BJR © 2018 The Authors. Published by the British Institute of Radiology

Received: 23 February 2018 | Revised: 25 May 2018 | Accepted: 13 June 2018

https://doi.org/10.1259/bjr.20180209

Cite this article as:
Waade GG, Sebuødegård S, Hogg P, Hofvind S. Breast compression across consecutive examinations among females participating in BreastScreen Norway. *Br J Radiol* 2018; **91**: 20180209.

THE ROLE OF IMAGING IN SCREENING SPECIAL FEATURE: FULL PAPER

Breast compression across consecutive examinations among females participating in BreastScreen Norway

[1]**GUNVOR G WAADE**, MSc, [2]**SOFIE SEBUØDEGÅRD**, MSc, [3]**PETER HOGG**, MPhil, FCR and [1,2]**SOLVEIG HOFVIND**, PhD

[1]Faculty of Health Sciences, Oslo Metropolitan University, Oslo, Norway
[2]Department of Breast Screening, Cancer Registry of Norway, Oslo, Norway
[3]Department of Radiography, University of Salford, Manchester, United Kingdom

Address correspondence to: Professor Solveig Hofvind
E-mail: *solveig.hofvind@kreftregisteret.no*

Objective: Breast compression is used in mammography to improve image quality and reduce radiation dose. However, optimal values for compression force are not known, and studies have found large variation in use of compression forces between breast centres and radiographers. We investigated breast compression parameters, including compression force, compression pressure and compressed breast thickness across four consecutive full field digital mammography screening examinations for 25,143 subsequently screened females aged 50-69 years.

Methods: Information from females attending four consecutive screening examinations at two breast centres in BreastScreen Norway during January 2007 - March 2016 was available. We compared the changes in compression force, compression pressure and compressed breast thickness from the first to fourth consecutive screening examination, stratified by cranio-caudal (CC) and mediolateral oblique (MLO) view.

Results: Compression force, compression pressure and compressed breast thickness increased relatively by 18.3, 14.4 and 8.4% respectively, from first to fourth consecutive screening examination in CC view ($p<0.001$ for all). For MLO view, the values increased relatively by 12.3% for compression force, 9.9% for compression pressure and 6.9% for compressed breast thickness from first to fourth consecutive screening examination ($p<0.001$ for all).

Conclusion: We observed increasing values of breast compression parameters across consecutive screening examinations. Further research should investigate the effect of this variation on image quality and females' experiences of discomfort and pain.

Advances in knowledge: Breast compression force, compression pressure and compressed breast thickness increased across consecutive screening examinations, which might be of influence for the females' experiences of discomfort and pain during the examination and for image quality.

INTRODUCTION

Consistent production of high quality mammograms is crucial in mammographic screening to allow optimal visualisation of the breast. Breast compression is used during image acquisition to achieve optimal image quality and reduced radiation dose.[1,2] The radiographer who performs the examination, positions and places the female's breast on the image detector and compresses the breast to reduce breast thickness.[3] Compression is measured in force, and the value is visible to the radiographer during the examination. However, optimal values for compression force are not known.[2] National and international guidelines for quality assurance in mammography either have a large range of accepted compression force values,[3–6] or they include subjective statements for the compression force.[2] For instance, the European guidelines for quality assurance in breast cancer screening and diagnosis suggest that "the breast should be properly compressed, but no more than is necessary to achieve a good image quality".[2] Further, the compression force is recommended to be minimum 98.1 Newton (N) (>10 kp) in Germany,[4] maximum 200 N (or 20 kg) in the UK,[5] between 120–200 N (12–20 daN) in Netherlands[3] and between 108–177 N (11–18 kg) in Norway.[6]

These large ranges in numeric values and subjective descriptions of breast compression may reflect possibilities for individualisation, that the radiographer can adjust the compression force to the individual breast and preferences of the females. However, lack of precise and objective recommendations for breast compression might lead to subjective and inconsistent variations in compression force between and within females. Studies have observed large variations between breast imaging centres and among radiographers in the use of compression forces,[7–11] also for the individual females.[10,11]

Several factors affect compression force application, such as positioning, the female and the radiographer. Positioning includes appropriate image receptor height,[12] distance between female and image receptor[3] and the positioning and fixating of the breast on the image receptor.[3] Factors related to the female, such as breast size and composition;[13] the female's cooperative ability, whether she is experiencing or tolerating discomfort or pain; and mobility, whether she has any tension or pain in neck or shoulder, may affect both the amount of compression force that is applied and also the positioning. The radiographer performs both the positioning and applying compression force. The practical, communication and social skills of the radiographer is thus of importance.

We assume that breast compression is a key factor for image quality. Varying breast compression for the same female when attending consecutive screening examinations might result in different image quality between images from different screening examinations. This may represent a challenge for the screen-readers in the reading process as they use prior mammograms for comparison. In this longitudinal retrospective study, we investigated breast compression parameters across four consecutive screening examinations for the individual females. The results of this study might provide insight to whether a change in breast compression practice is required or not.

