mAs	MGD (mGy)	Displayed dose (mGy)	NHSBSP remedial level (mGy)
20	21	26	Mo	Mo	27.6	0.66	0.76	>1.0
30	32	26	Mo	Rh	38.1	0.91	0.88	>1.5
40	45	29	Rh	Rh	38.3	0.86	1.08	>2.0
45	53	29	Rh	Rh	52.9	1.10	1.38	>2.5
50	60	29	Rh	Rh	60.4	1.11	1.49	>3.0
60	75	29	Rh	Rh	81.2	1.36	1.78	>4.5
70	90	30	Rh	Rh	81.0	1.36	1.91	>6.5

Table 2b Mean glandular dose for simulated breasts (Classic AOP in dose mode)

PMMA thickness (mm)	Equivalent breast thickness (mm)	kV	Target	Filter	mAs	MGD (mGy)	Displayed dose (mGy)	NHSBSP remedial level (mGy)
20	21	27	Mo	Mo	15.1	0.38	0.50	>1.0
30	32	26	Mo	Rh	27.9	0.53	0.65	>1.5
40	45	29	Rh	Rh	29.7	0.69	0.84	>2.0
45	53	29	Rh	Rh	39.2	0.81	1.04	>2.5
50	60	29	Rh	Rh	45.8	0.84	1.16	>3.0
60	75	30	Rh	Rh	53.3	1.01	1.38	>4.5
70	90	30	Rh	Rh	81.0	1.35	1.91	>6.5

Table 2c Mean glandular dose for simulated breasts (Classic AOP in contrast mode)

PMMA thickness (mm)	Equivalent breast thickness (mm)	kV	Target	Filter	mAs	MGD (mGy)	Displayed dose (mGy)	NHSBSP remedial level (mGy)
20	21	26	Mo	Mo	39.5	0.80	1.08	>1.0
30	32	26	Mo	Mo	63.4	1.22	1.42	>1.5
40	45	29	Rh	Rh	66.2	1.49	1.81	>2.0
45	53	29	Rh	Rh	84.8	1.76	2.17	>2.5
50	60	29	Rh	Rh	95.6	1.74	2.27	>3.0
60	75	29	Rh	Rh	120.6	2.02	2.61	>4.5
70	90	31	Rh	Rh	91.4	1.83	2.40	>6.5

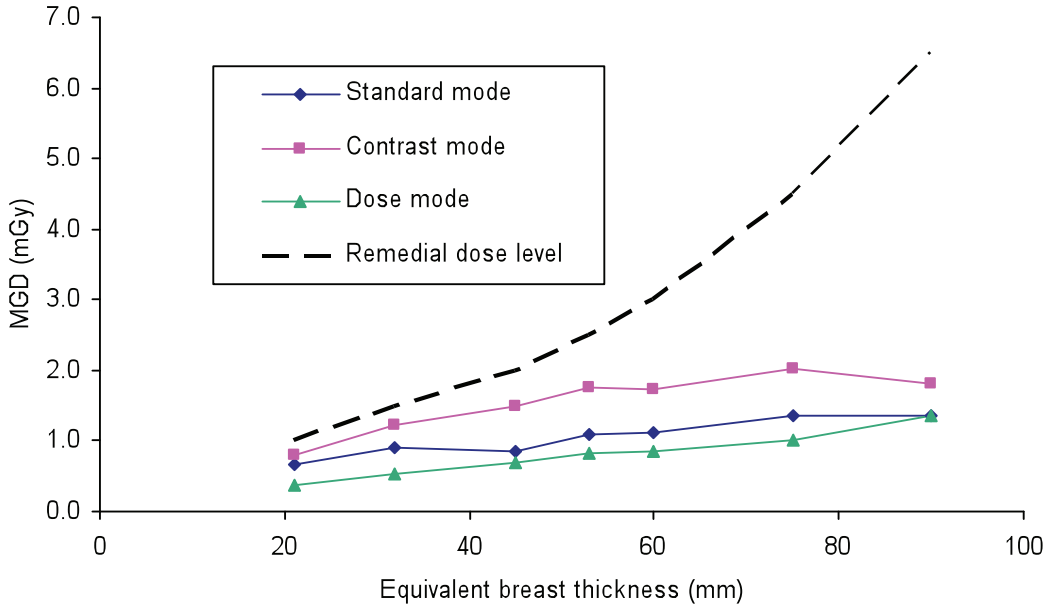

Figure 3 MGD for different thicknesses of simulated breasts using the three Classic AOP modes.

