Standardised or individualised x-ray tube angle for mediolateral oblique projections in digital mammography?

Abstract

Introduction

We aimed to investigate whether there were any differences in positioning criteria related to the presentation of the pectoralis major muscle (pectoral muscle) for women of different heights using a standardized 60 degrees X-ray tube angle for mammograms in mediolateral oblique (MLO) projection.

Methods

Data from MLO mammograms of right breasts of 45,193 women screened in BreastScreen Norway 2016-2019 were used. The positioning criteria were related to the pectoral muscle length (measure A and measure B), width and shape and considered adequate or inadequate depending on the degree of fulfilling the criteria. Data associated with the pectoral muscle were extracted from Volpara, an automated software for breast density assessment. Information on height was obtained from a self-reported questionnaire received by the women together with the invitation to attend the screening program. Women were divided into three groups based on the height percentiles (P) in the Norwegian growth curves: < 25th percentile (<P25th: ≤163 cm), 25th- 75th percentile (P25-P75th: 164-170 cm), and >75th percentile (>P75th: >170 cm). Logistic regression was used to analyse the odds of adequate pectoral muscle length A and B, and shape, adjusting each model for screening technique and equipment model. Results were presented with odds ratios (OR) and 95% confidence intervals (CI).

Results

Mean age of the screened women was 61.5 (SD= 4.8) years. The adequate measure for the pectoral muscle length A was obtained for 25.9% (11,724/45,193), length B for 76.3% (34,489/45,193), width for 75.0% (33,894/45,193) and shape for 97.6% (44,118/45,193) of the mammograms. Adjusted odds of an adequate pectoral muscle length A were lower for women of <P25th (OR=0.90, 95% CI: 0.86-0.95) compared to women of P25-75th. Odds of an adequate pectoral muscle length B were lower for women of <P25th (OR=0.88, 95%CI 0.84-0.93) and higher for women of >P75th (OR=1.08, 95%CI 1.02-1.14) compared to women of P25-75. Odds of an adequate pectoral muscle shape were higher for women of <P25th (OR=1.14, 95%CI 1.08-1.19) and lower for women of >P75th (OR=0.92, 95%CI 0.87-0.97) compared to women of P25-75th.

Conclusions

The 60 degrees X-ray tube angle might suit most of the female population offered mammographic screening in Norway, but women of a relatively low height (163 cm or lower) might benefit from an X-ray tube angle less than 60-degrees.

Implications for practice

Using 60 degrees X-ray tube angle for the MLO mammograms in Breast Screen Norway fit the majority of the participating women. More research is needed to change the protocol associated with the tube angle for women shorter than 163 cm.

Introduction

Breast cancer is the most common type of cancer among women worldwide (1). Population-based mammographic screening programs aim to reduce breast cancer morality through early detection of the disease (2). Screening examinations involve two-view mammography (craniocaudal, CC and mediolateral oblique, MLO) of each breast. Optimal visualization of the breast tissue is essential for perception of suspicious findings associated with breast cancer (3-5). Furthermore, current and prior mammograms are compared for subtle changes, which highlights the importance of reproducible breast positioning (3-6). Several factors affect the visualisation of the breast and reproducibility of the mammograms, for instance the equipment, positioning, and breast compression (4-7).

MLO mammograms involve angling the X-ray tube of the mammography machine to provide an oblique image of the breast, which is aimed at demonstrating a maximum amount of breast tissue and pectoralis major muscle (pectoral muscle) (4). The significance of the correct positioning of the pectoral muscle during mammography is difficult to undermine. Pectoral muscle attenuation might be used as a marker for breast cancer risk, while an insufficient overview of the pectoral muscle on the mammogram can cause missed cancers and an increase in false-positive screening results (3, 5, 6, 8-10).

The recommended angle of the x-ray tube varies between countries, normally between 45 and 60 degrees (3, 11, 12). In BreastScreen Norway, a 60 degrees x-ray tube angle has been used since the program started in 1996 (11). The Norwegian guidelines further state that if a different angle is used, this angle should be used on all mammograms of this woman to ensure reproducible mammograms (11). However, some authors recommend adjusting the angle of the X-ray tube to the size of the individual breast and angle of the chest wall (3), or the height of the woman (13). There is limited evidence behind such a recommendation and, in our opinion, individualised angle selection could potentially hamper effective screening, as it would demand a longer examination time (13). We wanted to take advantage of data collected as a part of BreastScreen Norway and investigate whether there were differences in measured positioning criteria associated with the pectoral muscle for women of different height using a standardized X-ray tube angle for MLO view. The results of this study will contribute to establishing evidence for individualising the angle of the X-ray tube based on the height of the women to optimize appearance of the pectoral muscle.

Literature review

Key training or senior radiographers, performing mammography in the UK, provided the recommendation to adjust the X-ray tube angle by women's height in a book chapter (#21 in part IV) called "Practical mammography" in 2015 (13). In detail, they described a step-by-step guide to positioning, where the starting point of the X-ray tube angle for MLO view was 50 degrees, and recommended to adjust the angle based on the height of the woman in order to have the sternum

and image receptor parallel to each other (13). An individual and correct angle was argued to be vital for optimal compression force on the breast and not chest wall/axilla, and for optimal breast tissue coverage. Optimal breast tissue coverage is not possible to measure. However, the pectoral muscle could be used as an indirect measure of the breast tissue coverage. Incorrect angle could also lead to inadequate compression of the breast and potentially increase the levels of pain for the women. Even though this was published in 2015, we have not been able to find this recommendation included in the UK guidelines for radiographers performing mammographic screening (12).

Methods

The Cancer Registry of Norway administers BreastScreen Norway, a population-based breast cancer screening program where about 640,000 women aged 50-69 years are offered biennial mammographic screening. The program has been described in detail elsewhere (14).
This study was part of the project "Quality assurance and improvement in BreastScreen Norway", which has been reviewed by the privacy ombudsman at the Oslo University Hospital (PVO 20/12601).

Study sample

We extracted information from women who participated in BreastScreen Norway in Hordaland and Rogaland, 2016-2019 (Figure 1). We identified 46,180 women screened with two-view mammography of both breasts who had responded to a questionnaire that was sent to all women invited in the program 2006 - 2016. Women were excluded if they had height values of <120 cm and >190 cm (n = 891) or their examinations were acquired with an X-ray tube angle for MLO view differing from +/- 60 degrees x-ray tube angle were excluded (n = 96). These values represented extremes and might be imputed incorrectly in the system. The reliability of mammographic equipment regarding the tube angulation is generally reported to be high by the vendors (15). These exclusions left 45,193 women for analyses. A total of 27,231 (60.3%) women were screened with two-view digital mammography (DM) 17,762 (39.8%) were screened with Digital Breast Tomosynthesis (DBT). The screening examinations were performed with equipment from GE Healthcare, SenoClaire digital mammography and SenoClaire 3D Breast Tomosynthesis 2016 - 2017, and Senographe Pristina digital mammography and Senographe Pristina 3D Breast Tomosynthesis 2018 -2019.

Data collection and variables

We obtained data on age (years), screening technique (DM or DBT), equipment model (SenoClaire or Pristina), breast characteristics (fibroglandular volume [cm^3], breast volume [cm^3] and volumetric breast density [%]), breast compression parameters (compression force [Newton, N], compression pressure [kilopascal, kPa] and compressed breast thickness [mm]), appearance of the pectoral muscle, height (cm) and weight (kg) of the women. Information on women's age, screening

technique and equipment was extracted from the Cancer Registry database, while data on breast characteristics, breast compression parameters and appearance of the pectoral muscle were extracted from an automated software for density assessment, Volpara (Volpara Density version 1.5.1; Volpara Health Technologies, Wellington, NZ) (16). Volpara uses information from the DICOM-header in addition to image data to obtain this information. Information on height of the women was obtained from a questionnaire that all women in the screening program received together with the invitation to attend breast screening between 2006 and 2016 (17). The value was self-reported by the women.