METHODS AND MATERIALS

The Regional committee for health research ethics approved this study (Reference 2016/938). BreastScreen Norway invites all females aged 50–69 years to biennial mammographic screening. The program is administered by the Cancer Registry of Norway, and is described in detail elsewhere.[14]

Information from 108,229 females screened with full field digital mammography using General Electric (GE, Senographe Essential) at two breast centres (Rogaland and Hordaland) as a part of BreastScreen Norway in the period from January 2007 to March 2016 was available. The available information was solely from females who had not refused the Cancer Registry to use data about their screening examination for quality assurance and research, and included both screening positive and negative cases. Both breast centres used flexible compression paddles during the study period and quality assurance of the equipment was performed daily and weekly by the radiographers according to guidelines of the program.[15] In addition, calibration of the equipment was performed and approved twice a year by representatives from the vendor. From each examination, the following data were extracted: female age, breast compression parameters [compression force (Newton, N); compression pressure (kilopascal, kPa); compressed breast thickness (mm)]; and breast characteristics [breast volume (cm^3); fibroglandular volume (cm^3); and volumetric breast density (percentage, %)]. This information was obtained retrospectively from the Cancer Registry's databases, the Digital Imaging and Communications in Medicine[16] header of the images and by assessing the images in an automated software for mammographic density estimation (VolparaDensity v. 4, Matakina, Wellington, New Zealand).[17]

We included solely information from subsequently screened females who had participated in four consecutive screening examinations (less than 2.5 years since the prior screening examination) with four standard views [left and right breast in craniocaudal (CC) and mediolateral oblique (MLO) view] (Figure 1). By including only subsequently screened females, we ensured that all females had at least one experience of breast compression before they entered the study population. Our final study population included 25,143 females with four consecutive screening examinations (100,572 examinations and 402,288 images in total), performed during the study period. In this paper "first screening examination" reflects the first screening examination for the females in the study period. The second, third and fourth consecutive screening examinations reflected the consecutive screening examinations 2, 4 and 6 years later, respectively.

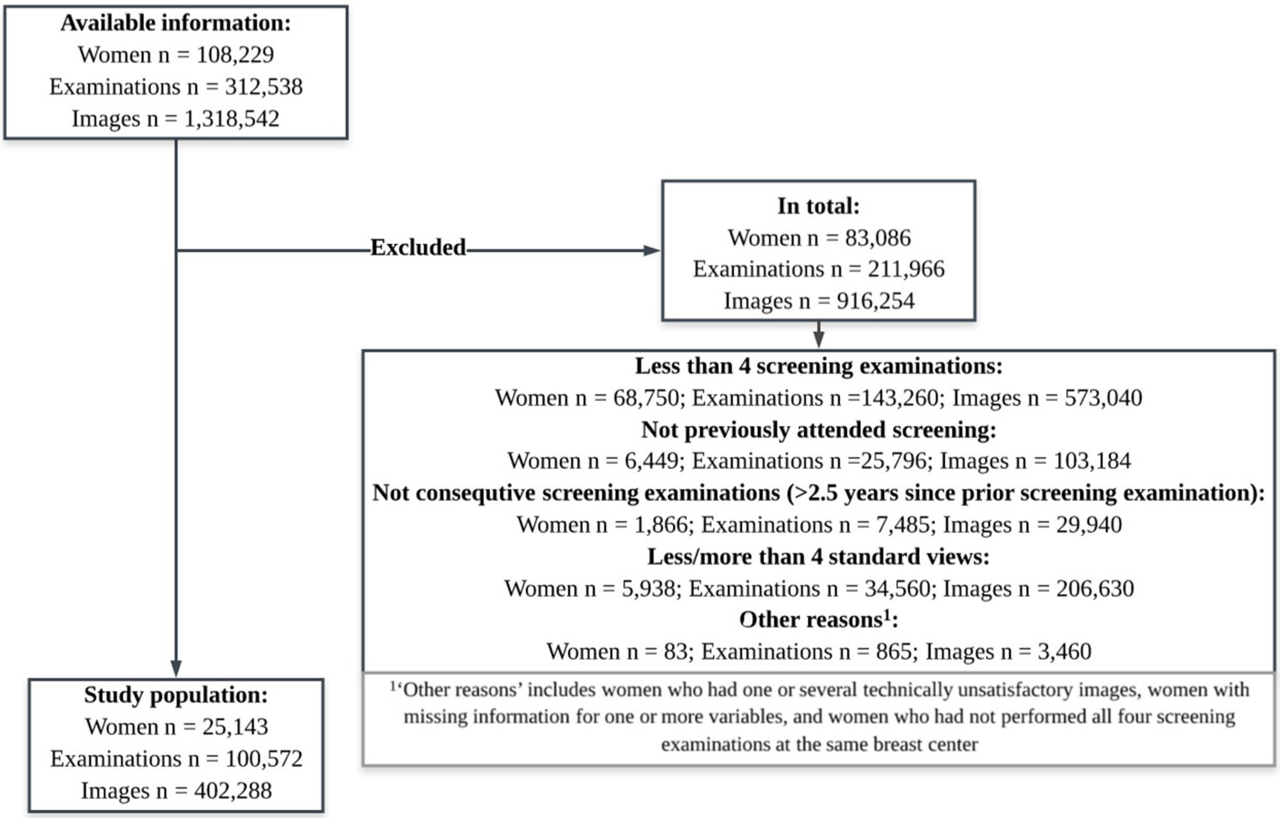
Statistical analysis

To meet assumptions of independency between observations, all analyses were performed for left breast only. We calculated mean and 95% confidence interval (95% CI) of age, breast volume, fibroglandular volume and volumetric breast density for the study population by consecutive screening examinations (first to fourth). Further, mean and 95% CI of compression force, compression pressure and compressed breast thickness were calculated by consecutive screening examinations and view (CC, MLO). Analysis of variance, Tukey's honestly significant different pairwise comparisons and t-tests were used to test for differences in mean values for the covariates. Percentage difference from first to fourth consecutive screening examination was calculated for compression force, compression pressure and compressed breast thickness.