3.1.2 CNR

The results of the contrast and CNR measurements are shown in Table 3 and Figure 6. The CNR required to meet the minimum acceptable and achievable image quality standards at the 60 mm breast thickness have been calculated and are shown in Table 3 and Figure 4. The CNR required at each thickness to meet the limiting values for CNR in the European protocol are also shown.

Table 3a Contrast and CNR measurements using Classic AOP (standard mode)

Equivalent breast thickness (mm)	kV target/ filter	mAs	Back-ground pixel value	% contrast for 0.2 mm Al	Measured CNR	CNR at minimum acceptable IQ	CNR at achievable lQ	CNR to meet European limiting value	European limiting values for relative CNR
21	26 Mo/Mo	27.6	676	20.6	31.4	10.7	15.6	12.3	>115
32	26 Mo/Rh	38.1	566	17.2	22.5	10.7	15.6	11.8	>110
45	29 Rh/Rh	38.3	648	13.7	18.3	10.7	15.6	11.3	>105
53	29 Rh/Rh	52.9	671	13.3	18.1	10.7	15.6	11.1	>103
60	29 Rh/Rh	60.4	577	12.9	15.9	10.7	15.6	10.7	>100
75	29 Rh/Rh	81.2	441	12.4	12.8	10.7	15.6	10.2	>95
90	30 Rh/Rh	81.0	316	11.4	9.8	10.7	15.6	9.7	>90

Table 3b Contrast and CNR measurements using Classic AOP (contrast mode)

Equivalent breast thickness (mm)	kV target/ filter	mAs	Back-ground pixel value	% contrast for 0.2 mm Al	Measured CNR	CNR at minimum acceptable IQ	CNR at achievable lQ	CNR to meet European limiting value	European limiting values for relative CNR
21	26 Mo/Mo	39.5	976	20.6	38.0	10.7	15.6	12.3	>115
32	26 Mo/Mo	63.4	730	19.2	29.9	10.7	15.6	11.8	>110
45	29 Rh/Rh	66.2	1127	13.7	24.7	10.7	15.6	11.3	>105
53	29 Rh/Rh	84.8	1084	13.3	24.0	10.7	15.6	11.1	>103
60	29 Rh/Rh	95.6	918	12.9	21.2	10.7	15.6	10.7	>100
75	29 Rh/Rh	120.6	659	12.2	16.3	10.7	15.6	10.2	>95
90	31 Rh/Rh	91.4	442	10.9	10.9	10.7	15.6	9.7	>90

Table 3c Contrast and CNR measurements using Classic AOP (dose mode)

Equivalent breast thickness (mm)	kV target/ filter	mAs	Back-ground pixel value	% contrast for 0.2 mm Al	Measured CNR	CNR at minimum acceptable IQ	CNR at achievable IQ	CNR to meet European limiting value	European limiting values for relative CNR
21	27 Mo/Mo	15.1	443	20.8	24.2	10.7	15.6	12.3	>115
32	26 Mo/Rh	27.9	410	17.6	18.7	10.7	15.6	11.8	>110
45	29 Rh/Rh	29.7	500	13.9	16.3	10.7	15.6	11.3	>105
53	29 Rh/Rh	39.2	495	13.5	15.4	10.7	15.6	11.1	>103
60	29 Rh/Rh	45.8	434	13.2	14.0	10.7	15.6	10.7	>100
75	30 Rh/Rh	53.3	355	12.1	11.1	10.7	15.6	10.2	>95
90	30 Rh/Rh	81	316	11.5	9.7	10.7	15.6	9.7	>90