We chose three positioning criteria as indirectly measures of breast tissue coverage, 1) the appearance of the pectoral muscle length, 2) pectoral muscle width and 3) pectoral muscle shape on the MLO projection. Length included two measures (pectoral muscle length A and B) as there is no consensus on a standard way to obtain this measure (Figure 2). The outcome of the variables was dichotomized into adequate and inadequate.

Length A was considered adequate if the pectoral muscle reached to the perpendicular line drawn from the nipple to the posterior edge of the image edge (line 1A in Figure 2), while length B was considered adequate if the muscle reached to the intersection between the posterior nipple line and the anterior margin of the pectoral muscle or the posterior image edge, whichever comes first (line 1B in Figure 2). Width, shown as line 2 in Figure 2, was considered adequate if the pectoral muscle measured >3 cm at the top corner of the image, while shape, shown as line 3 in the figure, was considered adequate if it was straight, in contrast to concave, convex, or serpentine.

The appearance of the pectoral muscle was investigated according to the women's height. We divided the women into three groups based on the height percentiles (P) in the Norwegian growth curves: < 25th percentile (<P25th:≤163 cm), 25th- 75th percentile (P25-P75th: 164-170 cm), and > 75th percentile (>P75th: >170 cm) (18). As no statistically significant differences were found between the results for the right and left breasts, the results from the right breasts were presented in the main tables and figures while results from the left breasts were shown in the Supplemental material.

Statistical analyses

Age, screening technique, fibroglandular volume, breast volume and volumetric breast density, compression force, compression pressure, compressed breast thickness, adequate pectoral muscle length A and B, width and shape were presented descriptively in a table stratified by the height categories, with mean and standard deviation (SD) for normally distributed continuous variables, medians and interquartile ranges (IQR) for continuous variables with a skewed distribution confirmed by normality plots, and frequencies and percentages for categorical variables. Logistic regression was used to analyse the odds of adequate pectoral muscle presentation separately length A and B, and shape adjusting each model for screening technique and equipment model. P25-P75th for height was

used as the reference. Results were presented as odds ratio (OR) with 95% confidence interval (CI). The pectoral muscle width was not included as this criterion was met by almost all images (97%). We further used unadjusted logistic regression models with height as a continuous variable to predict the mean margins for pectoral muscle length A and B, and shape at a 150 cm, 155 cm, 160 cm, 165 cm, 170 cm, 175 cm, 180 cm, and 185 cm. Finally, we explored the possibility of non-linear associations by creating restricted cubic splines with five knots from the height variable and including them in the regression model, then drawing graphs of the model with an estimated regression line with 95%CI.

Results

Mean age of the 45,193 women was 61.5 (SD=4.8) years. Median fibroglandular volume was 42.5 (IQR: 31.1-60-9) cm^3, breast volume 918.9 (IQR: 618.4-1264.5) cm^3 and volumetric breast density 4.9 (IQR: 3.1-8.0)%, respectively (Table 1). Mean compression force was 115.1 (SD=22.7) N, pressure 9.4 (SD=2.6) kPa and compressed breast thickness 59.6 (SD=13.1) mm. Compression pressure decreased by increasing height categories (<P25th:9.5, SD=2.7 kPa; P25-75th:9.3, SD=2.5 kPa; >P75th:9.2, SD=2.5 kPa), while fibroglandular volume (<P25th:41.1, IQR=30.1-58.4 cm^3; P25-75th:42.6, IQR=31.3-61.1 cm^3; >P75th:44.6, IQR=32.5-64.5 cm^3), breast volume (<P25th:900.3, IQR=619.4-1241.7 cm^3; P25-75th:919.2, IQR=621.1-1263.9 cm^3; >P75th:947.3, IQR=627.1-1295.3 cm^3), volumetric breast density (<P25th:4.7, IQR=3.0-7.8 %; P25-75th:4.9, IQR=3.0-8.1%; >P75th:5.1, IQR=3.1-8.3 %), compression force (<P25th:114.8, SD=22.6 N; P25-75th:115.0, SD=22.5 N; >P75th:115.5, SD=23.3 N), and compressed breast thickness (<P25th:59.4, SD=12.9 mm; P25-75th:59.6, SD=13.0 mm; >P75th:60.0, SD=13.3 mm) increased with increasing height categories

The percentage of mammograms with adequate pectoral muscle length A, pectoral muscle width and shape increased by increasing height categories, while the percentage of mammograms with adequate pectoral muscle length B decreased by increasing height categories (Table 1).

In the adjusted logistic regression model, odds of an adequate pectoral muscle length A were lower for women of <P25th (OR=0.90, 95%CI 0.86-0.95) compared to women of P25-75th, and lower for DM-Pristina (OR 0.78, 95%CI 0.74-0.82) and DBT-SenoClaire (OR=0.90, 95% 0.82-0.98) compared to DM-SenoClaire (Table 2). Odds of an adequate pectoral muscle length B were lower for women of <P25th (OR=0.88, 95%CI 0.84-0.93) and higher for women of >P75th (OR=1.08, 95%CI 1.02-1.14) compared to women in P25-75th. Further, the OR was lower for DM-Pristina (OR=0.66, 95%CI 0.63-0.70) and DBT-SenoClaire (OR=0.88, 95%CI 0.81-0.96) and higher for DBT-Pristina (OR=1.87, 95%CI 1.67-1.89) compared to DM-SenoClaire. Odds of an adequate pectoral muscle shape were higher for women of <P25 (OR=1.14, 95%CI 1.08-1.19) and lower for women of >P75th (OR=0.92, 95%CI 0.87-0.97) compared to women in P25-75th and were lower for DBT-SenoClaire (OR=0.83, 95%CI 0.76-0.90) and DBT-Pristina (OR=0.86, 95%CI 0.82-0.91) compared to DM-SenoClaire.

The point estimates for the probability of the adequate pectoral muscle length A increased by height from 22.2% to 30.6% and from 71.1% to 81.5% for length B, while the point estimates for the probability of the adequate pectoral muscle shape decreased by height from 79.5% to 69.2% (Table 3).

The probability of attaining adequate pectoral muscle length A increased from 19% to 29% by increasing height of the women, from 150 cm to 185 cm (Figure 3). The probability of adequate pectoral muscle length B increased from 71% to 79% by increasing height from 155 cm to 172 cm and were 79% and 78% for women at 172 cm and 180 cm, respectively. The probability of the adequate pectoral muscle width was 97% and 98% for women at height 155 cm and 180 cm. The probability of the adequate pectoral muscle shape decreased from 80% to 68% by increasing height from 155 cm to 180 cm, was at 75% for women between 165 cm and 172 cm, and 75% and 68% for women at height 173 cm and 180 cm, respectively.

Discussion

Among 45,193 women screened with digital mammography (DM) or digital breast tomosynthesis (DBT) in BreastScreen Norway with a 60 degrees X-ray tube angle in the MLO projection, the odds for adequate pectoral muscle length were lower for women 163 cm or lower, and higher for women 170 cm or higher, compared to women of 164-170 cm. An adequate pectoral muscle width was achieved in about 97% of images in our study. The distribution of adequate pectoral muscle shape decreased with women's height.

Adequate pectoral muscle length, width and shape on MLO mammogram are assumed to be of positive influence for visualization of suspicious lesions in the breast, specifically in the posterior inferior area of the mammogram, which represent an area in the breast where breast cancers might be missed (9, 19). Moreover, correct positioning might provide an equal distribution of compression force and, therefore, pressure over the breast, reducing the probability of discomfort and pain for the women (13).

