Optimisation of compression, image quality and radiation dose in mammography in Ireland

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Purpose

The study objective was to find achievable, objective and standardised compression depths (in centimetres) to assist radiographers to achieve the lowest possible radiation dose with highest diagnostic image quality in mammography within the symptomatic breast service in Ireland. The establishment of the mean glandular dose diagnostic reference levels was additionally required for the symptomatic breast service in the Republic of Ireland.

Background: The Department of Health and Children in Ireland aims to develop a system that is based on equity, quality and accountability; the aspiration is a Health Service that gives best possible quality of service to all end-users (NCF, 2006). This can only be facilitated by research into what constitutes the "best possible quality" across all sectors. X-ray examinations are a fundamental component of the healthcare that patients receive and contribute significantly to diagnosis, treatment and long-term clinical management (HIQA, 2006) and as such all X-ray examination must be optimised for ultimate patient care.

Modern breast imaging techniques encompass a whole range of imaging modalities both non-ionising (ultrasound, MRI, thermal imaging) and ionising (Computed Tomography, X-ray imaging, radionuclide imaging) (Lee et al., 2002; Brenner and Parisky, 2007). The most easily accessed and widely available imaging modality remains X-ray mammography (Barentz et al., 2006) and it is this type of imaging that is undergone by approximately 1.5 billion women per annum worldwide (IARC, 2009) and by over 118,000 women per annum in Ireland (NBSP, 2009).

Since this is an ionising radiation modality and as such contributes to radiation dose and thus to the risk of induced cancer (ICRP, 2007); multiple contributory, negating, exacerbating and improving factors were studied in this examination of radiation dose to gain understanding of the complex interaction required to deliver the lowest achievable radiation dose to the female breast. Efforts to reduce the radiation dose should be linked to and limited by image quality; 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).

The monitoring of patient dose delivered to those undergoing mammography is vital and baseline levels of what constitutes maximum deliverable dose or diagnostic reference levels (DRL) need to be established that are population specific; where dose guidelines
are consistently exceeded by a mammographic unit, imaging should be suspended (EUREF, 2006). The numerical value of dose delivered or diagnostic reference level for breast imaging is the Mean Glandular Dose (MGD); these MGDs for symptomatic mammography have not yet been established for Ireland. The diagnostic reference levels (MGDs) need to be matched to those European depths already measured and published.

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). Effective compression reduces the thickness or depth of tissue being irradiated thus minimising the amount of radiation required and maximises radiographic contrast, improving the safety and diagnostic efficacy of this common X-ray examination with no additional financial cost (Poulos et al., 2003). Tissue compression is crucial to optimising mammograms of the female breast; correct compression enhances diagnostic efficacy and radiation dose is reduced by a factor of 2 over the whole range of patient ages (Lee et al., 2002; Poulos et al., 2003).

The main aim of this work was to establish optimum compression values specific to a range of breast compositions, facilitating practice optimised for each type of presenting breast density. The main question posed by the work was thus: Is there an achievable, standardised and recommended breast tissue specific compression depth for the range of breast tissue compositions in the Irish setting which will aid mammographers (regardless of experience level) to achieve the lowest possible radiation dose with the highest possible diagnostic imaging quality?

It should be acknowledged that many other technical/procedural factors affect both dose and image quality; optimum levels for these have been specified for mammography in numerous European and National documents and all components were compared to these guideline documents within this study; namely the investigation of optimisation of mammographic examinations in the Republic of Ireland.
Methods and Materials

This large quantitative and qualitative prospective 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 depths.
- Compression depths in centimetres were examined, assessed and compared to other published studies.
- Compression forces in Newton were examined, assessed and compared to other published studies.
- 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.
- Additional image and patient criteria were examined to ensure that images were at the highest diagnostic standards, the criteria included:
  1. Surface skin rosette visibility assessment.
  2. Breast density classification for anatomical noise and detail visualisation.
  4. Patient body mass index effect on image quality and compression.
  5. Effect of First time attendees versus multiple attendees on image quality and compression achieved.
  6. Effect of breast surgical alteration on image quality and compression force achievable.
- Radiation dose (MGD) was collected from DICOM header information on digital images and were calculated for film-screen (analogue) breast images.
- Qualitative data on the patient experience and demographic data regarding hormonal status, disease status and patient parity were also obtained.
- 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.
The analysis process was guided by the Health Research Board (Ireland) Centre for Support and Training in Analysis and Research (CSTAR); conclusions were drawn from the mathematical modelling of the original data with Univariate Analysis of Variance:

