Compression force recommendations in mammography must be linked to image quality

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Authors: D. O'Leary, A. Teape, J. Hammond, L. Rainford, T. Grant; Dublin/IE
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Purpose

A number of past and more recent publications have suggested that the compression force applied to the breast must be reduced to encourage attendance at screening mammography. These studies (many with limited patient populations) have not used complex mathematical modelling nor used sufficient statistical correlation of compression force data to image quality to reinforce these contentions. Further qualitative evidence on compression force tolerance is also presented.

Background:

The following benefits of compression are well documented in the literature:

- Patient radiation dose is lowered through increase in penetration of the X-ray photons through the thinner compressed tissue.
- The image unsharpness is also decreased through the effective flattening out of the essentially ball-shaped breast structure and the creation of a flat structure uniform in thickness.
- Breast architecture is compressed over a larger area with consequent easier interpretation of images as structures are not overlapped, which in turn allows the subtle differences between healthy and cancerous tissues to be discerned.
- Unsharpness, both from patient movement and the equipment used to image the breast is also reduced by compression and primary contrast is raised due to the reduction of scatter and the improvement of the ratio of penetrating radiation to non-penetrating radiation reaching the image receptor.

(IPSM, 1994; EC, 1996; Jacobson, 1998; Lee et al., 2002; Poulos et al., 2003)

Compression of the breast is dependent on the compressibility of the breast (breast density), the radiographic technique and various patient-reliant factors. The compression of the breast in turn affects the radiation dose and reductions in radiation dose and compression (both compression level and compression force) must be limited by image quality.

Since compression of the breast has received multiple negative connotations from patients undergoing mammography, alternative strategies to combat the negativity have been introduced, many of which involve reduction of the compression force applied to the breast. Some units are thus fitted with compression force limiters set at arbitrarily decided departmental levels; other limiters are set at the current recommendations of the Mammography Quality Standards Act (ACR, 1999) between 110 Newton and 200 Newton
(N) while Lee et al., (2002) recommend a limit of 160N then caution that this amount of force is not necessary. Recommendations have been made in some national breast screening guidelines (based on a local survey by Lovegrove, 1992) that the compression force limiter is set at 140N since the range of force needed to compress the CC is 70-140N and the MLO is 100-140N (Lee et al., 2002).

It is essential therefore that the actual force required to compress the breast to an adequate compression depth for radiation dose reduction is examined together with image quality before limits on compression force are decided.

**Methods and Materials**

This large quantitative and qualitative study of symptomatic breast units geographically spread over the Republic of Ireland, collected image quality, compression (depths and forces) and radiation dose data from 18 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.
- Image analysis was undertaken using perfect, good, moderate and inadequate categorisation (PGMI; NHSBSP, 2000) and European guidelines on quality criteria for diagnostic radiographs (breast) (CEC, 1996).
- Additionally compression and radiation dose (MGD) analysis was undertaken.
- Initial mathematical modelling of data was undertaken which divided by the data by Unit, modality, patient position, image quality, breast volumes and radiation doses.
- The data was then analysed using Univariate Analysis of Variance mathematical modelling and SPSS statistical tests including ANOVA.

**Results**

*Compression forces applied and Image Quality attained:* The relationship between image quality and compression force is examined in the boxplots below.
Fig.: Key: Image quality described as: P= Perfect, G= good, M= Moderate, I = inadequate. (NHSBSP, 2000) CC= craniocaudal images and MLO = mediolateral oblique images

References: D. O'Leary; School of Medicine and Medical Science, Diagnostic Imaging, University College Dublin, Dublin, IRELAND

Figure 1: Box plot showing the relationship between the image quality categorisation and the compression forces applied to the breast.
Fig.: Key: Image quality described as: P= Perfect, G= good, M= Moderate, I = inadequate. (NHSBSP, 2000) CC = craniocaudal images and MLO = mediolateral oblique images

References: D. O'Leary; School of Medicine and Medical Science, Diagnostic Imaging, University College Dublin, Dublin, IRELAND

Figure 2: Box plot showing the relationship between the image quality categorisation and the compression force applied on the craniocaudal breast projections.
Fig.: Key: Image quality described as: P= Perfect, G= good, M= Moderate, I = inadequate. (NHSBSP, 2000) CC= craniocaudal images and MLO = mediolateral oblique images

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Figure 3: Box plot showing the relationship between the image quality categorisation and the compression force applied on the mediolateral breast projections.