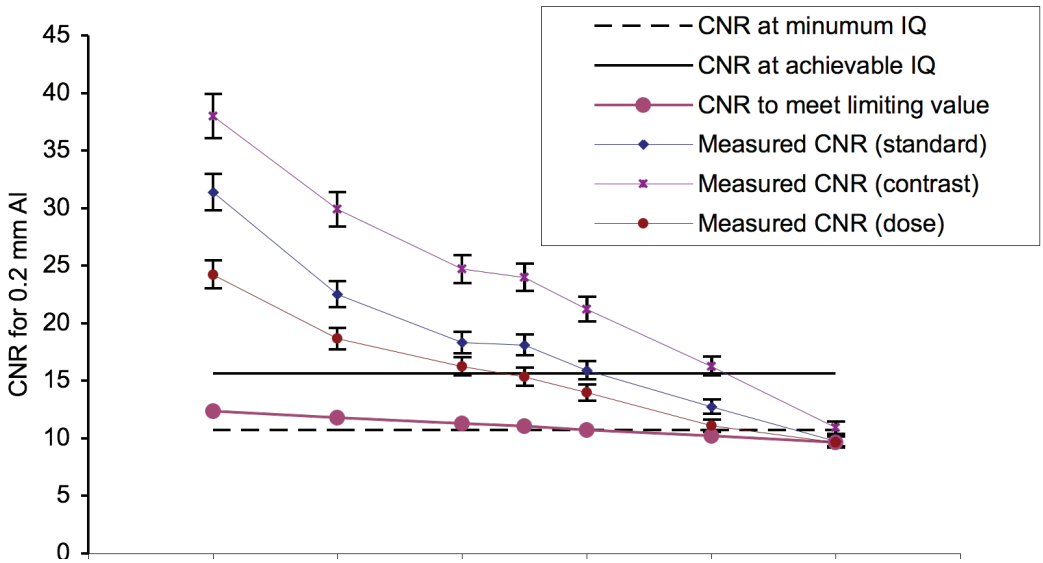

Figure 4 Measured CNR when using Classic AOP compared with the limiting values in the European protocol for the system (error bars indicate 95% confidence limits).

3.2 AEC performance: Profile

3.2.1 Dose

The mean glandular doses for breasts simulated with PMMA exposed under AEC control are shown in Table 4 and Figure 5 for the three AEC modes available. At all thicknesses the dose was below the remedial level in the NHSBSP protocol, which is the same as the maximum acceptable level in the European protocol.

Table 4a Mean glandular dose for simulated breasts (Profile AOP in standard mode)

PMMA thickness (mm)	Equivalent breast thickness (mm)	kV	Target	Filter	mAs	MGD (mGy)	Displayed dose (mGy)	NHSBSP remedial level (mGy)
20	21	26	Mo	Mo	25.2	0.64	0.71	>1.0
30	32	26	Mo	Rh	37.7	0.71	0.89	>1.5
40	45	27	Mo	Rh	54	0.96	1.15	>2.0
45	53	29	Rh	Rh	49.3	1.02	1.17	>2.5
50	60	29	Rh	Rh	53.4	1.02	1.15	>3.0
60	75	29	Rh	Rh	95.5	1.60	1.68	>4.5
70	90	31	Rh	Rh	118	2.25	2.44	>6.5

Table 4b Mean glandular dose for simulated breasts (Profile AOP in dose mode)

PMMA thickness (mm)	Equivalent breast thickness (mm)	kV	Target	Filter	mAs	MGD (mGy)	Displayed dose (mGy)	NHSBSP remedial level (mGy)
20	21	27	Mo	Mo	13.7	0.41	0.47	>1.0
30	32	26	Mo	Mo	27.9	0.54	0.89	>1.5
40	45	29	Rh	Rh	29.8	0.67	0.82	>2.0
45	53	29	Rh	Rh	39.3	0.81	0.94	>2.5
50	60	29	Rh	Rh	44.4	0.85	0.98	>3.0
60	75	30	Rh	Rh	62.3	1.18	1.29	>4.5
70	90	30	Rh	Rh	102.7	1.70	1.89	>6.5

Table 4c Mean glandular dose for simulated breasts (Profile AOP in contrast mode)

PMMA thickness (mm)	Equivalent breast thickness (mm)	kV	Target	Filter	mAs	MGD (mGy)	Displayed dose (mGy)	NHSBSP remedial level (mGy)
20	21	26	Mo	Mo	30.2	0.77	0.82	> 1.0
30	32	26	Mo	Mo	61.4	1.19	1.37	> 1.5
40	45	27	Mo	Rh	80.4	1.43	1.67	> 2.0
45	53	29	Rh	Rh	65.7	1.36	1.51	> 2.5
50	60	29	Rh	Rh	68.7	1.32	1.45	> 3.0
60	75	29	Rh	Rh	110.6	1.85	1.93	> 4.5
70	90	30	Rh	Rh	147.7	2.45	2.66	> 6.5