The necessity to individualise the angle of the X-ray tube according to the size of the breast has been argued as an effort to improve the visualization of the pectoral muscle in the MLO view (3). One study compared 35, 45 and 55 degrees angles for MLO images in DM, recommending a 55 degrees angle as more appropriate for women with longer thoraxes and small breasts and a 35 degrees angle for those with shorter thoraxes and large breasts (20).

The percentage of mammograms with adequate pectoral muscle length A was rather low (19%-29%) in our study, which might be associated with positioning and less attention to this parameter given by the radiographers. Choice of X-ray tube angle is related to women's height, but also to the body type, including chest width, thorax length, sternum angle or breast size (13). Therefore, individualising the X-ray tube angle not only by height, but also by breast volume, chest width, thorax

length and sternum angle might be a more optimal solution for obtaining a mammogram with an adequate quality and equally distributed compression force. However, such individualisation is time consuming and is not applicable in a screening setting. Nevertheless, women with a height 163cm or lower might benefit from a less than 60 degrees X-ray tube angle, because this would improve the quality of mammograms with regard to the length A and B. DM Pristina, DBT SenoClaire and DBT Pristina were associated with lower odds for adequate pectoral muscle length A and shape compared to DM SenoClaire, while DBT Pristina was associated with higher odds for adequate pectoral muscle length B, compared to DM SenoClaire. Pristina is the newest mammography equipment from GE and our finding might indicate better equipment, both for the women and the radiographers. However, the impact of the radiographers, performing the mammography, with regard to the length and extent of their experience in working with DM and DBT screening, might also be of influence. The results of the study might imply that 60 degrees X-ray tube angle was suitable for the Norwegian female population participated in the study. However, it is possible that women of 163 cm or lower might obtain a better positioning of pectoral muscle with a less than 60 degrees x-ray tube angle.

Study limitations

This study did not use the information about chest width, thorax length, sternum angle or breast size and relied solely on height as the main factor affecting the percentage of adequate mammograms. The Norwegian female population is on average 164-172 cm and the 60 degree X-ray tube angle could be considered suitable. However, chest width, thorax length, sternum angle or breast size might be confounders, and should be included in future studies on the topic. Is should be noted that the possibility to adjust the angle is mostly available for the radiographers performing mammography. The measurements of height reported by the women at various time points between 2006 and 2016 could have been higher than the height at the time of actual screening examination, which took place later in life, as aging might have been associated with decreasing height in postmenopausal women (21). We were unable to investigate the extent of the changes, but a validation study of reported height among women responding to the questionnaire used did not show substantial variation in the height reported at two years intervals (17). The lack of consensus on the measuring of the pectoral muscle length could be another limitation of the study, as pectoral muscle length A was generally adequate in no more than 30% of cases, while length B was adequate in more than 70% of cases. These results indicated major discrepancies in the measurements. Volpara is developed to measure image quality as one measure, where the pectoral muscle appearance represents one out of several measures (16, 22). However, a previous study made quantitative measurements of pectoral muscle angle and length to posterior nipple line and compared human versus Volpara metrics (23). That study showed adequate accuracy of the Volpara measures, especially to the level needed to observe trends within large sample sizes.

Conclusion

The results of the study might imply that 60 degrees X-ray tube angle was suitable for the Norwegian female population participated in the study. However, it is possible that women of 163 cm or lower might obtain a better positioning of pectoral muscle with a less than 60 degrees X-ray tube angle. Current practice, use of the 60 degrees X-ray tube angle for the MLO mammograms, will be kept in BreastScreen Norway until evidence of beneficial effects of a less than the 60 degrees X-ray tube angle for women 163 cm or lower is proven.

References

1. Bray F, Ferlay J, Soerjomataram I, Siegel RL, Torre LA, Jemal A. Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2018;68(6):394-424.
2. Lauby-Secretan B, Scoccianti C, Loomis D, Benbrahim-Tallaa L, Bouvard V, Bianchini F, et al. Breast-cancer screening—viewpoint of the IARC Working Group. N Engl J Med. 2015;372(24):2353-8.
3. Popli MB, Teotia R, Narang M, Krishna H. Breast Positioning during Mammography: Mistakes to be Avoided. Breast Cancer (Auckl). 2014;8:119-24.
4. Eklund GW. The Art of Mammographic Positioning. In: Friedrich M, Sickles EA, editors. Radiological Diagnosis of Breast Diseases. Berlin, Heidelberg: Springer Berlin Heidelberg; 2000. p. 75-88.
5. Bassett LW, Hirbawi IA, DeBruhl N, Hayes MK. Mammographic positioning: evaluation from the view box. Radiology. 1993;188(3):803-6.
6. Huppe AI, Overman KL, Gatewood JB, Hill JD, Miller LC, Inciardi MF. Mammography Positioning Standards in the Digital Era: Is the Status Quo Acceptable? AJR American journal of roentgenology. 2017;209(6):1419-25.
7. Branderhorst W, de Groot JE, Neeter LM, van Lier MG, Neeleman C, den Heeten GJ, et al. Force balancing in mammographic compression. Medical physics. 2016;43(1):518.
8. Cheddad A, Czene K, Hall P, Humphreys K. Pectoral Muscle Attenuation as a Marker for Breast Cancer Risk in Full-Field Digital Mammography. Cancer Epidemiology, Biomarkers & Prevention. 2015;24(6):985-91.
9. Muttarak M, Pojchamarnwiputh S, Chaiwun B. Breast carcinomas: why are they missed? Singapore Med J. 2006;47(10):851-7.
10. Majid AS, Paredes ESd, Doherty RD, Sharma NR, Salvador X. Missed Breast Carcinoma: Pitfalls and Pearls. RadioGraphics. 2003;23(4):881-95.
11. Ertzaas AH, M; Hantho, C; Hammond, RL; Larsen, AN; Music, J;, Westermann LT, L; Wåde, GG; Hofvind, S. Quality Assurance Manual in BreastScreen Norway - guidelines for radiographers [Kvalitetsmanual i Mammografiprogrammet– retningslinjer for radiografi]. Oslo: Cancer Registry of Norway; 2021. [cited 2022 February 19]. Available from: https://www.kreftregisteret.no/globalassets/publikasjoner-og-rapporter/mammografiprogrammet/2021-delmanual-for-radiografi.pdf
12. Public Health England, Breast Screening: Guidance for breast screening mammographers 2020. [cited 2022 February 19]. Available from: https://www.gov.uk/government/publications/breast-screening-quality-assurance-for-mammography-and-radiography/guidance-for-breast-screening-mammographers.
13. Mercer CE, Hill CA, Kelly A, Smith HL. Practical mammography. In: Hogg P, Kelly J, Mercer C, editors. Digital Mammography: A Holistic Approach. United Kingdom: Springer; 2015. p. 175-88.
14. Hofvind S. Cancer in Norway 2016. Special Issue: The Norwegian Breast Cancer Screening Program, 1996-2016: Celebrating 20 years of organised mammographic screening. Oslo: Cancer Registry of Norway; 2017. [cited 2022 February 19]. Available from: https://www.kreftregisteret.no/globalassets/cancer-in-norway/2016/mammo_cin2016_special_issue_web.pdf.
15. Sue Williams KT, Stella Campbell. Fundamentals of Mammography. 3rd ed ed: Elsevier Health Sciences; 2021.
16. VolparaSolutions. VolparaResearch. 2022 [cited 2022 February 19]. Available from: http://volparasolutions.com/solutions/volpararesearch/.
17. Tsuruda KM, Sagstad S, Sebuodegard S, Hofvind S. Validity and reliability of self-reported health indicators among women attending organized mammographic screening. Scandinavian journal of public health. 2018;46(7):744-51.
18. Júlíusson PB, Roelants M, Eide GE, Moster D, Juul A, Hauspie R, et al. [Growth references for Norwegian children]. Tidsskr Nor Laegeforen. 2009;129(4):281-6.