One-way between subjects analysis of Variance for compression forces

The one-way between subjects ANOVA was conducted to compare the effect of compression force applied to the breast on the image quality. The omnibus test shows that there was at least one (if not more) significantly different group in terms of the compression force applied to the breast which would affect the image quality: (F(3,3501)=21.823; 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 3 (the good images) where \( p=0.007 \) and Group 1 is also significantly different than Group 4 (the perfect images). Group 2 (the moderate images) is significantly different than group 3 (\( p<0.001 \)) and is also significantly different than Group 4 (\( p<0.001 \)).

**Table 1:** Tukey HSD showing the multiple comparisons of the dependent variable compression force in Newton against the image quality categories.

<table>
<thead>
<tr>
<th>Group</th>
<th>Difference</th>
<th>Std. Error</th>
<th>Sig.</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-10.99</td>
<td>2.523</td>
<td>.005</td>
<td>-15.48</td>
<td>-6.41</td>
</tr>
<tr>
<td>2</td>
<td>-9.190</td>
<td>1.427</td>
<td>.000</td>
<td>-12.86</td>
<td>-5.52</td>
</tr>
<tr>
<td>3</td>
<td>-13.673</td>
<td>2.005</td>
<td>.000</td>
<td>-18.83</td>
<td>-8.52</td>
</tr>
<tr>
<td>4</td>
<td>-4.483</td>
<td>1.795</td>
<td>.000</td>
<td>-9.10</td>
<td>-0.86</td>
</tr>
</tbody>
</table>

Fig.: Key: PGMICODED = PGMI recoded numerically where 1= inadequate, 2 = moderate, 3 = Good, 4= perfect (NHSBSP, 2000) *the mean difference is significant at the 0.05 level Sig. = significance level.

References: D. O’Leary; School of Medicine and Medical Science, Diagnostic Imaging, University College Dublin, Dublin, IRELAND

The mean compression forces for the category of image quality are shown in this table.

**Table 2:** Tukey HSD descriptive of how the dependent variable compression force in Newton affects image quality.
Fig.: Key: PGMICODED = PGMI recoded numerically where 1 = inadequate, 2 = moderate, 3 = Good, 4 = perfect (NHSBSP, 2000) Mean = mean forces in Newton applied to the breast.

References: D. O'Leary; School of Medicine and Medical Science, Diagnostic Imaging, University College Dublin, Dublin, IRELAND

The data set was split into digital (FFDM) and film-screen (analogue) images and then further divided into the two projections to examine the ANOVA of the compression force and the image quality. The compression force consistently showed significant effects on the image quality and in addition that the perfect and good images consistently required significantly more compression force than the moderate and adequate images:

Digital craniocaudal: $F(3,978)=10.709; p<0.001$

Digital mediolateral oblique: $F(3,977)=6.523; p<0.001$

Analogue craniocaudal: $F(3,767)=3.496; p=0.015$

Analogue mediolateral oblique: $F(3,767)=12.043; p<0.001.$

The mean compression force in Newton required to produce a perfect image in each of the categories:

Digital craniocaudal: 121.34N

Digital mediolateral oblique: 134.23N

Analogue craniocaudal: 112.23N

Analogue mediolateral oblique: 129.66N

Sample mean: 122.97N

Compression tolerance by patients
Radiographers were asked to give their opinion on the level of patient tolerance of the compression applied to the breast during the examination expressed as good, fair or poor. The patients expressed an opinion of their tolerance to the examination and any comments made by the patient for individual projections or for the examination as a whole were noted on the Data Acquisition Sheet.

Table 3: Patient opinion on tolerance of compression during examination.

<table>
<thead>
<tr>
<th>Patient Opinion on Patient toleration</th>
<th>FFDM &amp; FSM All views</th>
<th>FFDM All views</th>
<th>FSM All views</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOOD</td>
<td>73.7%</td>
<td>70.9%</td>
<td>77.6%</td>
</tr>
<tr>
<td>FAIR</td>
<td>23.2%</td>
<td>25.9%</td>
<td>19.8%</td>
</tr>
<tr>
<td>POOR</td>
<td>3.1%</td>
<td>3.6%</td>
<td>2.5%</td>
</tr>
</tbody>
</table>

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

All views means CC= craniocaudal images and MLO = mediolateral oblique images

Table 4: Radiographer opinion on patient tolerance of compression during examination.

