Is Individualizing Breast Compression during Mammography useful? – Investigations of pain indications during mammography relating to compression force and surface area of the compressed breast

Ist eine Individualisierung der mammografischen Brustkompression sinnvoll? – Untersuchungen zu Schmerzangaben bei der Mammografie in Bezug auf Kompressionskraft und Fläche der komprimierten Brust.

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ABTRACT

Purpose The aim of this paper is to determine how the presence of pain during mammographic compression could be reduced. To this end, we examine its relationship with compression force, surface-area of the compressed breast, breast density (ACR) and former operations.

Materials and Methods In 199 women 765 mammograms were performed. Women were asked to rate the level of pain on a scale of 0 – 10 (0: no, 10: highest pain). The surface-area of the breast under compression captured by the mammograms was measured using planimetry. 52 of the 199 women were asked to identify the area of the upper body with the highest level of pain.

Results The thickness of the compressed breast was 65.2 % of the uncompressed breast at a force of 10 daN (57.8 % at 15 daN). When the force was increased from 10 daN to 15 daN, the average glandular dose (AGD) declined by 17 %. Tolerance of compression was associated with the size of the breast. More than 50 % of the mammograms with a small compression less than 9 daN were associated with higher level of pain. In the oblique projection, 60 % of the women specified the axilla as the area of maximum pain.

Conclusion Women with larger breasts tolerated a greater force of compression. This implies a need for individualised examination depending on the size of the breast. Women with increased pain susceptibility terminated the compression early regardless of a small compression less than 9 daN. More than 50 % of the women identified areas outside breast as especially painful. Therefore, during examination, the areas around the breast should also be taken into consideration in order to minimize unnecessary discomfort.

Key Points

- With increased mammographic compression force, the effectiveness of breast thickness reduction declined.
- A compression force of 15 daN enabled an additional reduction by 17 % in average glandular dose (AGD) compared to 10 daN.
- Tolerance of increased compression force was related to breast surface area.
- Women with increased susceptibility of pain terminated the compression at a low force of less than 9 daN
- Pain relating to the mammographic procedure was identified outside the breast by more than 50 % of the women.

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ZUSAMMENFASSUNG

Ziel Ziel der Arbeit ist es zu ermitteln, wie das Schmerzempfinden bei der mammografischen Kompression reduziert werden kann. Hierfür untersuchten wir seine Beziehung zur Kompressionskraft, Fläche der komprimierten Brust, Brustdichte (ACR) und Voroperationen.

Material und Methodik Bei 765 Mammografien von 199 Patientinnen wurden die Kompressionsschmerzen auf einer Skala von 0 – 10 bewertet (0: keine, 10: stärkste Schmerzen). Die Fläche der Brust wurde im Mammogramm planimetriert. Bei 52 der 199 Frauen wurde das Thoraxwandareal mit den größten Schmerzen abgefragt.

Ergebnisse Die Dicke der komprimierten Brust entsprach 65,2 % der Dicke der nicht komprimierten Brust bei einer Kraft von 10 daN (57,8 % bei 15 daN). Eine Erhöhung der Kraft von 10 auf 15 daN führte zu einer zusätzlichen Reduktion der Parenchymdosis (AGD) um 17 %. Die Toleranz der Kompressionskraft war von der Größe der Brust abhängig. Über 50 % der Mammografien mit einer geringen Kompression von weniger als 9 daN waren mit stärkeren Schmerzen assoziiert. Bei den Schrägprojektionen war bei 60 % der Frauen die Axilla das schmerzhafteste Areal.

Schlussfolgerung Frauen mit einer größeren Brust tolerierten eine größere Kompressionskraft. Dies legt eine Individualisierung der Untersuchung in Abhängigkeit von der Größe der Brust nahe. Frauen mit einem erhöhten Schmerzempfinden beendeten die Kompression frühzeitig trotz einer geringen Kraft von weniger als 9 daN. Mehr als 50 % der Frauen empfanden Areale außerhalb der Brust als besonders schmerzhaft. Es sollte daher während der Untersuchung darauf geachtet werden, auch Areale außerhalb der Brust zu schonen.

Introduction

Adequate compression of the breast is an absolute prerequisite for a good mammogram. However, the procedure for breast compression has not been standardized with respect to compression force. The European guidelines do not provide any indication regarding the required compression force [1]. The guidelines of the German Medical Association require compression of at least 10 Kp, but do not offer advice on how to respond to complaints about the resulting pain [2].

Compression-related reduction of the irradiated tissue allows a decrease of radiation dose and thus a diminution of scattered radiation with an exponential relationship between breast thickness and average glandular dose (AGD) [3]. In addition, geometric blur is diminished since compression reduces the distance to the detector plate of the remote gland portions [4]. In addition to avoiding motion blur, adequate compression can also effect a reduction of superimposed tissue structures and thus improve the diagnostic distinction between tumors and artifacts [1]. Improper compression of the breast can cause pain in the woman, making acceptance of mammography more difficult [5]. Between 25 and 46 % of women participating in initial mammographic screening and not participating again, cited pain as the primary reason [6]. Previous surgery and radiation can amplify mammography-related pain [7, 8]. Numerous studies mention the influence of psychological factors influencing pain during mammography [9 – 19]. Recent investigations emphasize the significance of intramammary pressure in the guidance of breast compression during mammography [20 – 22]. The authors recommend adapting compression force to the size of the breast, and thus adjusting intramammary pressure.