19. Théberge I, Guertin MH, Vandal N, Côté G, Dufresne MP, Pelletier É, et al. Screening Sensitivity According to Breast Cancer Location. Can Assoc Radiol J. 2019;70(2):186-92.
20. Bedene A, Alukić E, Žibert J, Mekiš N. Mediolateral oblique projection in mammography: use of different angulation for patients with different thorax anatomies. Journal of Health Sciences. 2019;9(1):40-5.
21. Sorkin JD, Muller DC, Andres R. Longitudinal change in height of men and women: implications for interpretation of the body mass index: the Baltimore Longitudinal Study of Aging. American journal of epidemiology. 1999;150(9):969-77.
22. VolparaSolutions – Volpara Density [cited 2022 February 19]. Available from: http://www.volparasolutions.com/our-products/volparadensity/.
23. Waade GG, Danielsen AS, Holen Å S, Larsen M, Hanestad B, Hopland NM, et al. Assessment of breast positioning criteria in mammographic screening: Agreement between artificial intelligence software and radiographers. Journal of medical screening. 2021;28(4):448-55.

Table 1. Descriptive information for 45,193 mediolateral oblique mammograms of right breasts of women screened in BreastScreen Norway, 2016-2019

Table 2. Odds ratio of adequate pectoralis major muscle (pectoral muscle) length A and B, and shape associated with categories of women's height (<P25th: ≤163 cm, P25-P75th: 164-170 cm, and >P75th: >170 cm), adjusted for screening technique and equipment, for 45,193 mammograms of right breasts of women screened in BreastScreen Norway, 2016-2019

Table 3. Point estimates with 95% confidence interval (CI) of the probability of the adequate pectoralis major muscle (pectoral muscle) length A and B, and shape by women's height (150 cm - 185 cm) for mediolateral oblique mammograms of right breasts among women screened in BreastScreen Norway, 2016-2019

Figure 1. Study sample before and after exclusions

Figure 2. Positioning criteria defining the appearance of pectoralis major muscle (pectoral muscle); 1A) pectoral muscle length A; 1B) pectoral muscle length B; 2) pectoral muscle width and 3) pectoral muscle shape

Figure 3. The probability of adequate pectoralis major muscle (pectoral muscle) length A and length B, width and shape for mediolateral oblique mammograms of right breasts by women's height

Acknowledgements

This study is a part of a randomised controlled trial To-Be 2, which has received funding by the Norwegian Cancer Society (grant # 190184-2017). We would like to thank the radiographers and women who agreed to participate in this study. We thank Gunvor G Wåde and Anders S Danielsen for the valuable assistance with data management and analyses.