- All 63 variables were not required for analysis of each dependent variable namely compression, image quality and MGD.
- All patient data sets where full data were not available for all variables were discarded in order to gain the most complete picture from the data.
- The full data set was divided into two data sets namely Full field digital mammography (FFDM/ digital) data and Film/Screen mammography (FSM/ analogue) data. The FFDM/ FSM data sets were further split into craniocaudal (CC) images and mediolateral oblique (MLO) images for dose analysis and compression depth/ force analysis.
- The data sets were also split as required into perfect (P), good (G), moderate (M) and inadequate (I) images.
- The outliers in the variables radiation dose and compression were removed for the most part by removing the inadequate images from the full data sets.
Results

The *demographics* of the Irish mammography study population were comparable to other published literature and not so unique that the results could only be locally applied. Specific recommendations for the Irish population can be made due to the patient characteristics and geographical data spread (Altman and Bland, 1998; EC, 1996; EUREF, 2006; Faulkner et al., 2008).

*Images* were categorised as perfect (P), good (G), moderate (M) and inadequate (I) by the researcher and Kappa analysis of these categorisations was undertaken between the researcher and a panel of experts which showed moderate to good agreement over a range of image assessment areas. A tabulation of the percentages of images in each of these categorisations is shown in Table 1. The images have been divided into FFDM images (craniocaudal and mediolateral oblique images) and FSM images (craniocaudal images and mediolateral oblique images), all images in the study both FFDM and FSM are shown in the first column.

Table 1: Table showing the categorisation of images as PGMI in percentages.

<table>
<thead>
<tr>
<th>Image category</th>
<th>quality</th>
<th>FFDM &amp; FSM</th>
<th>FFDM MLO</th>
<th>FSM MLO</th>
<th>FFDM CC</th>
<th>FSM CC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>All views</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td></td>
<td>13.4%</td>
<td>16.3%</td>
<td>10.9%</td>
<td>13.1%</td>
<td>12.4%</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td>55.8%</td>
<td>58.7%</td>
<td>51.6%</td>
<td>54.5%</td>
<td>57.8%</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td>24.7%</td>
<td>19.2%</td>
<td>27.7%</td>
<td>28.4%</td>
<td>24.0%</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>6.2%</td>
<td>5.8%</td>
<td>9.8%</td>
<td>4.0%</td>
<td>5.8%</td>
</tr>
<tr>
<td>P &amp; G</td>
<td></td>
<td>69.2%</td>
<td>75%</td>
<td>62.5%</td>
<td>67.6%</td>
<td>70.2%</td>
</tr>
<tr>
<td>P,G &amp; M</td>
<td></td>
<td>87.6%</td>
<td>94.2%</td>
<td>90.2%</td>
<td>96%</td>
<td>94.2%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>n=3539</td>
<td>n=981</td>
<td>n=787</td>
<td>n=982</td>
<td>n=789</td>
</tr>
</tbody>
</table>

Key: FSM = Film screen mammography, FFDM = full field digital mammography.

*CC* = craniocaudal images, *MLO* = mediolateral oblique images.

The NHSBSP (2000), EUREF (2006) and the national quality assurance guidelines for mammography (NBSP, 2008) provide the minimum overall standards that image quality should reach in order to maximise diagnostic quality and minimise patient dissatisfaction.
with the screening service. The standards required are 75% of images in the perfect (P) and good (G) categories, 97% of images in the perfect (P), good (G) and moderate (M) categories and only 3% of images in the inadequate category. Table 1 shows that 13.4% of the images overall achieved a "perfect" categorisation and 6.2% of images were inadequate (I) according to the PGMI criteria. The results table also shows that the digital mediolateral oblique images are the only group to reach 75% in the P&G categorisation and that the lowest inadequate category percentage is in the analogue craniocaudal images. The quality standards are thus not being reached by the images in the study.

**Quality assurance** testing with regard to breast compression depths achievable and compression force applied was performed by the researcher on all mammography units and these were performing within the European limits and guidelines.

The mean **compression depth** achieved in this study was 53.65±14mm with a mode of 55mm which is comparable to the Hendrick et al., (2010) DMIST data of 54mm compression depth; the study in the Irish asymptomatic breast service by Baldelli et al., (2010) found a mean compression depth of 61.4±0.53mm. The focus on achievable optimal compression depths has been the centre of many publications which have postulated that not only are the compression depths crucial to radiation dose reduction and key to good image quality (IPSM, 1994, EC, 1996, Poulos et al.,2003; Li et al., 2010) but that the inconsistency of compression depths achieved on the breast in the clinical setting may be detrimental to both these entities (NHSBSP, 2000; ACR, 2007; NBSP, 2008; Li et al., 2010).