<table>
<thead>
<tr>
<th>Radiographer Opinion on patient toleration</th>
<th>FFDM &amp; FSM All views</th>
<th>FFDM All views</th>
<th>FSM All views</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOOD</td>
<td>79.9%</td>
<td>77.0%</td>
<td>83.5%</td>
</tr>
<tr>
<td>FAIR</td>
<td>16.2%</td>
<td>17.7%</td>
<td>14.2%</td>
</tr>
<tr>
<td>POOR</td>
<td>4.0%</td>
<td>5.3%</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

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

All views means CC= craniocaudal images and MLO = mediolateral oblique images

A tick-box set of comments were provided for convenience for the radiographer to complete which ranged from a severe reaction to the compression placed on the breast (patient faints) to the least severe (no comment or expresses surprise at the lack of discomfort/ pain). Most patients did not complain about the compression force or pressure on the breast; most complained about the sharp edges of the compression...
paddle, the image receptor and the loss of control due to the stance in mediolateral oblique projection. Further comments made by the radiographer concerned the shoulder pain and back pain experienced by the patient either from a pre-existing condition or induced by the positioning during the examination. Those patients who had previously had mammograms equated the new mammogram experience to previous mammogram experiences; either expressing that this was a poorer experience or a better experience.

Table 5: Patient comments noted by radiographer during examination

<table>
<thead>
<tr>
<th>Comments recorded by the radiographer on patient comments during the examination</th>
<th>FFDM &amp; FSM</th>
<th>FFDM MLO &amp; CC</th>
<th>FSM MLO &amp; CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>All views</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXPRESSES</td>
<td>9.5%</td>
<td>10.4%</td>
<td>8.3%</td>
</tr>
<tr>
<td>FAINTS</td>
<td>0.1%</td>
<td>0.2%</td>
<td>0%</td>
</tr>
<tr>
<td>ALL</td>
<td>2.0%</td>
<td>2.8%</td>
<td>1.0%</td>
</tr>
<tr>
<td>CRIES</td>
<td>5.0%</td>
<td>4.8%</td>
<td>5.3%</td>
</tr>
<tr>
<td>FACIAL</td>
<td>14.7%</td>
<td>18.5%</td>
<td>10.2%</td>
</tr>
<tr>
<td>FACIAL/CRIES</td>
<td>3.2%</td>
<td>3.6%</td>
<td>2.8%</td>
</tr>
<tr>
<td>RUBS</td>
<td>5.4%</td>
<td>5.1%</td>
<td>5.8%</td>
</tr>
<tr>
<td>RUBS/CRIES</td>
<td>0.7%</td>
<td>1.0%</td>
<td>0.3%</td>
</tr>
<tr>
<td>RUBS/FACIAL</td>
<td>3.3%</td>
<td>3.9%</td>
<td>2.5%</td>
</tr>
<tr>
<td>NONE</td>
<td>56.0%</td>
<td>49.7%</td>
<td>63.8%</td>
</tr>
</tbody>
</table>

Key: Expresses= expresses surprise at lack of discomfort/pain

Faints = patient faints

All = patient cries out, grimaces with pain, rubs her breasts.

Cries= patient cries out on compression of the breast

Facial= patient grimaces with discomfort/pain during compression

Rubs= patient rubs her breasts following compression to relieve discomfort

None= no comment made either physical or verbal on the compression
Discussion of results: The mean compression force in the study was 111 Newton (N) (standard deviation 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) 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 (no standard deviation given).

On examination of the Tukey HSD descriptors it becomes apparent 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 needed is 122 Newton for high image quality which is 15N higher than the digital mean compression force. This is a significant finding but it does appear to be contrary to the plethora of literature on pain/discomfort experienced in mammography with more recent publications advocating a drop of 30N from 120N to 90N (Chida et al., 2009) with subsequent 3mm change in compression depth. Poulos et al., (2003) and Poulos and McLean (2004) which is quoted in a large number of further publications on compression force and pain in mammography publications do not actually advise on the amount of compression reduction only that compression is applied until no further reduction in compression thickness is seen.

Correlation of patient experience and compression force

It would be unwise to recommend that the compression forces are increased to these levels without reviewing the qualitative data gained in this study; especially patient and radiographer opinion on tolerance and comments made during the mammograms. Almost 74% of patients felt that their tolerance of the mammogram was good while the radiographers expressed their opinion that 80% of patients demonstrated good tolerance of the compression forces. In light of the fact that the mean compression force in the study is approximately 11N below the mean recommendation level of 122N, one may extrapolate that this is due to the lowered compression forces however the mean compression force in the analogue mammograms was 120N and the patient tolerance of compression and radiographer opinion on tolerance are both higher for analogue than for digital. Additionally, a closer examination of patients who achieved perfect and good images within the study (FFDM and FSM) shows that 68% of these patients had
no comment to make on discomfort or pain experienced during the mammogram and 72.2% of patients undergoing FSM made no comment or expressed surprise at the lack of pain in the examination. The amount of reported pain and discomfort felt by patients during mammography in the publications is out of proportion to the current understanding of breast innervation since the breast is thought to be poorly supplied with nerves (Love, 2005; Hale and Hartmann, 2007) except in areola region which remains largely uncompressed (Ramsay et al., 2005); more research may be required in this area of anatomy. Greater correlation in the publications of exactly where the pain is felt by the patient may also be of benefit (Sapir et al., 2003) since this study found that patients expressed more discomfort with regard to the image receptor edges and the compression paddle edges; very few studies actually investigate this point and it was not a focus of this research.

