GUIDANCE ON BEAM QUALITY SELECTION IN THE NHS BREAST SCREENING PROGRAMME

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PREFACE

This guidance was originally published in June 2001. The guidance applies to the use of mammography x-ray sets with film/screen systems. This reissued version is identical to the original NHSBSP Report 01/06 with the exception of a new appendix which provides recommendations specific to GE x-ray sets. New guidance on beam quality selection with digital mammography systems is being prepared for publication as a separate document.

1. INTRODUCTION

In the early years of the NHS Breast Screening Programme it became established practice to use a tube voltage of 28 kV, with a molybdenum target and a molybdenum filter. There is in fact no specific guidance that requires or recommends this choice of exposure factors. In recent years there have been a number of publications which point out that the optimum choice of beam quality is different for different breasts.[1–6] The breast thickness and composition are the two most important factors affecting this choice. However, because of the complication of changing beam quality from one woman to another, this was only practised to a very limited extent. The introduction of a new generation of mammography x-ray sets that can automatically select (or recommend) a specific tube voltage, and sometimes also filter and target material, is making variation in beam quality selection much more common. These new machines provide the operator with a greater range of choices in optimising beam quality. It is therefore thought to be appropriate to produce some general advice on the implications of the options available.

The main issues to be considered in choosing a particular set of exposure parameters (and therefore beam quality) are the consequences for the absorbed dose to the glandular tissues and the image quality of the mammogram. A third consideration is the exposure time. As regards image quality, the choice of beam quality mainly affects the radiographic contrast. There is a smaller effect on the noise and the image unsharpness is little changed. By modelling and experimental measurement, it is possible to estimate the impact of beam quality choices on dose, contrast and exposure time. The publication of new data on the composition of the breasts involved in screening allows this modelling to be more accurate than in the past.[7]

2. GENERAL PRINCIPLES

The approach adopted here is to use the performance achieved using a tube voltage of 28 kV, with a molybdenum filter and target material (28 kV Mo/Mo) as the base line for a particular breast. Thus, the selection of a different beam quality for a particular type of breast will result in a shift in the dose, contrast and exposure time for that type of breast.

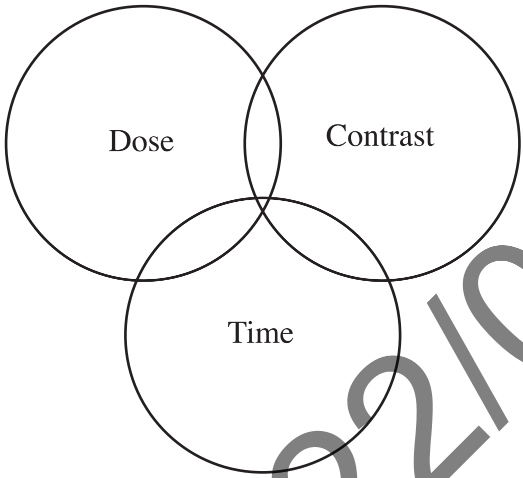

Figure 1 The three parameters to be considered in beam quality selection.

2.1 Contrast

The radiographic contrast between the tissues of the breast can be increased or decreased by selecting beam qualities that have lower or higher average photon energies. The contrast variation that can be achieved is typically within a range of ± 20% of the contrast achieved using 28 kV Mo/Mo. Generally, a contrast increase is at the cost of increased dose and vice versa. The corresponding relative increases or decreases in dose are usually much larger and typically within the range ± 50%. The radiographic contrast is also affected by the thickness of the compressed breast. Thus, thinner breasts (2 cm thick) have a contrast that is about 20% higher than average, while very thick breasts (10 cm thick) have a contrast that is about 20% lower than average. The reasons for a tendency to have less contrast with increasing thickness are 'beam hardening' and increased scatter.

In practice, the contrast apparent in a mammogram is strongly affected by the composition of the breast. Thus, fatty breasts have a relatively low 'intrinsic contrast' (ie dynamic range) while breasts with areas of dense breast tissue can have a very much higher 'intrinsic contrast'. Studies have shown that the amount of intrinsic contrast is not related to the breast thickness.