The initial research proposal over-simplified somewhat the creation of the look-up table for radiographers with regard to suggested optimum compression depths that should be objectively achieved on the breast. It was proposed that the 95th percentile of compression depth in centimetres for each bra size is computed and then tabulated; however despite the large national study the data were not sufficiently complete at each bra size to make such recommendations. Mathematical modelling of the data were then undertaken to create 4 equations for the calculation of this objective and optimal compression depth: for example the equation for film-screen (FSM) craniocaudal images (CC): Dose = #2 + #1 (bra size) + #2 (compression depth) +#3 (mAs)+ #4 (compression force) was proposed. There are however 7 possible statistical descriptors for each variable in the equation namely: mean, median, mode, minimum, maximum, 75th percentile and 95th percentile. A computational programme using a look-up table for the input variables with the seven descriptors was thus created for each of the 4 equations. The values obtained for compression depths were inconsistent which indicated that there were other variables that were not explicit that affect the achievable compression depths. Further analysis of the data were undertaken to investigate compression depths achievable on the breasts of Irish women. The starting point for this re-analysis was
the re-examination of image quality against each of the variables compression depth, compression force and mean glandular dose.

**Fig.**: Box plot showing the relationship between the image quality categorisation and the compression depths achieved on the breast.

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

**Figure 1:** Box plot showing the relationship between the image quality categorisation and the compression depths achieved on the breast.

The boxplot of image quality and compression depth in centimetres is shown in Figure 1; close examination of this shows that the median for the compression depth plots in all four image quality categories has an almost straight line relationship parallel to the X-axis and with very similar ranges which prompted additional statistical analysis. One-way analysis of variance (ANOVA) which is used to test for differences in more than two normally distributed independent groups was selected as a suitable test to explore whether any image quality category showed statistical differences with regard to
compression depth (Field, 2005). Both the omnibus test and the Tukey HSD showed that there is no significantly different compression depth which will affect the image quality of the mammogram indeed the compression depths in centimetres used to produce an inadequate image were imperceptibly different from those used to produce a perfect image.

The mean **compression force** in the study was 111Newton (N) with a large standard deviation of 35N; the mean compression for digital mammography was 105N while for analogue the mean was much higher at 120N. The compression force for craniocaudal images (107N) was lower than the mediolateral oblique images (116N); Lee et al., (2002) suggest the same upper range of 140N for both projections but the lower range of craniocaudal images is lower at 70N vs. 100N for the MLO. Baldelli et al., (2010) record a mean of 109N (no standard deviation given) for the Irish screening digital mammograms while Hendrick et al., (2010) record mean analogue compression forces of 107N and mean digital compression forces of 101N (again no standard deviation given). Figure 2 shows the actual mean compression depth in each unit in the study.
**Figure 2:** Bar Graph showing the mean compression forces achieved in the 16 mammography units (data labels showing mean force in Newton)

The relationship between image quality and compression force is examined in the boxplot Figure 3; where in contrast to Figure 1, the median compression force is higher for the perfect images than that in the inadequate images.

**Figure 3:** Box plot showing the relationship between the image quality categorisation and the compression forces applied to the breast.

**References:** School of Medicine and Medical Science, Diagnostic Imaging, University College Dublin - Dublin/IE
Additionally, the omnibus test for the ANOVA of the image quality and compression force showed that there was at least one significantly different image quality group in terms of the compression force applied and the Tukey HSD descriptors showed that the mean compression force that is required to achieve a perfect image is significantly higher than the compression force used to achieve a moderate or inadequate image.

The mean compression force in Newton thus required to produce a perfect image in each projection is:

- Digital craniocaudal: 121.34N
- Digital mediolateral oblique: 134.23N
- Analogue craniocaudal: 112.23N
- Analogue mediolateral oblique: 129.66N
- Sample mean: 122.97N

Figure 4 graphically shows the wide difference in mean glandular doses obtained in the mammographic departments within Ireland. The MGDs from the full field digital mammography (FFDM) units clearly (and as expected from the literature) are much lower than those obtained in the film screen mammography (FSM) units. The distribution and range of mean glandular doses in FFDM are much narrower with minimal outliers and are distributed equally about the median MGD. The FSM mean glandular doses in addition to being higher than those of FFDM are skewed around the median and have wider ranges.
An examination of the image quality and mean glandular doses obtained in the study showed that the widest distribution of radiation doses is consistently seen in the inadequate images for digital and analogue mammography units and for both projections. The ANOVA and Tukey HSD descriptor for image quality and MGD illustrated clearly that 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. The inadequate images were removed from the data set in the final mean glandular dose recommendation made below in Table 2.