Figure 1

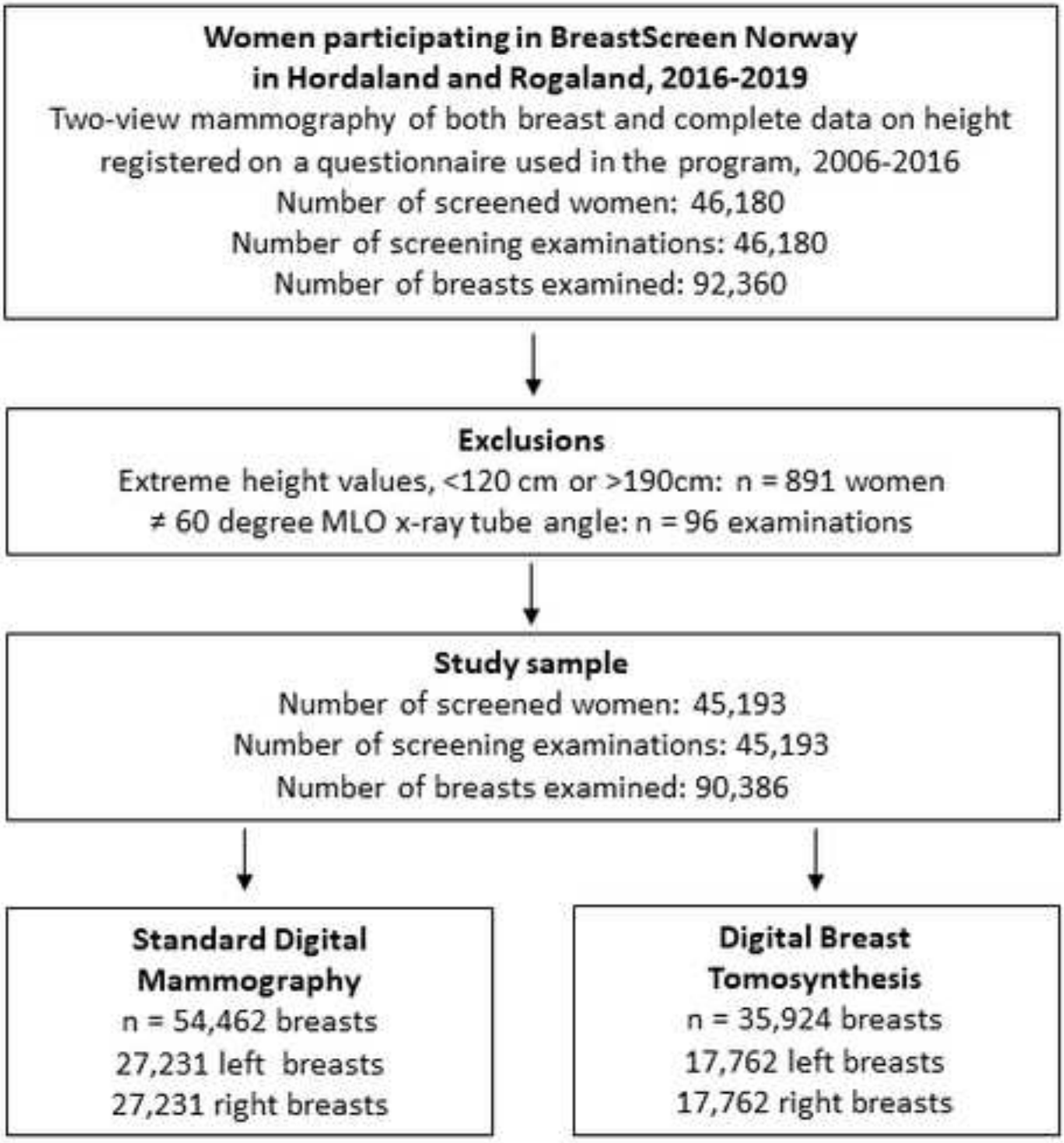


Figure 2

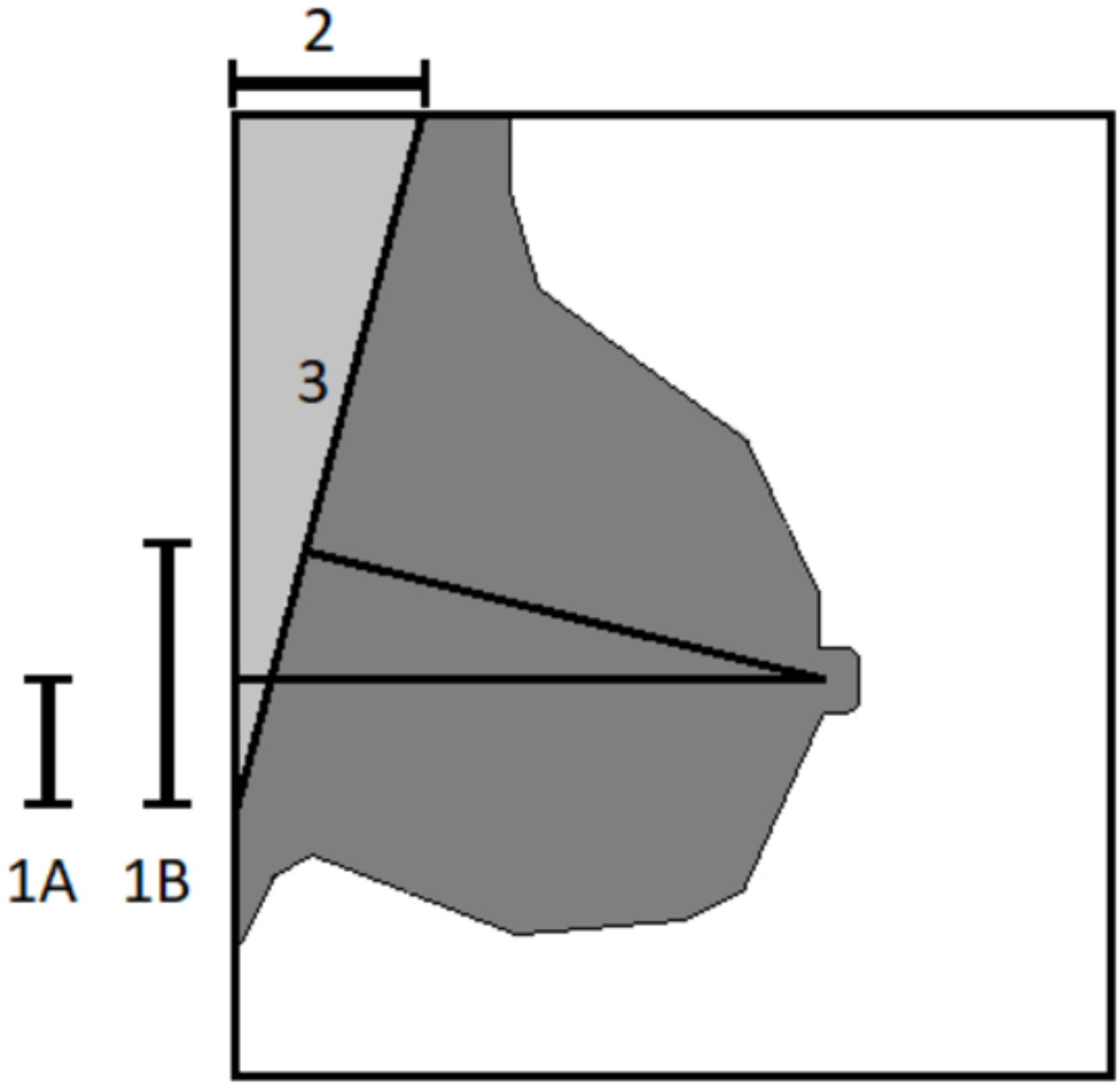


Figure 3

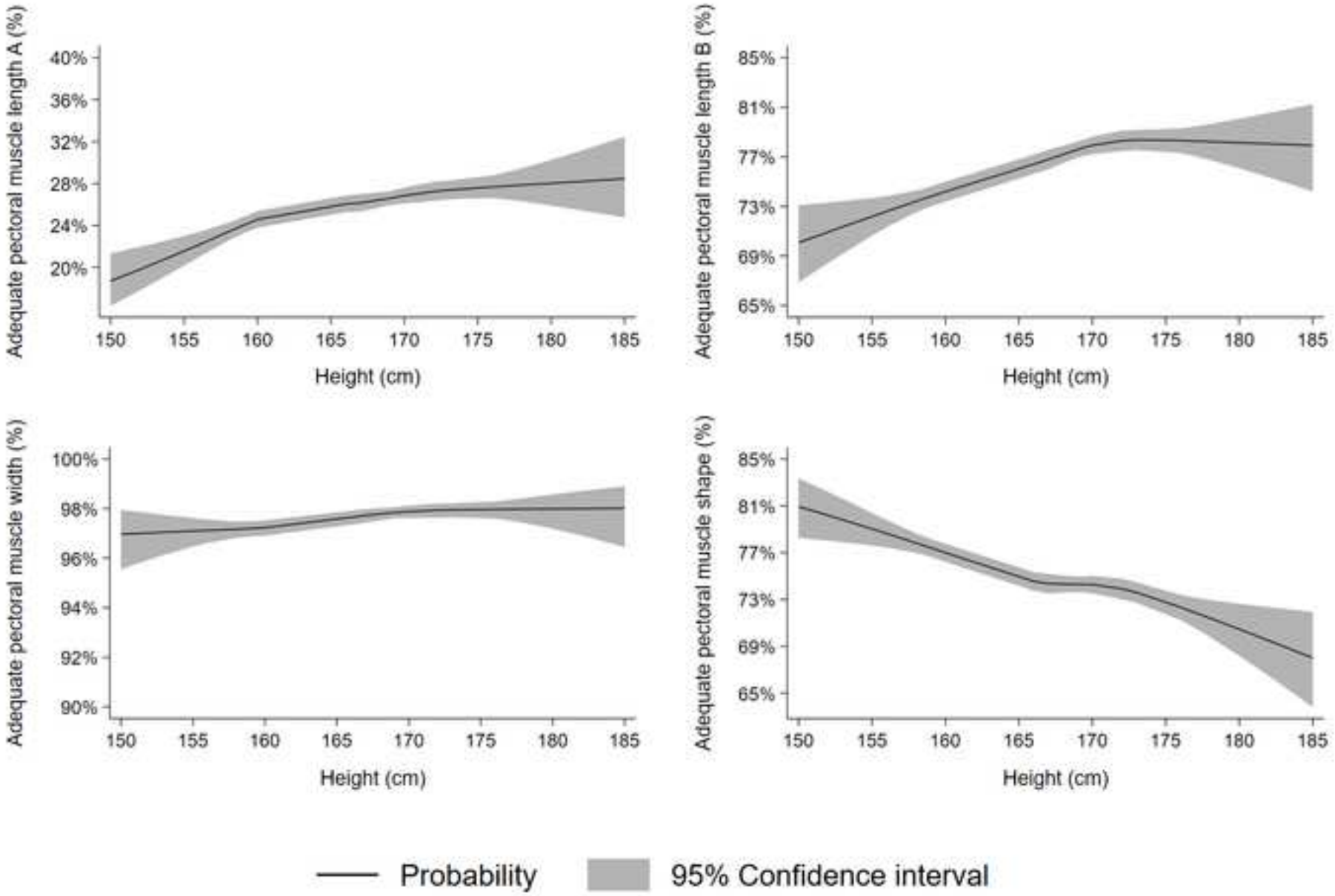


Table 1: Descriptive information for 45,193 mediolateral oblique mammograms of right breasts of women screened in BreastScreen Norway, 2016-2019