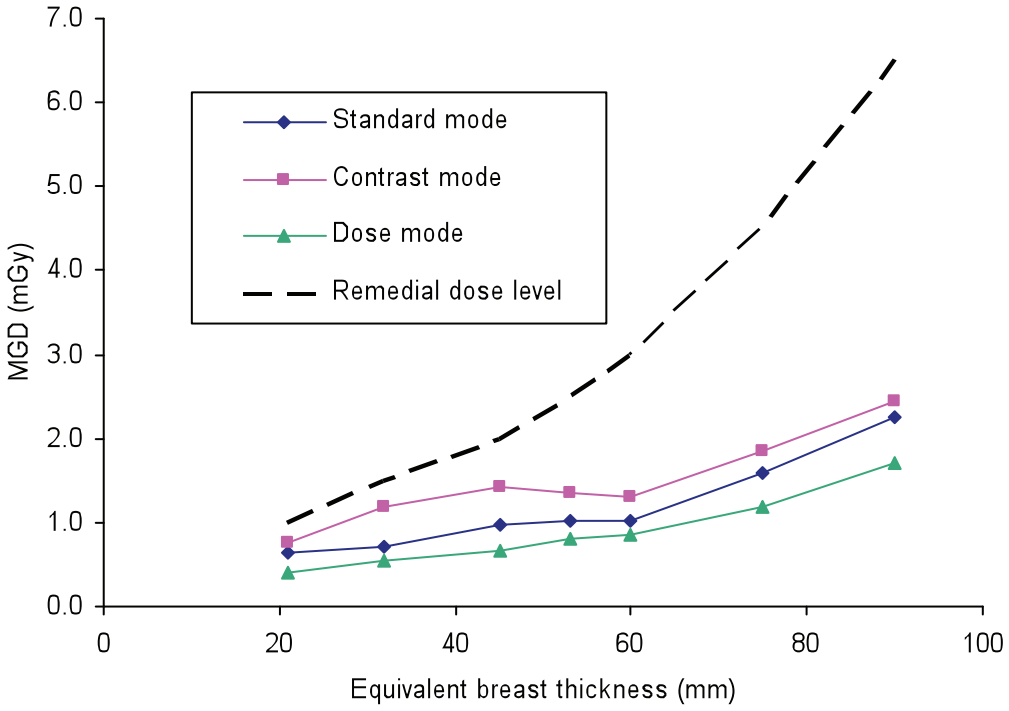

Figure 5 MGD for different thicknesses of simulated breasts using and the three Profile AOP modes.

3.2.2 CNR

The results of the contrast and CNR measurements using the Profile AOP are shown in Table 4 and Figure 6. The CNR required to meet the minimum acceptable and achievable image quality standards at the 60 mm breast thickness have been calculated and are shown in Table 5 and Figure 6. The CNR required at each thickness to meet the limiting values for CNR in the European protocol is also shown.

Table 5a Contrast and CNR measurements using Profile AOP (standard mode)

Equivalent breast thickness (mm)	kV target/ filter	mAs	Back-ground pixel value	% contrast for 0.2 mm Al	Measured CNR	CNR at minimum acceptable IQ	CNR at achievable lQ	CNR to meet European limiting value	European limiting values for relative CNR
21	26 Mo/Mo	25.2	622	20.7	29.6	10.4	15.1	12.3	>115
32	26 Mo/Rh	37.7	565	17.3	22.4	10.4	15.1	11.8	>110
45	27 Mo/Rh	54	520	15.9	18.8	10.4	15.1	11.3	>105
53	29 Rh/Rh	49.3	628	13.5	18.1	10.4	15.1	11.1	>103
60	29 Rh/Rh	53.4	512	13.0	15.4	10.4	15.1	10.7	>100
75	29 Rh/Rh	95.5	532	12.4	14.0	10.4	15.1	10.2	>95
90	31 Rh/Rh	118	598	11.0	13.0	10.4	15.1	9.7	>90

Table 5b Contrast and CNR measurements using Profile AOP (contrast mode)

Equivalent breast thickness (mm)	kV target/ filter	mAs	Back-ground pixel value	% contrast for 0.2 mm Al	Measured CNR	CNR at minimum acceptable IQ	CNR at achievable lQ	CNR to meet European limiting value	European limiting values for relative CNR
21	26 Mo/Mo	30.2	749	20.7	32.5	10.4	15.1	12.3	>115
32	26 Mo/Mo	61.4	714	19.2	31.1	10.4	15.1	11.8	>110
45	27 Mo/Rh	80.4	775	13.7	21.4	10.4	15.1	11.3	>105
53	29 Rh/Rh	65.7	841	13.3	20.9	10.4	15.1	11.1	>103
60	29 Rh/Rh	68.7	661	12.9	18.1	10.4	15.1	10.7	>100
75	29 Rh/Rh	110.6	613	12.2	16.4	10.4	15.1	10.2	>95
90	30 Rh/Rh	147.7	600	10.9	13.6	10.4	15.1	9.7	>90

Table 5c Contrast and CNR measurements using Profile AOP (dose mode)