We used generalised estimating equation (GEE) to investigate whether breast compression parameters changed between consecutive screening examinations. GEE is an appropriate statistical method to account for within-group dependency between the variables.[18] Using GEE, we performed a linear regression with robust standard errors with each of the breast compression parameters as the outcome variable and consecutive screening examinations as the explanatory variable, adjusting for breast volume, fibroglandular volume, the female's age, breast centre and calendar year, stratified by view. Breast volume was excluded from the model with compression pressure due to collinearity.[19] To simplify the interpretation of the intercept term in the linear regression model we standardised all covariates in the model. We modelled both the additive and the multiplicative change in breast compression parameters. The estimated coefficients represents the change in breast compression parameters between consecutive screening examinations.

All statistical analyses were conducted using Stata Statistical Software (v. 14.2, *Stata Corp*, College Station, TX).[20]

Figure 1. The number of females, examinations and images available for this study, the number excluded and the final study population.



RESULTS

Mean age of the study population was 58.1 years [95% CI (58.1–58.1)] at first screening examination, while mean breast volume, fibroglandular volume and volumetric breast density was 820.3 cm^3 [95% CI (816.5–824.1)], 45.5 cm^3 [95% CI (45.3–45.7)] and 6.6% [95% CI (6.6–6.7)], respectively (Table 1). Mean breast volume increased, while fibroglandular volume and volumetric breast density decreased by consecutive screening examinations. Females from Rogaland were slightly younger than females from Hordaland (first consecutive screening examination: 58.0 *vs* 58.2 years), had higher mean values of breast volume (853.4 *vs* 772.3 cm^3), fibroglandular volume (47.2 *vs* 42.9 cm^3) and volumetric breast density (6.7 *vs* 6.6) ($p < 0.001$ for all).

Mean observed compression force, compression pressure and compressed breast thickness increased by consecutive screening examinations for CC and MLO view ($p < 0.001$) (Table 2). For CC view, mean observed compression force, compression pressure and compressed breast thickness increased from 106.7 to 121.0 N, from 13.4 to 14.9 kPa and from 52.7 to 55.8 mm respectively, from first to fourth consecutive screening examination. For MLO view, the mean observed compression force, compression pressure and compressed breast thickness increased from 120.2 to 129.8 N, from 9.4 to 10.1 kPa and from 56.5 to 59.0 mm, respectively.

Compression force

Compression force increased by consecutive screening examinations when adjusting for breast volume, fibroglandular volume, the female's age, breast centre and calendar year (Table 3). For CC view, compression force increased by 5.8, 9.0 and 7.7 N respectively, from first to second, third and fourth consecutive screening examination ($p < 0.001$ for all). For MLO view, it increased by 6.0, 8.9 and 7.5 N respectively, from first to second, third and fourth consecutive screening examination ($p < 0.001$ for all).

Compression force increased relatively by 11.5, 17.1 and 18.3% in CC view and 9.6, 12.9 and 12.3% in MLO view, from first to second, third and fourth consecutive screening examination, respectively (Figures 2 and 3, $p < 0.001$ for all).

Compression pressure

Compression pressure increased by consecutive screening examinations when adjusting for fibroglandular volume, the female's age, breast centre and calendar year (Table 3). For CC view, compression pressure increased by 0.5, 1.1 and 1.4 kPa respectively, from first to second, third and fourth consecutive screening examination ($p < 0.001$ for all). For MLO view, it increased by 0.4, 0.7 and 0.8 kPa respectively, from first to second, third and fourth consecutive screening examination ($p < 0.001$ for all).

Table 1. Study population characteristics; mean values of age (years), breast volume (cm^3), fibroglandular volume (cm^3) and volumetric breast density (%) with 95% CI, by consecutive screening examinations (first to fourth), in total and by breast centre (Rogaland, Hordaland)

	Consecutive screening examinations							
	First		Second		Third		Fourth	
	Mean	(95% CI)	Mean	(95% CI)	Mean	(95% CI)	Mean	(95% CI)
Total (n = 25,143 females)								
Age, years	58.1	(58.1–58.1)	60.2	(60.1–60.2)	62.3	(62.3–62.3)	64.4	(64.4–64.5)
Breast volume, cm^3	820.3	(816.5–824.1)	835.5	(831.7–839.3)	860.3	(856.6–864.1)	889.4	(885.6–893.1)
Fibroglandular volume, cm^3	45.5	(45.3–45.7)	43.8	(43.6–44.0)	44.6	(44.4–44.8)	43.9	(43.7–44.1)
Volumetric breast density, %	6.6	(6.6–6.7)	6.2	(6.2–6.3)	6.0	(6.0–6.1)	5.7	(5.7–5.7)
Rogaland (n = 14,874 females)								
Age, years	58.0	(58.0–58.0)	60.1	(60.1–60.2)	62.3	(62.2–62.3)	64.5	(64.4–64.5)
Breast volume, cm^3	853.4	(848.2–858.6)	856.7	(851.4–862.0)	865.6	(860.4–870.8)	902.9	(897.7–908.1)
Fibroglandular volume, cm^3	47.2	(47.0–47.5)	44.8	(44.6–45.1)	46.4	(46.1–46.6)	45.4	(45.1–45.7)
Volumetric breast density, %	6.7	(6.7–6.8)	6.3	(6.3–6.3)	6.3	(6.2–6.3)	5.8	(5.8–5.9)
Hordaland (n = 10,269 females)								
Age, years	58.2	(58.2–58.3)	60.2	(60.2–60.3)	62.3	(62.2–62.3)	64.4	(64.4–64.5)
Breast volume, cm^3	772.3	(767.1–777.6)	804.7	(799.5–810.0)	852.7	(847.3–858.0)	869.7	(864.5–875.0)
Fibroglandular volume, cm^3	42.9	(42.6–43.2)	42.1	(42.1–42.6)	41.8	(41.8–42.4)	41.3	(41.3–41.9)
Volumetric breast density, %	6.6	(6.5–6.6)	6.1	(6.1–6.2)	5.7	(5.7–5.8)	5.5	(5.4–5.5)

CI, confidence interval.