The third major factor that affects the contrast in a mammogram is the film contrast. All mammography film types have relatively high contrast and act as a 'contrast amplifier'. However, in recent years new higher contrast film-screen systems have come into use. While these produce excellent quality mammograms in most cases, the overall contrast may be excessive for some breast types. For such breasts with a high 'intrinsic contrast' there is a conflict between the high contrast generated by the mammography system and the need for adequate latitude.

2.2 Radiation dose

The radiation dose to the glandular tissues of the breast is determined by many factors. However, when choosing the beam quality to use with a particular breast on a particular system one needs to consider mainly the breast thickness and composition. It has long been understood that thicker breasts tend to receive much higher doses than thin breasts. It is also expected that more glandular breasts require higher doses than fatty breasts. A closer examination of dose data has shown that thin breasts are usually very dense while thick breasts have a higher proportion of fat. If one uses 28 kV Mo/Mo, large breasts (10 cm thick) will receive about three times the average dose. This is one of the major justifications for selecting other exposure factors. However, in the attempt to lower doses to large breasts one must be careful to avoid a loss in contrast that results in an unacceptable image quality.

2.3 Exposure time

The exposure time required to complete a satisfactory mammogram can become quite long (eg up to 4 seconds for relatively thick and/or relatively dense breasts. Another major issue is that mammography systems have been found to vary very widely (by a factor of 10) in their exposure times for the same breast. For a given system and a given breast, the exposure time also depends on the x-ray exposure factors used.

Exposure time is important clinically, as a long exposure time is likely to increase the chance of motion blurring. However, a long exposure time will not itself cause motion blurring and an additional factor such as inadequate compression may be involved. A long exposure time is also undesirable because it may slightly increase patient dose due to the reciprocity failure of the film. A further problem with long exposure times is that for large breasts the back-up timer may terminate the exposure before there has been sufficient time to achieve the desired film density. This will then involve reduced image quality or necessitate a repeat exposure at different factors. On some modern sets that select factors automatically, the set may refuse to expose for some large breasts. In these cases manual factor selection may overcome the problem. If this happens more than very occasionally, there should be an investigation of the performance of the x-ray set in automatic mode. Although short exposure times are desirable, any attempt to reduce exposure time needs to bear in mind other factors, and in particular the effect on image quality.

2.4 Local factors

The best policy to be adopted in selecting beam quality is subject to the following local factors.

1. *Local film contrast* If the existing film contrast is very high it may be inappropriate to select beam qualities that further increase the contrast. Table 1 shows the typical film gradients and relative contrast found with current types of mammographic film.
2. *Dose for the existing system at 28 kV Mo/Mo* For example, if a system already has relatively high doses there may need to be more emphasis on reducing dose.
3. *Current exposure times and back-up timer setting* If an x-ray set has a relatively low output, resulting in long exposure times, it may be necessary choose a beam quality that shortens exposure times for large breasts. However, the underlying reasons for this should be investigated and if possible corrected (eg by replacing the x-ray tube).

Because local factors can affect the optimal choice of beam quality, guidance is intended to be flexible. A set of relevant questions and answers are provided later in this document to illustrate some of the issues that need to be considered. It is recommended that the local policy for beam quality selection should be decided following consultation with the medical physics service appointed by the screening centre.

Table 1 Average values of film contrast

Film type	Average film gradient (from 1.0 to 2.0 above base and fog)	Relative contrast (compared with Fuji UMMA-HC)
Fuji UMMA-HC	3.9	–
Agfa HDR	4.3	+ 10%
Kodak minR-2000	4.8	+ 23%
Fuji AD-M	5.1	+ 30%

3. STRATEGIES FOR OPTIMISATION

The optimisation procedure suggested here uses the contrast and dose found using a beam quality of 28 kV Mo/Mo as a reference. Depending on local circumstances one may choose to employ a strategy that keeps contrast losses to an absolute minimum or allow some small degree of contrast loss. Table 2 gives a choice of strategies along with suggestions as to when these should be used. Different optimisation strategies are suggested based on the contrast required relative to that obtained if 28 kV Mo/Mo had been used. Alternative contrast outcomes are 0%, < 5%, < 10% and < 15% contrast loss and a 5% contrast increase.