		Percentiles of height		
	All	**<P25th (≤163 cm)**	**P25-P75th (164-170 cm)**	**>P75th (>170 cm)**
	n = 45,193	n = 14,145	n = 21,366	n = 9,682
Mean age (SD), years	61.5 (4.8)	61.9 (4.8)	61.6 (4.8)	60.8 (4.7)
Screening technique				
DM, n (%)	27,231 (60.3)	8,674 (61.3)	12,876 (60.3)	5,681 (58.7)
DBT, n (%)	17,962 (39.8)	5,471 (38.7)	8,490(39.7)	4,001 (41.3)
Fibroglandular volume, cm^3				
Median (IQR)	42.5 (31.1-60.9)	41.1 (30.1-58.4)	42.6 (31.3-61.1)	44.6 (32.5-64.5)
Breast volume, cm^3				
Median (IQR)	918.9 (618.4-1264.5)	900.3 (618.4-1241.7)	919.2 (621.1-1263.9)	947.3 (627.1-1295.3)
Volumetric breast density, %				
Median (IQR)	4.9 (3.0-8.1)	4.7 (3.0-7.8)	4.9 (3.0-8.1)	5.1 (3.1-8.3)
Compression force, Newton				
Mean (SD)	115.1 (22.7)	114.8 (22.6)	115.0 (22.5)	115.5 (23.3)
Compression pressure, kPa				
Mean (SD)	9.4 (2.6)	9.5 (2.7)	9.3 (2.6)	9.2 (2.5)
Compressed breast thickness, mm				
Mean (SD)	59.6 (13.1)	59.4 (12.9)	59.6 (13.0)	60.0 (13.3)
Mammograms with adequate image quality, n				
Pectoral muscle length A n, %	11,724 (25.9)	3,449 (24.4)	5,628 (26.3)	2,647 (27.3)
Pectoral muscle length B n, %	33,894 (75.0)	10,890 (77.0)	15,942 (74.6)	7,062 (72.9)
Pectoral muscle width n, %	34,489 (76.3)	10,517 (74.4)	16,403 (76.8)	7,569 (78.2)
Pectoral muscle shape n, %	44,118 (97.6)	13,753 (97.2)	20,877 (97.7)	9,488 (98.0)

Abbreviations: DM: digital mammography; DBT: digital breast tomosynthesis; SD: standard deviation; IQR: interquartile range

Table 2. Odds ratio of adequate pectoralis major muscle (pectoral muscle) length A and B, and shape associated with categories of women's height (<P25th: ≤163 cm, P25-P75th: 164-170 cm, and >P75th: >170 cm), adjusted for screening technique and equipment, for 45,193 mammograms of right breasts of women screened in BreastScreen Norway 2016-2019

	Unadjusted			Adjusted		
	OR	95% CI	p-value	OR*	95% CI	p-value
Pectoral muscle length A						
Height						
<P25th	0.90	0.86-0.95	<0.01	0.90	0.86-0.95	<0.01
P25-P75th	1.00	-	-	1.00	-	-
>P75th	1.05	1.00-1.11	0.07	1.05	1.00-1.11	0.06
Technique and equpiment						
DM SenoClaire	1.00	-	-	1.00	-	-
DM Pristina	0.78	0.74-0.82	<0.01	0.78	0.74-0.82	<0.01
DBT SenoClaire	0.90	0.82-0.98	0.01	0.90	0.82-0.98	0.01
DBT Pristina	1.00	0.95-1.06	0.86	1.00	0.95-1.06	0.94
Pectoral muscle length B						
Height						
<P25th	0.88	0.83-0.92	<0.01	0.88	0.84-0.93	<0.01
P25-P75th	1.00	-	-	1.00	-	-
>P75th	1.08	1.02-1.15	<0.01	1.08	1.02-1.14	0.01
Technique and equpiment						
DM SenoClaire	1.00	-	-	1.00	-	-
DM Pristina	0.67	0.63-0.70	<0.01	0.66	0.63-0.70	<0.01
DBT SenoClaire	0.88	0.81-0.96	<0.01	0.88	0.81-0.96	<0.01
DBT Pristina	1.78	1.68-1.89	<0.01	1.78	1.67-1.89	<0.01
Pectoral muscle shape						
Height						
<P25th	1.14	1.08-1.20	<0.01	1.14	1.08-1.19	<0.01
P25-P75th	1.00	-	-	1.00	-	-
>P75th	0.92	0.87-0.97	<0.01	0.92	0.87-0.97	<0.01
Technique and equpiment						
DM SenoClaire	1.00	-	-	1.00	-	-
DM Pristina	0.99	0.94-1.05	0.84	0.99	0.94-1.05	0.86
DBT SenoClaire	0.83	0.76-0.90	<0.01	0.83	0.76-0.90	<0.01
DBT Pristina	0.86	0.82-0.91	<0.01	0.86	0.82-0.91	<0.01

* Adjusted for screening technique and equipment model

Abbreviations: OR: odds ratio; CI: confidence interval; DM: digital mammography; DBT: digital breast tomosynthesis

Table 3: Point estimates with 95% confidence interval (CI) of the probability of the adequate pectoralis major muscle (pectoral muscle) length A and B, and shape by women's height (150 cm - 185 cm) for mediolateral oblique mammograms of right breasts among women screened in BreastScreen Norway 2016-2019

	Adequate pectoral muscle length A		Adequate pectoral muscle length B		Adequate pectoral muscle shape	
Women's height	Point estimate	95% CI	Point estimate	95% CI	Point estimate	95% CI
150 cm	22.2 %	21.1-23.3%	71.1 %	69.8-72.5%	79.5 %	78.5-80.1%
155 cm	23.3 %	22.4-24.1%	72.8 %	71.9-73.7%	78.2 %	77.4-79.1%
160 cm	24.4 %	23.8-25.0%	74.4 %	73.8-75.0%	76.9 %	76.3-77.4%
165 cm	25.6 %	25.2-26.0%	75.9 %	75.5-76.3%	75.4 %	75.0-75.9%
170 cm	26.8 %	26.3-27.3%	77.4 %	77.0-77.9%	74.0 %	73.5-74.4%
175 cm	28.0 %	27.3-28.8%	78.8 %	78.2-79.5%	72.4 %	71.7-73.2%
180 cm	29.3 %	28.2-30.4%	80.2 %	79.3-81.1%	70.8 %	69.7-80.0%
185 cm	30.6 %	29.1-32.1%	81.5 %	80.3-82.6%	69.2 %	67.6-70.7%

Figure A1. The probability of the adequate pectoralis major muscle (pectoral muscle) length A and B, width and shape by height for mediolateral oblique mammograms of left breasts among women screened in BreastScreen Norway 2016-2019