Compression pressure increased relatively by 7.7, 12.1 and 14.4% in CC view and 6.2, 9.2 and 9.9% in MLO view, from first to second, third and fourth consecutive screening examination, respectively (Figures 2 and 3, $p < 0.001$ for all).

Compressed breast thickness

Compressed breast thickness decreased from first to second screening examination and increased from second to fourth when adjusting for breast volume, fibroglandular volume, the female's age, breast centre and calendar year (Table 3). For CC view, compressed breast thickness changed by –0.4, 0.6 and 2.3 mm respectively, from first to second, third and fourth consecutive screening examination ($p < 0.001$ for all). For MLO view, it changed by –0.4, 0.7 and 2.2 mm respectively, from first to second, third and fourth consecutive screening examination ($p < 0.001$ for all).

Compressed breast thickness increased relatively by 0.3, 3.7 and 8.4% in CC view ($p < 0.01$ for all) and 0.5, 3.1 and 6.9% in MLO view ($p < 0.001$ for all), from first to second, third and fourth consecutive screening examination, respectively (Figures 2 and 3).

DISCUSSION

Our study identified that compression force, compression pressure and compressed breast thickness increased statistically significantly by consecutive screening examinations when adjusting for breast volume, fibroglandular volume, the female's age, breast centre and calendar year. From first to fourth consecutive screening examination, compression force, compression pressure and compressed breast thickness increased relatively by 18.3, 14.4 and 8.4% respectively in CC view and by 12.3, 9.9 and 6.9% for MLO view.

One explanation for this increase might be related to changes in the breasts; the females' breast volume increased, while fibroglandular volume decreased across consecutive screening examinations, thus the volumetric breast density decreased. Decreasing fibroglandular volume is likely to be a result of involution, the process where dense tissue is replaced by fatty tissue.[21] As the females' age and breasts change over the consecutive screening examinations, one could expect the radiographers to alter the breast compression too, in order to compensate for a different breast composition. However, breast compression parameters also increased when adjusting for breast volume, fibroglandular volume, age, breast centre and calendar year. Thus, other factors related to the practice at the breast centres may be reason for the change in breast compression over time or by consecutive screening examination.[10,11] Nevertheless, radiographers from the two breast centres informed us that no deliberate change in local practice for breast compression or positioning occurred during the study period (e-mail correspondence, November 2017).

Implications for clinical practice

It is unknown what size of changes in breast compression parameters will cause an effect on image quality. However, we assume that varying breast compression will have consequences for image quality and experiences of discomfort and

Table 2. Breast compression parameters: mean observed compression force (Newton, N), compression pressure (kilopascal, kPa) and compressed breast thickness (mm) with 95% CI, by consecutive screening examinations (first to fourth) and view (CC, MLO), in total and by breast centre (Rogaland, Hordaland). Percentage change (% change) is from first to fourth screening examination

	Consecutive screening examinations								
	First		Second		Third		Fourth		
	Mean	(95% CI)	Mean	(95% CI)	Mean	(95% CI)	Mean	(95% CI)	% change
Total (n = 25,143 females)	CC view								
Force, Newton	106.7	(106.4–107.0)	114.4^{b}	(114.2–114.7)	120.0^{b}	(119.7–120.2)	121.0^{b}	(120.8–121.2)	13.4 %
Pressure, kiloPascal	13.4	(13.3–13.5)	14.0^{b}	(13.95–14.09)	14.6^{b}	(14.5–14.64)	14.9^{b}	(14.81–14.96)	11.2 %
Breast thickness, mm	52.7	(52.5–52.8)	52.2^{b}	(52.1–52.4)	53.7^{b}	(53.5–53.8)	55.8^{b}	(55.6–55.9)	5.9 %
Rogaland (n = 14,874 females)									
Force, Newton	114.7	(114.3–115.0)	119.5^{b}	(119.2–119.8)	124.9^{b}	(124.6–125.2)	125.1	(124.9–125.3)	9.1 %
Pressure, kiloPascal	14.5	(14.4–14.6)	14.5	(14.43–14.62)	14.7^{a}	(14.64–14.85)	15.0^{b}	(14.94–15.15)	3.4 %
Breast thickness, mm	53.3	(53.2–53.5)	51.5^{b}	(51.3–51.6)	51.5	(51.3–51.6)	54.1^{b}	(53.9–54.2)	1.5 %
Hordaland (n = 10,269 females)									
Force, Newton	95.2	(94.8–95.6)	107.0^{b}	(106.8–107.5)	112.9^{b}	(112.6–113.2)	115.0^{b}	(114.7–115.4)	20.8 %
Pressure, kiloPascal	11.8	(11.7–11.9)	13.3^{b}	(13.19–13.38)	14.3^{b}	(14.22–14.42)	14.7^{b}	(14.56–14.76)	24.6 %
Breast thickness, mm	51.7	(51.5–51.9)	53.3^{b}	(53.1–53.6)	56.8^{b}	(56.6–57.1)	58.3^{b}	(58.1–58.5)	12.8 %
Total (n = 25,143 females)	MLO view								
Force, Newton	120.2	(119.9–120.5)	126.9^{b}	(126.6–127.1)	130.4^{b}	(130.2–130.7)	129.8^{a}	(129.6–130.0)	8.0 %
Pressure, kiloPascal	9.4	(9.4–9.5)	9.8^{b}	(9.7–9.8)	10.0^{b}	(10.0–10.1)	10.1^{a}	(10.1–10.1)	7.4 %
Breast thickness, mm	56.5	(56.3–56.6)	56.2^{a}	(56.0–56.3)	57.2^{b}	(57.0–57.3)	59.0^{b}	(58.8–59.1)	4.4 %
Rogaland (n = 14,874 females)									
Force, Newton	126.3	(125.9–126.6)	129.6^{b}	(129.3–129.9)	132.0^{b}	(131.7–132.3)	131.6	(131.4–131.9)	4.2 %
Pressure, kiloPascal	9.8	(9.7–9.8)	9.7^{a}	(9.6–9.7)	9.7	(9.7–9.8)	9.8	(9.7–9.8)	0.0%
Breast thickness, mm	56.9	(56.7–57.1)	55.5^{b}	(55.3–55.7)	55.3	(55.1–55.5)	57.5^{b}	(57.3–57.7)	1.1 %
Hordaland (n = 10,269 females)									
Force, Newton	111.4	(110.9–111.9)	123.0^{b}	(122.6–123.4)	128.2^{b}	(127.9–128.6)	127.2^{b}	(126.8–127.5)	14.2 %
Pressure, kiloPascal	9.0	(8.9–9.0)	9.9^{b}	(9.8–9.9)	10.5^{b}	(10.5–10.6)	10.6	(10.5–10.6)	17.8 %
Breast thickness, mm	55.8	(55.5–56.0)	57.1^{b}	(56.8–57.3)	60.0^{b}	(59.7–60.2)	61.2^{b}	(61.0–61.4)	9.7 %

