Greater links to image quality should be applied to mean glandular dose diagnostic reference levels

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Purpose

This large study of symptomatic breast units geographically spread over the Republic of Ireland, collected image quality and radiation dose data from 18 mammography units (16 mammography units in the final analysis). The effect of image quality on radiation dose (mean glandular dose; MGD) and vice versa was examined; the MGD diagnostic reference level has been to date proposed only with regard to compression level achieved not image quality required.

Published radiation dose levels or mean glandular doses (MGD) delivered to the breast are expressed in terms of the compression levels applied to the breast (either in centimetres or millimetres) or as mean MGDs for the population which are sometimes qualified as being in the 75th or 95th percentile of the measured population. There are no discoverable published papers which describe in the methodology the image quality assessment or whether the inadequate images were discarded prior to assessment of the mean glandular dose recommendations for that population.

Background:

Over the last 40 years, X-ray imaging of the breast (mammography) has been established as the leading imaging modality for the widespread detection of both palpable and occult breast cancers (Barentz et al., 2006). Newer technologies are being evaluated for widespread use but mammography remains the leading modality being both inexpensive and widely available (Brenner and Parisky, 2007). More than forty years of research has resulted in mammography being studied from virtually all possible perspectives and all in radiology, medicine and surgery are now familiar with the radiological appearances of the "normal" breast.

All X-ray examinations represent a biological risk proportional to the radiation delivered (ICRP, 2007); radiation doses should therefore be kept as low as reasonably achievable, consistent with good image quality (Brennan, McDonnell and O’Leary, 2004). Efforts to reduce the radiation dose should therefore be linked to and limited by image quality and additionally the radiation dose should only be lowered to levels compatible with image quality sufficient for adequate diagnosis (EC, 1996). This is particularly important in breast imaging where breast tissue due to its proliferative nature, is more radiation sensitive than the majority of other tissues in the body therefore radiation dose must be kept to a minimum (Ronckers, Erdmann and Land, 2005).

Breast tissue is largely composed of two tissues and these two tissues are easily differentiated on images due to the fact that they attenuate the X-ray beam differently,
thus it would appear that the breast is simple to image. However, the healthy fibroglandular tissue is extremely difficult to differentiate from the cancerous breast tissue in which it arises on the image, since the cancerous tissue and the fibroglandular tissues attenuate the beam to almost the same degree (Highnam and Brady, 1999). The difference in X-ray attenuation between normal breast tissue (attenuation coefficient: 0.509) and cancerous tissue (attenuation coefficient of an infiltrating ductal carcinoma: 0.529) is very small therefore to facilitate visualisation of a lesion the need for excellent image quality is higher than any other part of the body (Heine & Thomas, 2008; Highnam & Brady, 1999). This differentiation of the closely associated tissue on the image is achieved mainly through breast compression and radiographic technique.

Breast compression is an essential component of radiographic technique both as a patient dose-reducing tool and for increasing the image quality (Lee et al., 2002); the benefits of compression are well documented in the literature (Poulos et al., 2003). The radiographic technique of mammography applied by the radiographer has the greatest influence on the dose received by the glandular tissue of the breast and correct positioning during mammography has been shown to improve breast cancer detection rates (Taplin et al., 2002) through subsequent increase in image quality.

Mammographic image quality is defined as the ease of ability of the observer to discern radiologically significant detail in the mammographic image (ICRU: Report 82, 2009). Across the world, image quality evaluation criteria for mammograms range from purely subjective image evaluation to objective evaluation criteria with similarities in individual sections of these; syntax, grammar and colloquial phrasing are apparent to make these criteria more acceptable and usable by the local populations. The two methods most used worldwide in numerous screening programmes are the Quality Assurance Guidelines for Radiographers: Report no 30 (NHSBSP, 2000, p11-15), more popularly known as the PGMI image criteria/ categorisation (Lee et al., 2002; Li et al., 2010) and the European Guidelines on quality for diagnostic radiographic images (CEC, 1996). The perfect image will meet all criteria within the guidelines; the good will have some minor errors in a minimum of the criteria; the moderate will still be acceptable for diagnostic purposes but will have further errors while the inadequate image must be repeated since it is not deemed fit for diagnostic purposes.