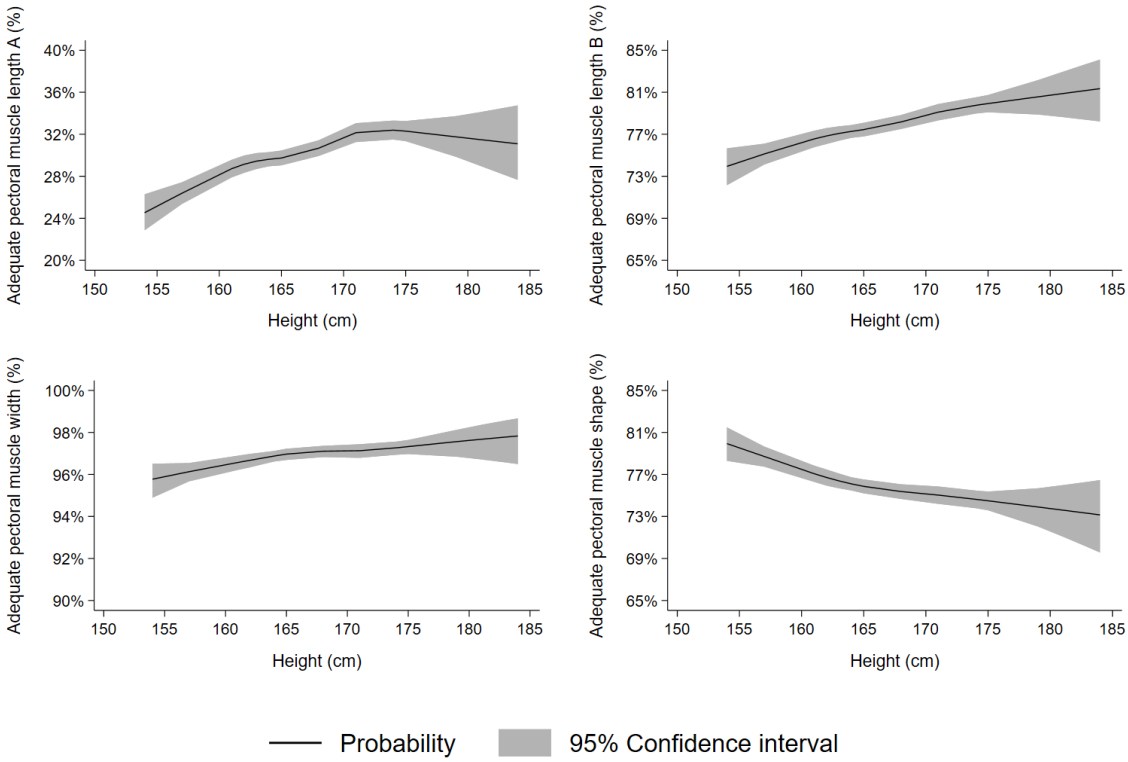
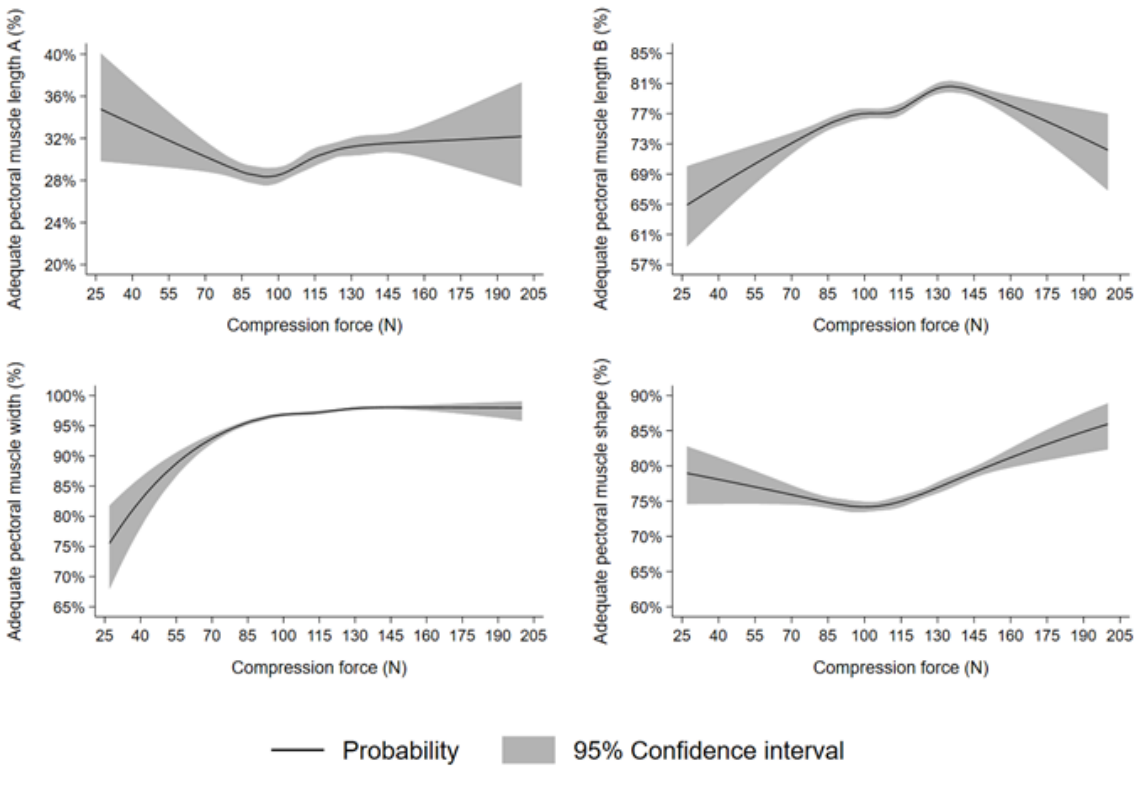
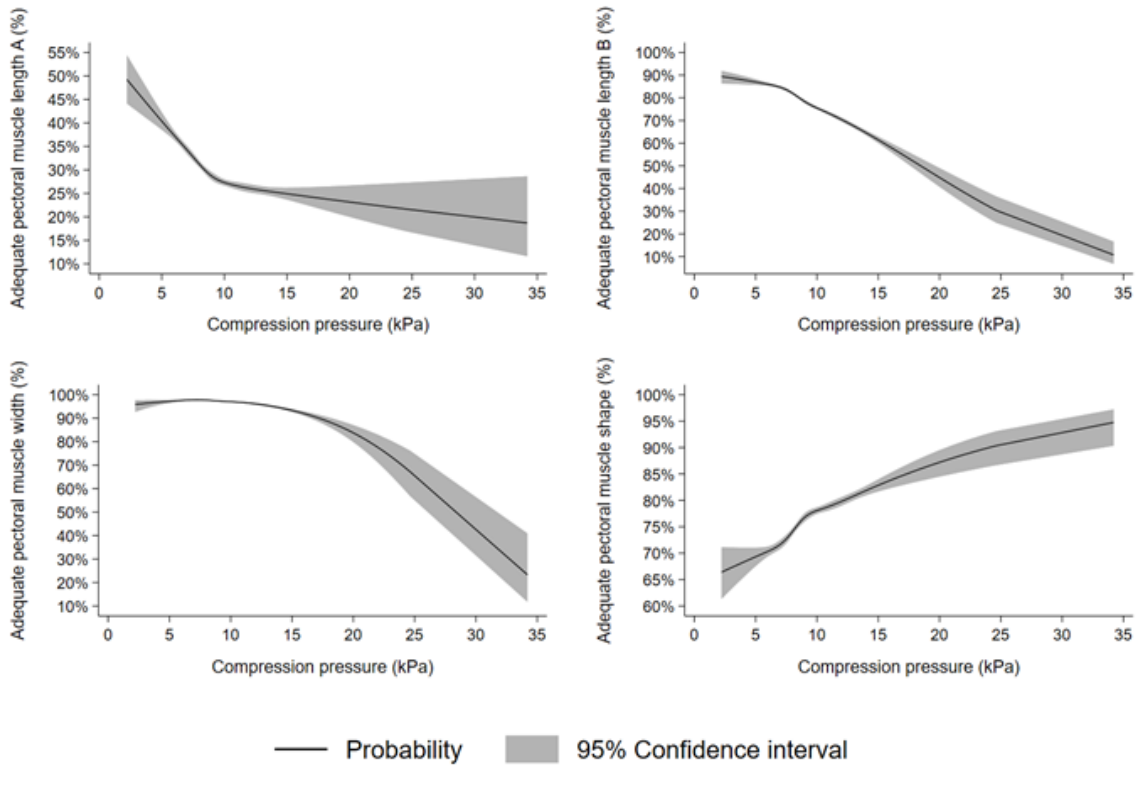


Figure A2. The probability of the adequate pectoralis major muscle (pectoral muscle) length A and B, width and shape by A. compression force (Newton, N) and B. compression pressure (kilopascal, kPa), by height for mediolateral oblique mammograms of left breasts among women screened in BreastScreen Norway 2016-2019