Table 2 When to use different beam quality selection strategies

	Contrast objective (relative to 28 kV Mo/Mo)	**When to use**
Strategy 1	0% contrast loss	Where the current contrast (using 28 kV Mo/Mo) is relatively low
Strategy 2	≤ 5% contrast loss	This strategy is recommended for most situations as it achieves a useful dose saving for very little contrast loss
Strategy 3	≤ 10% contrast loss	This strategy is recommended where clinical staff find that overall contrast tends to be slightly high
Strategy 4	≤ 15% contrast loss	Only recommended for occasional use where there is a specific need to reduce the contrast for a particular type of breast. Routine use of the x-ray factors in strategy 4 will lead to excessive contrast loss and should normally be avoided
Strategy 5	≥ 5% contrast increase	Strategy 5 in Table 3 shows the factors one could use if one wished to increase contrast. This is done by lowering the kV below 28. In this case, the dose and exposure time are increased. Increases in contrast are possible for the thinner breasts by using 25–27 kV Mo/Mo. However, for larger breasts, much lower kV cannot be used because the exposure time becomes excessive. Thus, significant increases in contrast are not available for such breasts

Table 3 shows the x-ray factors, which result in the desired relative contrast with the lowest dose. The dose and contrast are shown for different beam qualities relative to those found using 28 kV Mo/Mo for the same thickness of breast. Factors, which would result in prolonged exposure times (in this case greater than 3 seconds) are avoided. The data shown in Table 3 are based on experimental measurements on a specific x-ray set (Siemens Mammomat 3000) and in practice can be expected to vary slightly from system to system.

The factors that are given in Table 3 assume a typical breast composition and method of dose estimation given by Dance *et al*.[7] Where a breast is more or less dense than is typical for a given thickness the ideal factors would in principle be slightly different. Denser breasts require spectra with slightly higher average energy, and conversely with fatty breasts. In practice, the effects on the ideal beam quality of differences in breast composition are much less than those of thickness, and can generally be ignored. Note that the relative contrasts quoted are calculated for each thickness of breast. There is a gradual reduction in contrast with increasing thickness.

It is recommended that screening centres consult with their local medical physics service to ensure that an exposure strategy is employed, which meets local contrast needs, radiation doses are acceptable, and excessive exposure times are avoided. The best way of doing this depends on the model of x-ray set and the nature of any automatic features it may have. The particular case of the Siemens Mammomat 3000 x-ray set is considered further in Appendix 1. The GE Senographe 800T and DM x-ray sets are considered in Appendix 2.

Table 3 Optimal beam qualities for different contrast optimisation criteria using a Siemens Mammomat 3000

Strategy	Optimisation criteria (relative to 28 kV Mo/Mo)	Breast thickness (cm)	Beam quality (kV target filter)	Relative contrast	Relative dose	Relative exposure time
1	0% contrast loss	2	28 Mo/Mo	100%	100%	100%
		3	24 Mo/Rh	100%	77%	154%
		4	25 Mo/Rh	101%	87%	133%
		5	28 Mo/Mo	100%	100%	100%
		6	28 Mo/Mo	100%	100%	100%
		7	28 Mo/Mo	100%	100%	100%
		8	26 Mo/Rh	100%	79%	108%
		9	28 Mo/Mo	100%	100%	100%
		10	(not available due to limit on exposure time of 3 s)			
2	≤ 5% contrast loss	2	25 Mo/Rh	96%	62%	135%
		3	27 Mo/Rh	95%	67%	102%
		4	27 Mo/Rh	96%	81%	99%
		5	27 Mo/Rh	96%	80%	100%
		6	27 Mo/Rh	96%	79%	100%
		7	28 Mo/Rh	95%	74%	81%
		8	28 Mo/Rh	96%	72%	77%
		9	29 Mo/Rh	95%	68%	67%
		10	30 Mo/Rh	95%	63%	60%
3	≤ 10% contrast loss	2	29 Mo/Rh	90%	49%	86%
		3	29 Mo/Rh	91%	62%	80%
		4	29 Mo/Rh	91%	78%	74%
		5	30 Mo/Rh	90%	75%	65%
		6	30 Mo/Rh	90%	73%	64%
		7	26 W/Rh	91%	59%	97%
		8	27 W/Rh	91%	55%	81%
		9	28 W/Rh	91%	51%	70%
		10	29 W/Rh	91%	47%	60%
4	≤ 15% contrast loss	2	32 Mo/Rh	89%	45%	67%
		3	32 Mo/Rh	89%	58%	62%
		4	24 W/Rh	85%	69%	144%
		5	27 W/Rh	85%	61%	98%
		6	28 W/Rh	85%	57%	84%
		7	29 W/Rh	85%	52%	68%
		8	29 W/Rh	87%	48%	63%
		9	30 W/Rh	87%	44%	54%
		10	31 W/Rh	87%	41%	47%