Table 2: Final Mean Glandular Dose Recommendations
<table>
<thead>
<tr>
<th></th>
<th>FFDM units all projections</th>
<th>FFDM units: Craniocaudal projection</th>
<th>FFDM units: mediolateral projection</th>
<th>FSM units all projections</th>
<th>FSM units: Craniocaudal projection</th>
<th>FSM units: mediolateral projection</th>
<th>FFDM /FSM units all projections</th>
<th>FFDM units all projections</th>
<th>4.5cm breast compression</th>
<th>4.5cm breast compression</th>
<th>FSM units all projections</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean MGD: 1.33mGy</td>
<td>Mean MGD: 1.28mGy</td>
<td>Mean MGD: 1.37mGy</td>
<td>Mean MGD: 2.64mGy</td>
<td>Mean MGD: 2.49mGy</td>
<td>Mean MGD: 2.78mGy</td>
<td>Mean MGD: 1.68mGy</td>
<td>Mean MGD: 1.13mGy</td>
<td>Mean MGD: 1.2mGy</td>
<td>Mean MGD: 1.2mGy</td>
<td>Mean MGD: 1.5mGy</td>
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<tr>
<td></td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 1.5mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 1.45mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 1.56mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 3.17mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 2.99mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 3.38mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 1.2mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 1.2mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 1.5mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 1.5mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 1.5mGy</td>
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<tr>
<td></td>
<td>FFDM /FSM units all projections</td>
<td>FFDM units all projections</td>
<td>FSM units all projections</td>
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<tr>
<td><strong>5.5-6.5cm breast compression</strong></td>
<td>Mean MGD: 2.04mGy</td>
<td>Mean MGD: 1.40mGy</td>
<td>Mean MGD: 2.88mGy</td>
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<tr>
<td></td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 2.47mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 1.5mGy</td>
<td>75&lt;sup&gt;th&lt;/sup&gt; Percentile: 3.41mGy</td>
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<tr>
<td></td>
<td>95&lt;sup&gt;th&lt;/sup&gt; Percentile: 4.33mGy</td>
<td>95&lt;sup&gt;th&lt;/sup&gt; Percentile: 2.4mGy</td>
<td>95&lt;sup&gt;th&lt;/sup&gt; Percentile: 5.84mGy</td>
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</tbody>
</table>
Fig. 0: Box plot showing the relationship between the image quality categorisation and the compression depths achieved on the breast.

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**Fig. 0:** Key: Blue bar = FFDM digital mammography unit; green = FSM analogue mammography unit

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**Fig. 0:** Box plot showing the relationship between the image quality categorisation and the compression forces applied to the breast.

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Fig. 0: Key: Blue bars = FFDM digital mammography units, green bars = FSM analogue mammography units

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Conclusion

Objective optimal compression depths could not be proposed due to higher than expected inadequate image quality rates (6.2%) and inconsistent compression forces; other factors may also impact on the compression depths attained which could not be teased out by mathematical modelling of the current data set. However compression forces are low affecting image quality; a significant finding is that greater compression force by 11-15N is needed to achieve perfect images. MGDs received by perfect images are significantly lower than inadequate images.

Greater training of radiographers performing mammography is required to aid in the standardisation of mammographic projections with regard to achievable compression depth, application of compression force and MGDs delivered to the breasts of Irish women attending symptomatic breast services. The Health Information Quality Authority which regulates the symptomatic breast services in Ireland (HIQA, 2006) requirements for radiologist training and review of performance are extremely specific; this is not so for radiographers undertaking mammographic imaging beyond suggesting that a postgraduate certificate in mammography is recommended. More explicit guidelines regarding radiographer training and bi-annual individual mammographer technique/image quality review is recommended for implementation and enforcement in the symptomatic units in line with that seen in national and international screening programmes.

MGD is proposed at the 95th percentile for 55-65mm breast compression for full field digital mammography units at 2.4mGy and for film-screen units at the mean MGD in line with other European publications as 2.64mGy.
References


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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