Published radiation dose levels or mean glandular doses (MGD) delivered to the breast are expressed in terms of the compression levels applied to the breast (either in centimetres or millimetres) or as mean MGDs for the population which are sometimes qualified as being in the 75th or 95th percentile of the measured population. Since there are no published papers which describe in the methodology the image quality assessment or whether the inadequate images are discarded prior to assessment of the mean glandular dose for the population; this research examined the effect of image quality on the mean glandular doses and vice versa.
Methods and Materials

This large quantitative and qualitative prospective patient study of symptomatic breast units geographically spread over the Republic of Ireland, collected image quality, compression and radiation dose data from 16 mammography units resulting in 4790 patient images.

- Data was collected from a minimum of 60 consecutive patients in each unit and all patient images were in digital format (film-screen images were digitised at recommended levels).
- Quality assurance parameters for equipment were checked and examined to ensure all mammographic equipment was functioning at stated European levels.
- Radiation dose (mean glandular dose; MGD) was collected from DICOM header information on digital images and were calculated for film-screen (analogue) breast images.
- The images were assessed for the visualisation of breast tissues and clarity of anatomical information against the PGMI categories (NHSBSP, 2000) and the CEC anatomical image quality criteria (CEC, 1996). Image analysis was undertaken to ensure that the MGD recommended was consistent with adequate diagnostic image quality. Kappa analysis of the researcher image categorisations were examined against a panel of experts.
- Additional image and patient criteria were examined to ensure that images were at the highest diagnostic standards, the criteria included:

  1. Pectoral-nipple line analysis
  2. Surface skin rosette visibility
  3. Breast density classification for anatomical noise and detail visualisation
  4. Breast size and volume calculation for lesion conspicuity
  5. Patient body mass index effect on image quality
  6. Effect of First time attendees versus multiple attendees
  7. Effect of breast surgical alteration on image quality.

The quantitative and qualitative data were analysed using mathematical modelling and SPSS statistical tests including ANOVA. High image quality was matched to lowest achievable radiation doses; inadequate images were discarded from the dataset for recommendations of MGD.
Results

The image quality in the study, assessed as described in the Method section, showed a 6.2% inadequacy rate which is higher than that recommended by national guidelines (NBSP, 2008) and UK guidelines (NHSBSP, 2000). The inadequate images were however discarded for the final recommendations on mean glandular dose.

**Mean Glandular Dose delivered and Image Quality attained**

The data set was split into digital (FFDM) and film-screen (analogue) images and then further divided into the two projections (craniocaudal and mediolateral oblique) to examine fully the effect of radiation dose delivered to the breast and image quality obtained and vice versa. The relationship between, distribution of and range of mean glandular dose within image quality categorisations of perfect, good, moderate and inadequate is shown in the following boxplots.
**Figure 1:** Box plot showing the relationship between the image quality categorisation and the mean glandular doses delivered to the breast.

![Box plot showing the relationship between image quality categorisation and mean glandular doses](image)

**Figure 2:** Box plot showing the relationship between image quality categorisation and mean glandular doses delivered to the digital breast images.

![Box plot showing the relationship between image quality categorisation and mean glandular doses](image)
**Fig.**: Key to Image Quality: P = perfect, G = good, M = moderate, I = inadequate (NHSBSP, 2000)

**References:** School of Medicine and Medical Science, Diagnostic Imaging, University College Dublin - Dublin/IE

**Figure 3:** Box plot showing the relationship between image quality categorisation and mean glandular doses delivered to the analogue breast images.
**Fig.**: Key to Image Quality: P= perfect, G= good, M= moderate, I= inadequate (NHSBSP, 2000)

**References**: School of Medicine and Medical Science, Diagnostic Imaging, University College Dublin - Dublin/IE

**Figure 4**: Box plot showing the relationship between image quality categorisation and mean glandular doses delivered to the craniocaudal breast images.
Figure 5: Box plot showing the relationship between image quality categorisation and mean glandular doses delivered to the mediolateral oblique breast images.