Table 3 continued

Strategy	Optimisation criteria (relative to 28 kV Mo/Mo)	Breast thickness (cm)	Beam quality (kV target filter)	Relative contrast	Relative dose	Relative exposure time
5	≥ 5% contrast increase	2	24 Mo/Mo	107%	109%	171%
		3	25 Mo/Mo	107%	111%	158%
		4	25 Mo/Mo	108%	116%	166%
		5	26 Mo/Mo	106%	114%	142%
		6	26 Mo/Mo	107%	118%	143%
		7	26 Mo/Mo	107%	121%	152%
		8	26 Mo/Mo	108%	125%	160%
		9–10	(not available due to limit on exposure time of 3s)			

4. QUESTIONS AND ANSWERS ON CHOOSING BEAM QUALITY IN MAMMOGRAPHY

Q: Maintaining existing contrast Our current system using 28 kV Mo/Mo achieves acceptable doses and exposure times and we wish to maintain the existing contrast levels. What beam quality should be selected?

A: For almost all types of breast encountered in screening, the use of a Mo/Mo combination will yield the highest contrast. The use of a higher kV, or a different target material and/or filter material will reduce the dose but at the expense of some loss of contrast. Therefore you will need to continue using 28 kV Mo/Mo or lower to avoid contrast loss.

Q: Fuji AD film We have switched to the new high contrast film/screen system from Fuji (ie Fuji AD-M) and this has increased our film contrast. Although this produces very good films most of the time, occasionally there is excessive contrast and the dense glandular parts of the breast are too 'white'. What can we do about this?

A: The new Fuji AD-M film screen system has about 30% more contrast than the Fuji UM system, so you may encounter excessive contrast for a few women. You should not use a kV lower than about 28 Mo/Mo since this will further increase contrast. In cases of excess contrast, where you wish to repeat a film you can achieve about a 10% contrast reduction by using 30 kV Mo/Mo. If you have a rhodium filter you can achieve larger contrast reductions and substantial dose savings. Thus using 28 kV Mo/Rh will also reduce contrast by about 5–10% but for a greater dose saving than 30 kV Mo/Mo. If you use 30 kV Mo/Rh you will get an 11–14% reduction in contrast at a lower dose.

Q: DMR modes I have a relatively high contrast film/screen combination (eg Kodak MinR2000 or Fuji AD-M) which I use with a DMR. Which automatic mode should I use?

A: The 'contrast' mode on a DMR or 800T is probably better avoided, with these very high contrast films as in most cases you won't need more contrast. So you could use the 'standard' mode, which will have the added benefit of reducing the doses – especially to large breasts. The 'dose' mode will further reduce the contrast. While this is probably not desirable for most breast types it may be useful if you need to repeat a film because of excessive contrast.

Q: Rhodium filter It has been the practice in our centre to use 28 kV Mo/Mo for most women, but to switch to 30 kV Mo/Mo for women with thick breasts on compression. We are getting a new x-ray set with a rhodium filter. How should we use it?

A: Your previous policy had the advantage of reducing doses to large breasts by about 20%, but involved losing about 10% of the contrast. You also had the advantage of shorter exposure times for these large breasts. Now you have a rhodium filter it can achieve slightly bigger dose reductions. Use 26–28 kV Mo/Rh instead of 30 kV Mo/Mo to keep contrast losses to less than 10%, and higher kV (29–32 kV Mo/Rh) where you want to further shorten exposure times and reduce dose, but are prepared to lose more contrast.

Q: Alternative target materials We are getting a new x-ray set that has not only a rhodium filter, but also a choice of target material (tungsten or rhodium). When should we use it?