Equivalent breast thickness (mm)	kV target/ filter	mAs	Back-ground pixel value	% contrast for 0.2 mm Al	Measured CNR	CNR at minimum acceptable IQ	CNR at achievable IQ	CNR to meet European limiting value	European limiting values for relative CNR
21	27 Mo/Mo	13.7	405	20.8	23.0	10.4	15.1	12.3	>115
32	26 Mo/Mo	27.9	413	17.6	19.3	10.4	15.1	11.8	>110
45	29 Rh/Rh	29.8	507	13.9	16.9	10.4	15.1	11.3	>105
53	29 Rh/Rh	39.3	499	13.5	16.7	10.4	15.1	11.1	>103
60	29 Rh/Rh	44.4	422	13.2	14.1	10.4	15.1	10.7	>100
75	30 Rh/Rh	62.3	423	12.1	12.7	10.4	15.1	10.2	>95
90	30 Rh/Rh	102.7	413	11.5	12.3	10.4	15.1	9.7	>90

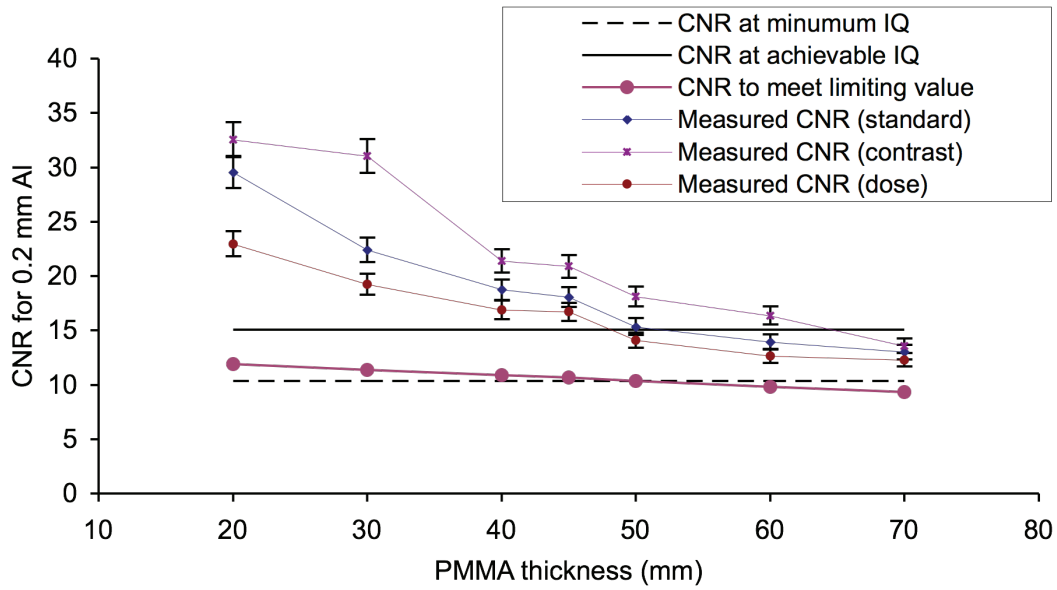

Figure 6 Measured CNR using Profile AOP compared with the limiting values in the European protocol for the system (error bars indicate 95% confidence limits).

4. DISCUSSION

The new Profile AOP broadly achieves the objectives intended by the manufacturer and summarised in section 2.1. Using the original Classic AOP modes, the CNR dropped to close to the minimum acceptable at 70 mm thickness of PMMA (ie 9.7). Using the new Profile AOP modes, the CNR was well above this level at 12.3–13.0 depending on the mode selected. This represents a 24–33% increase in CNR at this thickness. The price paid for this improvement in image quality for large/dense breasts is an increase in MGD of 26–66% for these types of breast. Even so, the largest measured MGD for a breast equivalent to 70 mm of PMMA was only 2.45 mGy in contrast mode. This is still a lower dose than might be expected with most film-screen systems and well below the remedial level of 6.5 mGy.

It is important to point out that the MGDs calculated here are for a standard breast with a uniform distribution of breast tissue. The AEC in this type of system is designed to increase doses when there are locally dense areas of tissue. As a result, actual patient doses measured in a patient dose survey can be expected to be somewhat higher than described here. However, they should still be well within the currently acceptable levels and the increased dose will ensure good image quality in such dense tissue areas.

5. CONCLUSIONS

The new choice of AEC design is a welcome development and it is recommended that where possible users should switch to the new Profile modes. This will provide greater certainty that these systems meet the current image quality standards for all types of breast.

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