Aims and objectives

Mammographic screening is associated with a substantial and significant reduction in breast cancer mortality [1]. However, the breast is a highly radiation-sensitive organ, and although low, the risk of a radiation-induced cancer is concerning to many women, and can adversely affect adherence to screening programs [2]. For routine screening, it is therefore important that x-ray dose is kept as low as possible without compromising on image quality or the ability to detect cancers. To keep patient doses at a minimum, accurate calculations for monitoring and tracking dose are essential, and methods for estimating dose that take into account individual patient characteristics are needed.

Most mammography manufacturers estimate a mean glandular dose (MGD) for each exposure taken and insert that value into a DICOM tag for the image. However, there are many different algorithms for estimating MGD and it is not clear which manufacturers use which algorithm. Further, all the algorithms need an estimate of glandularity in the breast and, again, it is not clear what assumptions each manufacturer makes. Therefore, given the wide range of glandularity that exists in the population, radiation dose may be under- or over-estimated in the manufacturer-reported doses [3, 4].

Data from the large DMIST trial demonstrated that large variations in the average MGD reported by x-ray manufacturers exist [5]. For digital mammography, mean dose per view ranged from 1.78- 2.50 mGy across several manufacturers’ systems. Without a standardized method for estimating dose, it is difficult to determine whether such variation is due to patient factors (e.g. glandularity), technologist factors (e.g. degree of breast compression), manufacturer factors (e.g. varying dose algorithms and different detector technologies), or a combination of these.

In this study, the manufacturer-reported MGDs in the DICOM headers were compared to patient-specific MGDs generated using the woman’s specific glandularity and using the same MGD estimation algorithm.
Methods and materials

Raw digital mammograms from 102 women with a wide-range of breast densities with standard four-view temporal mammograms were analyzed (i.e. left and right craniocaudal and mediolateral oblique views). 96 women were imaged one year apart on GE Healthcare (GE) or Hologic Selenia (Hologic) x-ray systems and 6 women were imaged over several years on a mix of GE, Hologic and Siemens Novation systems.

All images were run through automated breast density assessment software (VolparaDensity™), to obtain the volumetric breast density (VBD), breast volume (BV) and, at each pixel in the image, an estimate of the volume of dense tissue between that pixel and the x-ray source (a "density map").

Our intent was to use Dance's algorithm for dose estimation [6-9] but, rather than use his rough estimate of glandularity from the breast thickness, we sought to use the woman’s actual glandularity, which we can compute from the density map. The VBD for a woman is the percentage of fibroglandular tissue within the entire breast, this is typically a low number (0-35% when the skin is excluded), whereas Dance defines glandularity as being the percentage of glandular tissue inside the glandular disk. To generate "Dance's glandularity" we focused only on a central portion of the breast, and we excluded the top and bottom layers of subcutaneous fat. Figure 1 shows the relationship between our estimates of Dance’s glandularity and breast thickness for a large US dataset (blue dots), compared to the relationship reported by Dance et al [6-9] for two separate age ranges. The figure shows that the values used by Dance appear to represent mid-range values for all the potential glandularities which might exist for each breast thickness.

We use average dose estimates and Pearson Correlation Coefficients (PCCs) to compare manufacturer reported doses to patient-specific doses, and to compare dose estimates over time for consistency. Unless otherwise stated, "average" refers to mean values.
**Fig. 1:** VolparaDensity estimates volumetric breast density. Each of the blue dots in this graph represents an image and the relationship between breast thickness for that image and Dance’s glandularity as generated from the volumetric density map. The green and red markers show the rough values reported by Dance et al, for a small UK population; Dance’s reported values represent the mid-range values for glandularity at any thickness.

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Results

Manufacturer & Patient-Specific Dose Comparison

Patient-specific MGD estimates per view (Figure 2) were highly correlated with the GE- and Hologic-reported doses (PCC’s = 0.916 and 0.879, respectively). However, the overall average MGD per view for reported and patient-specific estimates were significantly different: 2.04 and 2.27 for GE, respectively, and 1.90 and 2.21 for Hologic, respectively (Figure 3). Compared to patient-specific estimates, GE and Hologic tended to underestimate MGD, more so in dense and fattier breasts respectively (Figure 4).

Dose Comparison Over Time

Both the reported and patient-specific MGD estimates over time were poorly correlated (Figure 5). PCCs for women imaged on GE first were 0.466 and 0.367 for the reported dose and patient-specific dose estimates, respectively. PCCs for women imaged on Hologic first were 0.144 and 0.147 for the reported dose and patient-specific dose estimates, respectively.