A: Using a target material other than molybdenum generally involves a substantial loss of contrast, typically 15–25% as compared to 28 kV Mo/Mo. It also results in a large dose saving of about 50%. As a result these alternative target materials should probably only be used sparingly and in exceptional situations. (An example of such an exceptional situation is radiotherapy treated breasts, which can be hard to penetrate.) The Siemens Mammomat 3000 recommends the use of a W/Rh combination for larger breasts (option 4). To avoid a large loss in contrast in these breasts it would be better to use a Mo/Rh combination. Reprogramming is possible if required.

Q: Dense tissues Does the use of more penetrating radiation improve the visualisation of dense glandular tissues?

A: Yes it can do. Although more penetrating radiation generally results in an overall reduction in radiographic contrast, the local contrast in parts of the mammogram may be improved. This happens with tissues such as the pectoral muscle and dense glandular tissue that may be suboptimally displayed at a relatively low optical density (eg < 0.8). By using more penetrating radiation these tissues are displayed at a higher film density where there is more film contrast. In a similar way the tissues that are displayed at relatively high optical densities (> about 3.0), such as the skin line may be better displayed due to a reduction in optical density.

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APPENDIX 1: ADJUSTING THE OPDOSE SYSTEM ON SIEMENS MAMMOMAT 3000 X-RAY SETS

The Siemens Mammomat 3000 systems have an OPDOSE facility, which selects the appropriate factors to use for different types of breast. This system makes the selection solely on compressed breast thickness. Four thickness bands can be defined with different x-ray factors selected for each. However the width of these bands are adjustable by the engineer, and the factors recommended within each band are adjustable by the user. The factory settings are not always ideal and should be reviewed by screening centres in collaboration with their local medical physics service. Table A1.1 shows settings that are typical of those set in the factory. Table A1.2 shows modified settings that are proposed to minimise contrast losses for the larger breasts. These settings also cause a modest contrast increase for thinner breasts. Whether this is desirable should be reviewed in the light of local film contrast and the appearance of clinical films.

Table A1.1 Typical factory settings

Compressed breast thickness range	Typical factory settings	Relative contrast	Relative dose
< 3 cm	26 Mo/Mo	102%	104%
3–4.5 cm	27 Mo/Mo	101%	103%
4.5–6 cm	27 Mo/Rh	95%	75%
> 6 cm	26 W/Rh	87–94%	52–57%

Table A1.2 Modified settings to minimise contrast loss for larger breasts

Compressed breast thickness range	Recommended settings	Relative contrast	Relative dose
< 4 cm	26 Mo/Mo	102%	106%
4–5 cm	27 Mo/Mo	103%	107%
5–9 cm	27 Mo/Rh	94–97%	74–76%
> 9 cm	29 Mo/Rh	94%	67%

APPENDIX 2: ADJUSTING THE AEC SYSTEMS ON GE SENOGRAPHE 800T AND DMR X-RAY SETS

The GE models of x-ray sets use a sophisticated AEC that selects tube voltage, target and filter materials depending on the thickness and attenuation of the breast. There are also three modes of operation; 'standard', 'contrast' and 'dose' modes. The 'contrast' mode adjusts the selections to achieve higher contrast at the expense of a higher dose, while the 'dose' mode does the opposite. The service engineer has a degree of discretion to adjust how the AEC operates on each set. The actual performance can be tested using different thicknesses of Perspex to simulate breasts of different attenuation. In normal circumstances, it is suggested that the x-ray sets be used in 'standard' mode and that the selections shown in Table A2.1 are appropriate for maintaining adequate contrast while keeping doses to a minimum. If the selections are not within the range shown the servicing agent should be asked to make the appropriate adjustments. It is recommended that the other modes are only used in exceptional circumstances.

Note This appendix was added in April 2007 as a supplement to the original guidance published in 2001 and is intended to apply when using film-screen systems. Different guidance applies when using digital mammography systems, including computerised radiography (CR) systems, and this will be published as a separate report later in 2007.

Table A2.1 Recommended settings of tube voltage and target/filter materials when using GE x-ray sets in 'standard' mode

Perspex thickness (cm)	GE 800T	DMR
2 cm	25–27 kV Mo/Mo	As left
4 cm	26–28 kV Mo/Mo	As left
6 cm	29–30 kV Mo/Rh	As left
7 cm	31–32 kV Mo/Rh	31 kV Rh/Rh