**Compression force and compression depth achieved:**

The relationship between compression forces applied to reduce the compression depth achieved on the breast is intuitive since as the compression force increases the breast thickness reduces (Helvie et al., 1994; Lee et al., 2002; Poulos and McLean, 2004). The literature leads one to believe this relationship is significant (Poulos and McLean, 2004; Helvie et al., 1994; Saunders and Samei, 2008) however the findings of this study show the relationship is small and non-significant except for the film-screen mediolateral oblique images and digital craniocaudal images. The significant relationships in the Poulos and McLean (2004) study could be explained by the small sample size however Helvie et al., (1994) included 250 paired images. Compression force and compression depth achieved on the breast is thus too complex to be studied in isolation; image quality and patient experience must be considered concomitantly.

**Summary:**

The amount of compression force consistently showed significant effects on the image quality and in addition the perfect and good images consistently required significantly more compression force than the moderate and inadequate images. The mean compression force in Newton required to produce a perfect image was found to be: 121.34N for digital craniocaudal; 134.23N for digital mediolateral oblique; 112.23N for analogue craniocaudal and 129.66N for analogue mediolateral obliques. Only 2% of patients expressed dissatisfaction with the compression force applied.

**Images for this section:**
Fig. 1: Key: Image quality described as: P= Perfect, G= good, M= Moderate, I = inadequate. (NHSBSP, 2000) CC= craniocaudal images and MLO = mediolateral oblique images
Fig. 2: Key: Image quality described as: P = Perfect, G = good, M = Moderate, I = inadequate. (NHSBSP, 2000) CC = craniocaudal images and MLO = mediolateral oblique images
**Fig. 3:** Key: Image quality described as: P = Perfect, G = good, M = Moderate, I = inadequate. (NHSBSP, 2000) CC = craniocaudal images and MLO = mediolateral oblique images
**Fig. 4:** Key: PGMICODED = PGMI recoded numerically where 1= inadequate, 2 = moderate, 3 =Good, 4= perfect (NHSBSP, 2000) *the mean difference is significant at the 0.05 level Sig. = significance level.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>95% Confidence Interval for Mean</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
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<td>212</td>
<td>105.43</td>
<td>35.050</td>
<td>2.407</td>
<td></td>
<td>100.69</td>
<td>110.18</td>
<td>30</td>
<td>200</td>
</tr>
<tr>
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<td>104.33</td>
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<td>1.193</td>
<td></td>
<td>101.99</td>
<td>106.68</td>
<td>29</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>1966</td>
<td>113.52</td>
<td>34.910</td>
<td>0.787</td>
<td></td>
<td>111.98</td>
<td>115.07</td>
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<tr>
<td>4</td>
<td>468</td>
<td>118.01</td>
<td>34.667</td>
<td>1.602</td>
<td></td>
<td>114.86</td>
<td>121.16</td>
<td>30</td>
<td>200</td>
</tr>
<tr>
<td>Total</td>
<td>3505</td>
<td>111.38</td>
<td>35.209</td>
<td>0.595</td>
<td></td>
<td>110.21</td>
<td>112.55</td>
<td>20</td>
<td>210</td>
</tr>
</tbody>
</table>

**Fig. 5:** Key: PGMICODED = PGMI recoded numerically where 1= inadequate, 2 = moderate, 3 =Good, 4= perfect (NHSBSP, 2000) Mean= mean forces in Newton applied to the breast.
Conclusion

Compression forces currently delivered in Irish Symptomatic centres for breast imaging are too low and these affect the image quality seen in these departments. Greater compression force by 11-15N to result in a mean compression force of 122N, is needed to achieve a perfect image in these mammographic units for all images. Further training of radiographers performing mammography is required to standardise the undertaking of the mammographic projections with regard to raised application of compression force. Higher compression forces appear to be tolerable by the women currently undergoing breast imaging in Ireland. Greater compression forces will in turn result in lower compression depths and consequently lower radiation doses (MGD) delivered to the breasts of Irish women attending the symptomatic breast services.

References


**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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The author can be contacted by email at desiree.oleary@ucd.ie.