CC, craniocaudal; CI, confidence interval; MLO, mediolateral oblique.

Compression force.

[a] Statistically significantly different to prior screening examination, $p < 0.05$.

[b] Statistically significantly different to prior screening examination, $p < 0.001$.

Table 3. Results from linear regression of the effect of consecutive screening examination (1-4) on compression force (Newton, N), compression pressure (kilopascal, kPa) and compressed breast thickness (mm), when adjusting for breast volume, fibroglandular volume (FGV), breast centre, the female's age and calendar year, by view (CC, MLO)

	Compression force		Compression pressure		Compressed breast thickness	
	Coef	95% CI	Coef	95% CI	Coef	95% CI
CC view						
Consecutive screening examination						
1[a]	1.00		1.00		1.00	
2	5.82[b]	(5.35–6.28)	0.54[b]	(0.43–0.65)	−0.38[b]	(-0.55–−0.21)
3	8.95[b]	(8.17–9.73)	1.11[b]	(0.90–1.32)	0.60[b]	(0.26–0.93)
4	7.68[b]	(6.56–8.81)	1.38[b]	(1.07–1.69)	2.26[b]	(1.75–2.76)
Breast volume	0.01[b]	(0.01–0.01)			0.03[b]	(0.03–0.03)
FGV	0.06[b]	(0.05–0.07)	−0.03[b]	(-0.03–−0.03)	−0.04[b]	(-0.05–−0.04)
Breast centre						
Rogaland[a]	1.00		1.00		1.00	
Hordaland	−13.67[b]	(-13.93–−13.41)	−1.51[b]	(-1.63–−1.38)	1.92[b]	(1.72–2.12)
Age	0.19[b]	(0.16–0.23)	−0.18[b]	(-0.20–−0.17)	−0.30[b]	(-0.33–−0.28)
Year	0.69[b]	(0.52–0.86)	0.20[b]	(0.15–0.24)	0.05	(-0.03–0.13)
Constant	115.5[b]	(114.89–116.10)	14.07[b]	(13.89–14.26)	52.18[b]	(51.89–52.47)
MLO view						
Consecutive screening examination						
1[a]	1.00		1.00		1.00	
2	6.04[b]	(5.55–6.53)	0.36[b]	(0.30–0.42)	−0.36[b]	(-0.52–−0.20)
3	8.93[b]	(8.11–9.76)	0.71[b]	(0.60–0.82)	0.70[b]	(0.39–1.01)
4	7.50[b]	(6.32–8.69)	0.84[b]	(0.67–1.01)	2.21[b]	(1.74–2.69)
Breast volume	0.01[b]	(0.01–0.01)			0.03[b]	(0.03–0.03)
FGV	0.01[b]	(0.00–0.02)	−0.02[b]	(-0.02–−0.02)	−0.04[b]	(-0.04–−0.04)
Breast centre						
Rogaland[a]	1.00		1.00		1.00	
Hordaland	−6.38[b]	(-6.66–−6.09)	0.03	(-0.03–0.08)	4.12[b]	(3.95–4.29)
Age	0.09[b]	(0.05–0.13)	−0.08[b]	(-0.09–−0.07)	−0.25[b]	(-0.28–−0.23)
Year	0.11	(-0.07–0.29)	0.05[b]	(0.02–0.07)	0.00	(-0.07–0.08)
Constant	123.82[b]	(123.18–124.46)	9.34[b]	(9.25–9.44)	54.88[b]	(54.62–55.15)

CC, craniocaudal; CI, confidence interval; FGV, fibroglandular volume; MLO, mediolateral oblique.