The widest distribution of doses is consistently seen in the inadequate images for digital and analogue mammography units and for both projections. The median MGD is lower in the perfect images with smaller ranges and the perfect images exhibit the fewest outliers in each of these graphs.

**One-way between subjects analysis of Variance for Mean Glandular Doses**

The one-way between subjects ANOVA was conducted to compare the effect of mean glandular dose delivered to the breast on the image quality. The omnibus test showed that there was at least one (if not more) significantly different group in terms of the mean glandular dose delivered to the breast which affects the image quality ($F(3,3535)=29.453$, $p<0.001$). In the Tukey HSD descriptive table (Table 1) it can be shown that Group 1 (the inadequate images) is significantly different than Group 2 (the moderate images).
where p<0.001 and Group 1 is also significantly different than Group 3 (the good images) and group 4 (the perfect images) where p<0.001. Group 2 (the moderate images) is significantly different than group 1 (p<0.001), group 3 (p=0.030) and group 4 (p<0.001).

Table 1: Tukey HSD descriptive showing the multiple comparisons of the dependent variable mean glandular dose in mGy against the image quality categories.

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<th>(J) PGMICODED</th>
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<td>0.356 - 0.772</td>
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**Fig.** Key: PGMICODED = PGMI recoded numerically, Sig. = significance level. 1= inadequate, 2 = moderate, 3 = Good, 4= perfect *the mean difference is significant at the 0.05 level

**References:** School of Medicine and Medical Science, Diagnostic Imaging, University College Dublin - Dublin/IE

A further examination of the Tukey HSD descriptive in Table 2 shows that the doses required to produce a perfect image is much lower than those required to produce inadequate, moderate and good images. The mean MGD for each of image quality category is shown in this table (this is for the full data set both analogue and digital).

Table 2: Tukey HSD descriptive of how the dependent variable MGD in mGy affects image quality.
Fig.: Key: PGMI recoded numerically: 1 = inadequate, 2 = moderate, 3 = Good, 4 = perfect, Mean = mean MGD delivered to the breast in mGy.

References: School of Medicine and Medical Science, Diagnostic Imaging, University College Dublin - Dublin/IE

The data set was split into analogue and digital images and then further divided into the two projections to examine the ANOVA of the mean glandular dose and the image quality. The MGD consistently showed significant effects with regard to the image quality and in addition that the perfect images consistently required significantly less MGD than the good, moderate and adequate images:

- Digital craniocaudal: F(3,978)=2.841; p=0.037
- Digital mediolateral oblique: F(3,977)=4.896; p=0.002
- Analogue craniocaudal: F(3,785)=7.993; p<0.001
- Analogue mediolateral oblique: F(3,783)=7.961; p<0.001.

Table 3: Tukey HSD descriptive of how the dependent variable MGD in mGy affects image quality.
Fig.: Key: PGMI recoded numerically: 1 = inadequate, 2 = moderate, 3 =Good, 4 = perfect, Mean= mean MGD delivered to the breast in mGy. CC= craniocaudal projection; MLO= Mediolateral projection.

References: School of Medicine and Medical Science, Diagnostic Imaging, University College Dublin - Dublin/IE

A full Tukey HSD descriptive table is shown in Table 3, with the mean MGD in each image quality categorisation divided into digital and analogue images and into the craniocaudal and mediolateral projection. The summary for perfect images with regard to dose is presented below:

The mean MGD in mGy associated with a perfect image in each of the categories:

- Digital craniocaudal : 1.23mGy
- Digital mediolateral oblique: 1.28mGy
- Analogue craniocaudal: 2.10mGy
- Analogue mediolateral oblique: 2.25mGy