Adequate pectoral muscle length A (%)
40%
36%
32%
28%
24%
20%
25 40 55 70 85 100 115 130 145 160 175 190 205
Compression force (N)
Adequate pectoral muscle length B (%)
85%
81%
77%
73%
69%
65%
61%
57%
25 40 55 70 85 100 115 130 145 160 175 190 205
Compression force (N)
Adequate pectoral muscle width (%)
100%
95%
90%
85%
80%
75%
70%
65%
25 40 55 70 85 100 115 130 145 160 175 190 205
Compression force (N)
Adequate pectoral muscle shape (%)
90%
85%
80%
75%
70%
65%
60%
25 40 55 70 85 100 115 130 145 160 175 190 205
Compression force (N)
Probability
95% Confidence interval

A


Adequate pectoral muscle length A (%)
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
0 5 10 15 20 25 30 35
Compression pressure (kPa)
Adequate pectoral muscle length B (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0 5 10 15 20 25 30 35
Compression pressure (kPa)
Adequate pectoral muscle width (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0 5 10 15 20 25 30 35
Compression pressure (kPa)
Adequate pectoral muscle shape (%)
100%
95%
90%
85%
80%
75%
70%
65%
60%
0 5 10 15 20 25 30 35
Compression pressure (kPa)
Probability
95% Confidence interval

B

Table A1. Descriptive information for 45,193 examinations of left breasts of women screened in BreastScreen Norway 2016-2019

		Percentiles of height		
	All breasts	**<P25th (≤163 cm)**	**P25-P75th (164-170 cm)**	**>P75th (>170 cm)**
	n = 45,193	n = 14,145	n = 21,366	n = 9,682
Mean age (SD), years	61.5 (4.8)	61.9 (4.8)	61.6 (4.8)	60.8 (4.7)
Screening technique				
DM, n (%)	27,231 (60.3)	8,674 (61.3)	12,876 (60.3)	5,681 (58.7)
DBT, n (%)	17,962 (39.8)	5,471 (38.7)	8,490(39.7)	4,001 (41.3)
Fibroglandular volume, cm^3				
Median (IQR)	42.1 (30.8-60.0)	40.2 (29.8-57.0)	42.3 (31.1-60.4)	44.4 (32.2-63.5)
Breast volume, cm^3				
Median (IQR)	934.0 (631.1-1,284.6)	915.2 (623.5-1,262.1)	934.1 (633.8-1,283.1)	962.7 (635.4-1,319.9)
Volumetric breast density, %				
Median (IQR)	4.7 (3.0-7.8)	4.5 (3.0-7.5)	4.7 (3.0-7.8)	4.9 (3.1-8.0)
Compression force, Newton				
Mean (SD)	113.9 (22.9)	114.0 (22.8)	113.7 (22.8)	114.2 (23.4)
Compression pressure, kPa				
Mean (SD)	9.3 (2.5)	9.5 (2.6)	9.2 (2.5)	9.1 (2.4)
Compressed breast thickness, mm				
Mean (SD)	60.3 (13.3)	60.1 (13.2)	60.3 (13.3)	60.6 (13.6)
Mammograms with adequate image quality, n (%)				
Pectoral muscle length A n, %	13,597 (30.1)	3,948 (27.9)	6,533 (30.6)	3,116 (32.2)
Pectoral muscle length B n, %	35,152 (77.8)	10,789 (76.3)	16,655 (78.0)	7,708 (79.6)
Pectoral muscle width n, %	43,797 (96.9)	13,646 (96.5)	20,733 (97.0)	9,418 (97.3)
Pectoral muscle shape n, %	34,334 (76.0)	10,970 (77.6)	16,148 (75.6)	7,216 (74.5)

Abbreviations: DM: digital mammography; DBT: digital breast tomosynthesis; SD: standard deviation; IQR: interquartile range

Table A2. Odds ratio of adequate pectoralis major muscle (pectoral muscle) length A and B, and shape associated with categories of height (<P25th: ≤163 cm, P25-P75th: 164-170 cm, and >P75th: >170 cm), adjusted for screening technique and equipment, for 45,193 mammograms of left breasts of women screened in BreastScreen Norway 2016-2019

	Unadjusted OR	95% CI	p-value	Adjusted OR*	95% CI	p-value
Pectoral muscle length A						
Height			<0.01			<0.01
<P25th	0.88	0.84-0.92	<0.01	0.88	0.84-0.92	<0.01
P25-P75th	1.00	-	-	1.00	-	-
>P75th	1.08	1.02-1.13	<0.01	1.08	1.02-1.14	<0.01
Technique and equpiment			<0.01			<0.01
DM + SenoClaire	1.00	-	-	1.00	-	-
DM + Pristina	0.75	0.71-0.79	<0.01	0.75	0.71-0.79	<0.01
DBT + SenoClaire	0.95	0.87-1.03	0.19	0.95	0.87-1.03	0.19
DBT + Pristina	0.96	0.91-1.01	0.10	0.95	0.91-1.00	0.07
Pectoral muscle length B						
Height			<0.01			<0.01
<P25th	0.91	0.86-0.96	<0.01	0.92	0.87-0.96	<0.01
P25-P75th	1.00	-	-	1.00	-	-
>P75th	1.10	1.04-1.17	<0.01	1.10	1.04-1.17	<0.01
Technique and equpiment			<0.01			<0.01
DM + SenoClaire	1.00	-	-	1.00	-	-
DM + Pristina	0.71	0.67-0.75	<0.01	0.71	0.67-0.75	<0.01
DBT + SenoClaire	1.05	0.96-1.15	0.29	1.05	0.96-1.15	0.30
DBT + Pristina	1.63	1.54-1.74	<0.01	1.63	1.53-1.73	<0.01
Pectoral muscle shape						
Height			<0.01			<0.01
<P25th	1.12	1.06-1.17	<0.01	1.12	1.06-1.17	<0.01
P25-P75th	1.00	-	-	1.00	-	-
>P75th	0.95	0.89-1.00	0.05	0.95	0.90-1.00	0.06
Technique and equpiment			<0.01			<0.01
DM + SenoClaire	1.00	-	-	1.00	-	-
DM + Pristina	0.98	0.93-1.04	0.47	0.98	0.93-1.04	0.48
DBT + SenoClaire	0.83	0.76-0.90	<0.01	0.83	0.76-0.90	<0.01
DBT + Pristina	0.86	0.81-0.91	<0.01	0.86	0.81-0.91	<0.01

*Mutually adjusted

Abbreviations: OR; odds ratio; CI: confidence interval; DM: digital mammography; DBT: digital breast tomosynthesis

Table A3. Point estimates for with the probability of the adequate pectoralis major muscle (pectoral muscle) length A and B, and shape by women's height (150 cm - 185 cm) for mediolateral oblique mammograms of left breasts among women screened in BreastScreen Norway 2016-2019

	Pectoral muscle shape		**Pectoral muscle length A**		**Pectoral muscle length B**	
Women's height	Point estimate	95% CI	Point estimate	95% CI	Point estimate	95% CI
150 cm	79.4 %	78.3-80.5%	25.2 %	24.1-26.4%	73.3 %	72.0-74.6%
155 cm	78.4 %	77.6-79.3%	26.7 %	25.8-27.6%	74.7 %	73.8-75.6%
160 cm	77.4 %	76.8-78.0%	28.1 %	27.5-28.7%	76.1 %	75.5-76.7%
165 cm	76.3 %	75.9-76.7%	29.6 %	29.2-30.1%	77.5 %	77.1-77.9%
170 cm	75.2 %	74.7-75.7%	31.2 %	30.7-31.7%	78.7 %	78.3-79.2%
175 cm	74.0 %	73.3-74.8%	32.8 %	32.0-33.6%	80.0 %	79.3-80.6%
180 cm	72.8 %	71.8-73.9%	34.4 %	33.3-35.6%	81.2 %	80.3-82.1%
185 cm	71.6 %	70.1-73.1%	36.1 %	34.5-37.7%	82.3 %	81.2-83.4%