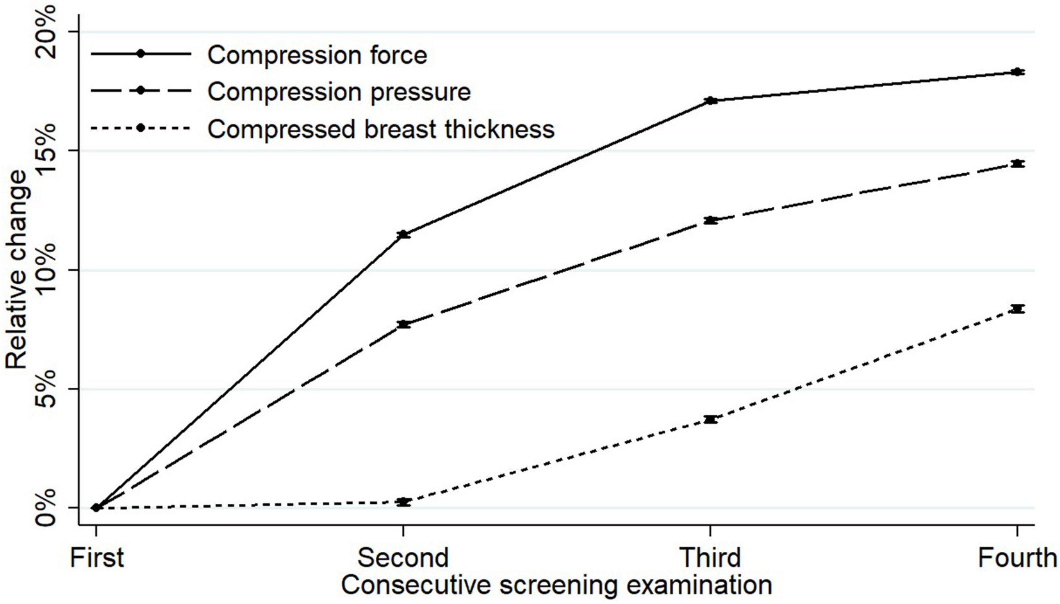
[a] Reference.

[b] Statistically significant, $p < 0.001$

pain. With today's guidelines for breast compression, breast compression parameters increase by consecutive screening examinations in BreastScreen Norway, also when adjusting for breast related factors. Thus, the quality between the images from the consecutive screening examinations might be different. This may challenge the screen-reader when comparing with prior mammograms. Further, some females find mammography painful.[22–24] Increased breast compression over time might have consequences for the experiences of the females. Uncomfortable or painful experiences can influence whether the females re-attend screening.[25,26] However, a study by Moshina et al observed that females receiving the lowest values of compression force (<10.0 kg) or compression pressure (<9.0 kPa) at their prevalent screening examination had the lowest re-attendence for subsequent screening (85%).[27] Further research investigating the effect of varying breast compression on image quality and experiences of discomfort or pain for the females is needed.

Given the assumption that varying breast compression affect image quality and experiences of the females, there should be a goal to reduce this variation in order to have similar experiences

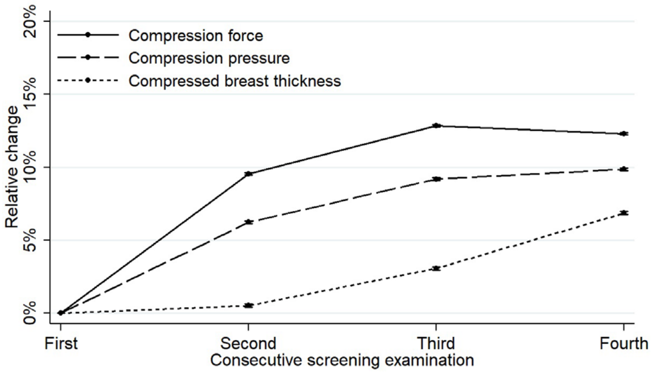
Figure 2. Percentage differences in compression force (Newton, N; solid line), compression pressure (kilopascal, kPa; long dashed line) and compressed breast thickness (mm, short dashed line) and 95% CI from first consecutive screening examination for CC view. The values are adjusted for breast volume, fibroglandular volume, the female's age, breast centre and calendar year, using linear regression of GEE. CC, cranio caudal; CI, confidence interval; GEE, generalised estimating equation.



and comparable images for the same female, regardless of location and radiographers performing the examinations.

One way to reduce variation in breast compression is to standardise a compression pressure and implement breast compression paddles displaying the pressure for the radiographers during the examination.[28–30] However, use of such paddles are still highly dependent on positioning, thus the paddle itself does not guarantee similar breast compression. For instance, if pressure is concentrated to the pectoral muscle at one screening examination and at the breast itself at the consecutive,[31,32] there might still be different breast compression and image quality.

Figure 3. Percentage differences in compression force (Newton, N; solid line), compression pressure (kilopascal, kPa; long dashed line) and compressed breast thickness (mm, short dashed line) and 95% CI from first consecutive screening examination for MLO view. The values are adjusted for breast volume, fibroglandular volume, the female's age, breast centre and calendar year, using linear regression of GEE. CI, confidence interval; GEE, generalised estimating equation; MLO, mediolateral oblique.



As a solution to reduce variation in breast compression for females from one screening examination to another, we recommend standardising positioning technique, thereby increasing focus on and facilitating reproducible imaging. A national step-by-step guide to positioning technique could be developed, as in the Dutch Screening Program.[3] The radiographers could check prior images and compression force applied at prior screening examination to reduce variation. With only minor changes in breast positioning and compression parameters, the image quality should be comparable. However, if a suboptimal compression force were used at the prior screening examination, this could continue through several consecutive screening examinations, leading to consistent production of images with reduced image quality. However, by performing continuous quality assurance, this issue could be solved.