These results indicate that the MGD received by women can vary widely over time. As indicated earlier, this could be due to patient, technologist or manufacturer-based reasons and in further work we will seek to better identify the reasons utilizing the patient-specific results where we understand the dose algorithm being used and the glandularity value used.

For the 6 women with multiple mammograms available, the trends over time for average MGD were similar between the reported and the patient-specific estimates (Figures 6-11). For some women, the average MGD received, per view, was fairly consistent over time (Figures 7 and 10). In contrast, Figure 9 shows a patient experiencing the largest change in average MGD (patient-specific estimate) over two consecutive years (i.e. 3 mGy), which corresponded with a -5.8 mm and +1.9% change in compressed breast thickness and VBD, respectively. Patient, technologist and manufacturer-related factors contributed to some women experiencing larger variations in average MGD, whilst others experienced more consistent doses, over several years.
Fig. 2: Women in the study were imaged one year on GE and the next year on Hologic, or vice versa. This Scatterplot shows the correlation between the patient-specific MGD per view and the manufacturer-reported MGD per view, for GE (blue) and Hologic (red) images.

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**Fig. 3:** Bar graph showing the average MGD per view (i.e. calculated as the mean across all individual image views from the 102 women), as determined from the manufacturer-reported MGD or estimated from the patient-specific dose. *p < 0.001 as determined by Student’s t-test.

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**Fig. 4:** The average MGD per view was determined for each four-view study, and correlated to the corresponding VDG scores for each study. Boxplots show the trends in average MGD by VDG categories, for the manufacturer-reported (A and C) and patient-specific MGD estimates (C and D).

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**Fig. 5:** Cases were analyzed separately for women who were imaged the first year on a GE system (A), and women who were imaged the first year on a Hologic system (B). Scatterplots show the correlations of the MGD estimates per view, for mammograms taken one year apart. The manufacturer-reported and patient-specific dose estimates are shown in blue and red, respectively.
Fig. 6: Graph showing the changes in average MGD (calculated as the mean across a single study) for one woman imaged over multiple years on different x-ray systems (Hologic = H; GE = G). The manufacturer-reported and patient-specific MGD estimates are the blue and red lines, respectively (left y-axes). Grey lines represent either the volumetric breast density (top panel) or compressed breast thickness (bottom panel) on the right y-axes.
**Fig. 7:** Graph showing the changes in average MGD (calculated as the mean across a single study) for one woman imaged over multiple years on Hologic x-ray systems (Hologic = H). The manufacturer-reported and patient-specific MGD estimates are the blue and red lines, respectively (left y-axes). Grey lines represent either the volumetric breast density (top panel) or compressed breast thickness (bottom panel) on the right y-axes.

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Fig. 8: Graph showing the changes in average MGD (calculated as the mean across a single study) for one woman imaged over multiple years on different x-ray systems (Hologic = H; GE = G, and Siemens = S). The manufacturer-reported and patient-specific MGD estimates are the blue and red lines, respectively (left y-axes). Grey lines represent either the volumetric breast density (top panel) or compressed breast thickness (bottom panel) on the right y-axes.

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Fig. 9: Graph showing the changes in average MGD (calculated as the mean across a single study) for one woman imaged over multiple years on Hologic x-ray systems (Hologic = H). The manufacturer-reported and patient-specific MGD estimates are the blue and red lines, respectively (left y-axes). Grey lines represent either the volumetric breast density (top panel) or compressed breast thickness (bottom panel) on the right y-axes.

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**Fig. 10:** Graph showing the changes in average MGD (calculated as the mean across a single study) for one woman imaged over multiple years on Hologic x-ray systems (Hologic = H). The manufacturer-reported and patient-specific MGD estimates are the blue and red lines, respectively (left y-axes). Grey lines represent either the volumetric breast density (top panel) or compressed breast thickness (bottom panel) on the right y-axes.

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Fig. 11: Graph showing the changes in average MGD (calculated as the mean across a single study) for one woman imaged over multiple years on different x-ray systems (Hologic = H; Siemens = S). The manufacturer-reported and patient-specific MGD estimates are the blue and red lines, respectively (left y-axes). Grey lines represent either the volumetric breast density (top panel) or compressed breast thickness (bottom panel) on the right y-axes.

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Conclusion

The results presented here indicate that the patient-specific estimates of MGD, which incorporate the individual glandularities of the women and use a standard dose algorithm, differ from, but correlate well with the reported doses from GE and Hologic systems. These patient-specific estimates of MGD could be used to help standardize dose monitoring for patients undergoing routine screening on different x-ray systems.
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References