Image Quality and compression levels

The diagnostic reference levels for the breast or mean glandular doses (MGDs) are commonly equated to the compression levels achieved on the breast. This is likely due to the method of calculation of MGD using the compression depth in centimetres achieved on the breast. This large study found that the median compression level plotted against the four image quality categories has an almost straight line relationship parallel to the X-axis and each image quality category has very similar ranges which prompted additional statistical analysis. The one-way analysis of variance (ANOVA) showed that
there is no significantly different compression level which will affect the image quality of the mammogram indeed the compression levels in centimetres used to produce an inadequate image were imperceptibly different from those used to produce a perfect image. A search of the literature showed very similar results in other studies (Helvie et al., 1994; Poulos and Rickard, 1997) and most published studies show small standard deviations from the median (Baldelli et al., 2010). Equally Saunders and Samei (2008) hypothesise in a Monte Carlo algorithm that since digital image contrast is far less limited by scatter that radiographers can reduce the compression levels applied to the breast during mammography; the authors contend that given a constant mean glandular dose that the compression levels could be reduced by 12.5% without loss of image quality (although this has not yet been tested clinically since the authors do admit that in addition to a yet-to-be invented automatic exposure control device, that a number of other conditions are also required to retain the image quality such as changes to mammographic technique inter alia).
**Fig. 0:** Key to Image Quality: P = perfect, G = good, M = moderate, I = inadequate (NHSBSP, 2000)

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**Fig. 0:** Key to Image Quality: P= perfect, G= good, M= moderate, I= inadequate (NHSBSP, 2000)

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CC = craniocaudal projection; MLO = Mediolateral projection.

Fig. 0: Key: PGMI recoded numerically: 1 = inadequate, 2 = moderate, 3 = Good, 4 = perfect, Mean = mean MGD delivered to the breast in mGy.

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MLO

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<td>86</td>
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<td>1.7823</td>
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<td>2.421</td>
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<td>Total</td>
<td>787</td>
<td>2.784</td>
<td>1.4899</td>
<td>0.0531</td>
<td>2.680</td>
<td>2.889</td>
<td>0.6</td>
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Fig. 0: Key: PGMI recoded numerically: 1 = inadequate, 2 = moderate, 3 = Good, 4 = perfect, Mean = mean MGD delivered to the breast in mGy. CC = craniocaudal projection; MLO = Mediolateral projection.

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Conclusion

The balance of the best possible image quality for diagnosis and lowest possible patient radiation dose is termed diagnostic optimisation and this has become the cornerstone of all International Commission on Radiological Protection documents (ICRP, 1996), European guidelines (EC, 1996; EC, 2001) and legislation (EU directive 97/43/Euratom) and national guidelines (HIQA, 2006; NBSP, 2008) and legislation (SI478 of 2002; SI125 of 2000). The optimisation of any examination will examine all of the possible influencing factors that simultaneously affect both the radiation dose and the image quality; the achievable MGD for all populations should thus be described simultaneously with the image quality attained in the calculation of that MGD. Additionally the inadequate images in the data set used for the calculation of the MGD should be discarded prior to the calculation and recommendation of that diagnostic reference level.

The influence of the highest image quality on the attainment of the lowest possible radiation dose has been shown in this research and thus greater consideration must be given to ensuring that virtually all mammogram images achieve the “perfect” appellation. Greater standardisation of training of radiographers performing mammography is required to aid in the achievement of high quality and standardised mammographic projections and to thus ensure that the MGDs delivered to the breasts of Irish women attending the symptomatic breast services are at their lowest levels. Additionally, MGD diagnostic reference levels should be linked to image quality standards/levels achieved when described in academic and research publications.


ICRP (2007). Recommendations of the International Commission on Radiological Protection *ICRP Publication 103; Ann. ICRP* 37 (2-4)


Personal Information

This research study was undertaken in fulfilment of a PhD by research on the part of Desiree O'Leary. The information presented here forms a third of the whole study; other parts are presented in other posters and oral presentations. The research examined mean glandular dose, image quality, compression force and compression depth in Irish Symptomatic Breast centres.

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