Limitations

Only 2 of the 16 breast centres in BreastScreen Norway were included in the study. The study did not include information about the individual radiographers, which could have provided insight in variation in breast compression between radiographers on the same females, as shown in the longitudinal studies from the UK.[10,11] The study population included both females with positive and negative screening examinations. We did not have information about the outcome of the examinations on an individual level; however, most of the examinations were negative screening examinations. Further research investigating variation in breast compression among females with positive *vs* negative screening examinations is recommended. Further, we did not assess image quality, thus we do not know whether the increased breast compression observed in our study had an effect of image quality. Studies have reported different effects on image quality with changes in breast compression parameters of this magnitude,[33–38] from minimal and no impact on image quality,[33–36] to considerable and significant effects on image quality.[37,38]

CONCLUSIONS

This is the first study investigating breast compression parameters over consecutive screening examinations in BreastScreen Norway. We identified an increase in compression force, compression pressure and compressed breast thickness over time when adjusting for breast volume, fibroglandular volume, age of the females, breast centre and calendar year. This might impact image quality and experiences of discomfort and pain by the females. Further research investigating the consequences of varying breast compression parameters on image quality and experiences of the females is needed.

ACKNOWLEDGEMENTS

We thank the radiographers at Hordaland and Rogaland for their contribution to the study.

REFERENCES

1. Kopans D. *Breast imaging*. 3 ed. London: Lippincott Williams & Wilkins; 2007. pp. ISBN: 0-7817-4768-6.
2. Perry N, Broeders M, Wolf Cd, Törnberg S, Holland R, Karsa Lv. *European guidelines for quality assurance in breast cancer screening and diagnosis. 4 ed*: European Communities; 2006. ISBN: 92-79-01258-4. ISBN: 92-79-01258-4. http://www.euref.org/european-Guidelines.
3. Landsveld-Verhoeven Cv. *The right focus; Manual on mammography positioning technique*. Nijmegen: LRCB; 2015. ISBN: 978-90-821079-1-3.
4. Germany, Mamma. *Leitlinie der Bundesärztekammer zur Qualitätssicherung in der Röntgendiagnostik – Qualitätskriterien röntgendiagnostischer Untersuchungen*. Berlin: The German Medical Association; 2007. pp. 62–4. http://www.bundesaerztekammer.de/fileadmin/user_upload/downloads/LeitRoentgen2008Korr2.pdf.
5. Cush S, Johnson S, Jones S, Passmore D, Deogund K, Vegnuti Z. *Quality assurance guidelines for mammography including radiographic quality control. NHS Cancer Screening Programmes - National Quality Assurance Coordinating Group for Radiography*; 2006. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/470807/nhsbsp63_uploaded_231015.pdf.
6. Vee B, Gullien R, Handberg E, Hoftvedt IJ, Iden K, Ertzaas AK. *Chapter 5: Directions for radiographers in the Quality assurance manual of the Norwegian Breast Cancer Screening Program (NBCSP)*. Oslo: The Cancer Registry of Norway, Institute og population-based cancer research, Oslo; 2011. pp. 10. https://www.kreftregisteret.no/globalassets/mammografiprogrammet/arkiv/publikasjoner-og-brosjyrer/kval-man-radiograf_v1.0_innholdsfortegnelse.pdf.
7. Waade GG, Moshina N, Sebuødegård S, Hogg P, Hofvind S. Compression forces used in the Norwegian Breast Cancer Screening Program. *Br J Radiol* 2017; **90**: 20160770. doi: https://doi.org/10.1259/bjr.20160770
8. Waade GG, Sanderud A, Hofvind S. Compression force and radiation dose in the Norwegian Breast Cancer Screening Program. *Eur J Radiol* 2017; **88**: 41–6. doi: https://doi.org/10.1016/j.ejrad.2016.12.025
9. Branderhorst W, de Groot JE, Highnam R, Chan A, Böhm-Vélez M, Broeders MJ, et al. Mammographic compression-a need for mechanical standardization. *Eur J Radiol* 2015; **84**: 596–602. doi: https://doi.org/10.1016/j.ejrad.2014.12.012
10. Mercer CE, Hogg P, Szczepura K, Denton ERE. Practitioner compression force variation in mammography: A 6-year study. *Radiography* 2013; **19**: 200–6. doi: https://doi.org/10.1016/j.radi.2013.06.001
11. Mercer CE, Szczepura K, Kelly J, Millington SR, Denton ERE, Borgen R, et al. A 6-year study of mammographic compression force: Practitioner variability within and between screening sites. *Radiography* 2015; **21**: 68–73. doi: https://doi.org/10.1016/j.radi.2014.07.004
12. Smith H, Szczepura K, Mercer C, Maxwell A, Hogg P. Does elevating image receptor increase breast receptor footprint and improve pressure balance? *Radiography* 2015; **21**: 359–63. doi: https://doi.org/10.1016/j.radi.2015.02.001
13. Khan-Perez J, Harkness E, Mercer C, Bydder M, Sergeant J, Morris J. Volumetric Breast Density and Radiographic Parameters. In: Fujita H, Hara T, Muramatsu C, eds. *Breast Imaging - 12th International Workshop, IWDM 2014, Gifu City, Japan, June 29 – July 2, 2014 Proceedings. 8539*. **2014**: Springer; 2014. pp. 265–72.
14. Cancer in Norway 2016. Special Issue: The Norwegian Breast Cancer Screening Program, 1996-2016: Celebrating 20years of organised mammographic screening. In: Hofvind S, ed.. Oslo: Cancer Registry of Norway; 2017. pp. ISBN: 978-82-473-0055-8.
15. Pedersen K, Landmark ID, Bredholt K, Hauge IHR. *Chapter 10: Technical quality control - constancy controls for digital mammography systems in the Quality assurance manual of the Norwegian Breast Cancer Screening Program (NBCSP)*. Oslo: The Cancer Registry of Norway, Institute og population-based cancer research, Oslo; 2009.
16. NEMA. Digital Imaging Communication in Medicine (DICOM). 2018. Available from: http://dicom.nema.org/.
17. Highnam R, Brady M, Yaffe MJ, Karssemeijer N, Harvey J. *Robust breast composition measurement - VolparaTM*. Digital Mammography: Springer; 2010. pp. 342–9.
18. Vittinghoff E, Glidden DV, Shiboski SC, McCulloch CE, Gail M, Krickeberg K. Repeated Measures and Longitudinal Data Analysis. In: *Regression Methods in Biostatistics - Linear, Logistic, Survival, and Repeated Measures Models. Statistics for Biology and Health*. 2nd. New York: Springer; 2012. pp. 261–308.
19. Moshina N, Roman M, Waade GG, Sebuødegård S, Ursin G, Hofvind S. Breast compression parameters and mammographic density in the Norwegian Breast Cancer Screening Programme. *Eur Radiol* 2018; **28**: 1662-1672. doi: https://doi.org/10.1007/s00330-017-5104-5
20. StataCorp. *Stata statistical software: release 14. College station*. TX: StataCorp LP; 2015.
21. Darlington A. Anatomy of the breast. In: Hogg P, Kelly J, Mercer C, eds. *Digital mammography: a holistic approach*. United Kingdom: Springer; 2015. pp.. 3–10.
22. Davey B. Pain during mammography: Possible risk factors and ways to alleviate

pain. *Radiography* 2007; **13**: 229–34. doi: https://doi.org/10.1016/j.radi.2006.03.001

23. Keemers-Gels ME, Groenendijk RP, van den Heuvel JH, Boetes C, Peer PG, Wobbes TH. Pain experienced by women attending breast cancer screening. *Breast Cancer Res Treat* 2000; **60**: 235–40. doi: https://doi.org/10.1023/A:1006457520996
24. Whelehan P. Pain in mammography. In: Hogg P, Kelly J, Mercer C, eds. *Digital mammography: a holistic approach*. United Kingdom: Springer; 2015. pp. 113–7.
25. Whelehan P, Evans A, Wells M, Macgillivray S. The effect of mammography pain on repeat participation in breast cancer screening: a systematic review. *Breast* 2013; **22**: 389–94. doi: https://doi.org/10.1016/j.breast.2013.03.003
26. Hofvind SS, Wang H, Thoresen S. The Norwegian Breast Cancer Screening Program: re-attendance related to the women's experiences, intentions and previous screening result. *Cancer Causes Control* 2003; **14**: 391–8. doi: https://doi.org/10.1023/A:1023918610664
27. Moshina N, Sebuødegård S, Holen ÅS, Waade GG, Tsuruda K, Hofvind S. The impact of compression force and pressure at prevalent screening on subsequent re-attendance in a national screening program. *Prev Med* 2018; **108**: 129–36. doi: https://doi.org/10.1016/j.ypmed.2018.01.008
28. de Groot JE, Hopman IGM, van Lier M, Branderhorst W, Grimbergen CA, den Heeten GJ. Pressure-standardised mammography does not affect visibility, contrast and sharpness of stable lesions. *Eur J Radiol* 2017; **86**: 289–95. doi: https://doi.org/10.1016/j.ejrad.2016.11.030
29. de Groot JE, Branderhorst W, Grimbergen CA, den Heeten GJ, Broeders MJM. Towards personalized compression in mammography: a comparison study between pressure- and force-standardization. *Eur J Radiol* 2015; **84**: 384–91. doi: https://doi.org/10.1016/j.ejrad.2014.12.005
30. de Groot JE, Broeders MJM, Branderhorst W, den Heeten GJ, Grimbergen CA. A novel approach to mammographic breast compression: Improved standardization and reduced discomfort by controlling pressure instead of force. *Med Phys* 2013; **40**: 081901. doi: https://doi.org/10.1118/1.4812418
31. Dustler M, Andersson I, Brorson H, Fröjd P, Mattsson S, Tingberg A, et al. Breast compression in mammography: pressure distribution patterns. *Acta Radiol* 2012; **53**: 973–80. doi: https://doi.org/10.1258/ar.2012.120238
32. Dustler M, Andersson I, Förnvik D, Tingberg A. The effect of breast positioning on breast compression in mammography: a pressure distribution perspective-M. *SPIE Medical Imaging* 2012; **8313**: 83134M.
33. Mercer CE, Hogg P, Cassidy S, Denton ERE. Does an increase in compression force really improve visual image quality in mammography? – An initial investigation. *Radiography* 2013; **19**: 363–5. doi: https://doi.org/10.1016/j.radi.2013.07.002
34. Poulos A, McLean D, Rickard M, Heard R. Breast compression in mammography: how much is enough? *Australas Radiol* 2003; **47**: 121–6. doi: https://doi.org/10.1046/j.0004-8461.2003.01139.x
35. Chida K, Komatsu Y, Sai M, Nakagami A, Yamada T, Yamashita T, et al. Reduced compression mammography to reduce breast pain. *Clin Imaging* 2009; **33**: 7–10. doi: https://doi.org/10.1016/j.clinimag.2008.06.025
36. Lau S, Abdul Aziz YF, Ng KH, Aziz YFA, KH N. Mammographic compression in Asian women. *PLoS One* 2017; **12**: e0175781. doi: https://doi.org/10.1371/journal.pone.0175781
37. O'Leary D, Teape A, Hammond J, Rainford L, Grant T. Compression force recommendations in mammography must be linked to image quality. *Proceedings of the European Congress of Radiology* 2011: 1–19.
38. Korf A, Herbst CP, Rae WID. The relationship between compression force, image quality and radiation dose in mammography. *SA J Radiol* 2009; **13**: 86–92. doi: https://doi.org/10.4102/sajr.v13i4.486