The aim of the study was to investigate the relationships among compression pressure, the surface area of the compressed breast, breast density according to the classification of the American College of Radiology (ACR) [23], prior surgery as well as the pain indicated by the examined women. In addition, the influence of the compression force on the thickness of the compressed breast and average glandular dose (AGD) was analyzed.

Materials and Methods

Relationship between breast thickness while compressed and compression force

To determine the relationship between compression force and breast thickness under compression, a pilot study was conducted with 30 women. A digital display of these parameters by the mammography unit was recorded using a video camera and subsequently assessed in slow motion. The average values of breast thickness as a percentage of initial uncompressed thickness was graphically displayed in relation to the respective compressive force for the four projections.

Relationship among pain indications during mammography and compression force, the surface area of the breast, breast density according to ACR [23] as well as previous surgery.

Patients

765 mammographic images (Mammomat, Siemens Healthcare GmbH, Erlangen, Germany) were obtained in craniocaudal and mediolateral-oblique projections of 199 symptomatic patients (average age 58.2 years, standard deviation 13.7 years, maximum 90 years, minimum 30 years). The study did not include asymptomatic women having early detection examinations (population-related mammographic screening). The patients were accepted into the study without exclusionary criteria in the order of their appearance for the examination.

In their medical history, 52 of the 199 patients indicated breast surgery (17 patients with a biopsy, 25 with a lumpectomy (24 of whom had radiation), and 10 with ablation).

Technical procedure for breast compression

The sequence of positions was the same for all patients. For bilateral examination: 1. right craniocaudal (RCC); 2. left craniocaudal (LCC); 3. right mediolateral-oblique (RMLO); and 4. left mediolateral-oblique (LMLO). For unilateral examination: craniocaudal before mediolateral-oblique. Compression force greater than 10 daN was attempted, depending on the patient's individual pain tolerance. The "OpComp" function (device-controlled automatic optimization of compression force) was not used when determining force [24]. The 18 × 24 cm table was routinely used. The 24 × 30 cm table was used in the case of very large breasts. The mammographic settings were performed by three trained and very experienced technicians. Compression force (in kilopond, kp) and breast thickness (in cm) under compression were taken from the display of mammography unit. The compression force values in kp displayed by the mammography unit were calibrated with an electronic scale (linear of regression: compression force$_{(corrected)}$ = 1.01156 × compression force$_{(unit\ display\ in\ kp)}$ − 0.38140; correlation coefficient = 0.99997) and subsequently converted to decanewton (daN) (1 daN = 1.0197 kp).

Quantification of pain indication

The Numeric Rating Scale (NRS) criteria were used to quantify the pain level [25]. This scale allows standardized assessment of pain perception. After each mammographic image was acquired, the patient was asked to describe her pain using a scale of 0 – 10 (0 = no pain; 10 = unbearable pain).

Planimetry and ACR classification of the mammographic images

Plane measurements (in cm^2) were made of each of the four projections with respect to the surface areas of the compressed breasts using a polygon function of the viewing software (Osirix PRO, aycan Digitalsysteme GmbH, Würzburg, Germany). In addition, tissue thickness was evaluated visually based on the mammographic images in accordance with the classification of the American College of Radiology (ACR) [23].

Radiation dose

The automated system of the mammography unit, using the device-specific dosage optimization program ("Opdose"), selected the exposure program as a function of breast thickness under compression [24]. The average glandular dose (in milligray) was taken from the visual display of the mammography unit.

Statistics

The study design was concomitant prospective. The values of the categories pain, compression force and surface area for the 765 mammograms were broken down into three classes with the greatest similar number of observations (▶ **Table 1**). The variables for pain sensation and compression force are discrete. This explains the greater variation of number of examinations classified into the three respective categories ("low", "medium" and "greater" for pain, and "low", "medium" and "great" for compression force). Statistical evaluation was performed descriptively using contingency tables and stacked columns (to 100 %) (Excel, Microsoft Cooperation, Redmond, WA, USA), as well as using a statistical procedure for testing for the independence of two attributes (chi square test of unrelated samples and the Dixon and Mood staircase method for related samples). The ratio of radiation dose and breast thickness under compression was set as a scatter plot for 752 mammograms (data regarding dose or breast thickness was not documented for 13 of the 765 mammograms) and descriptively represented as a 4th order polynomial; the correlation coefficient was determined using Excel (Microsoft Cooperation, Redmond, WA, USA).

Topographical distribution of compression-related pain

After each mammogram, the last 52 of the 199 patients were asked to indicate the site on their body where pain during the mammogram was the greatest. Four regions on each side were differentiated: breast, upper thoracic wall, lower thoracic wall and axilla.

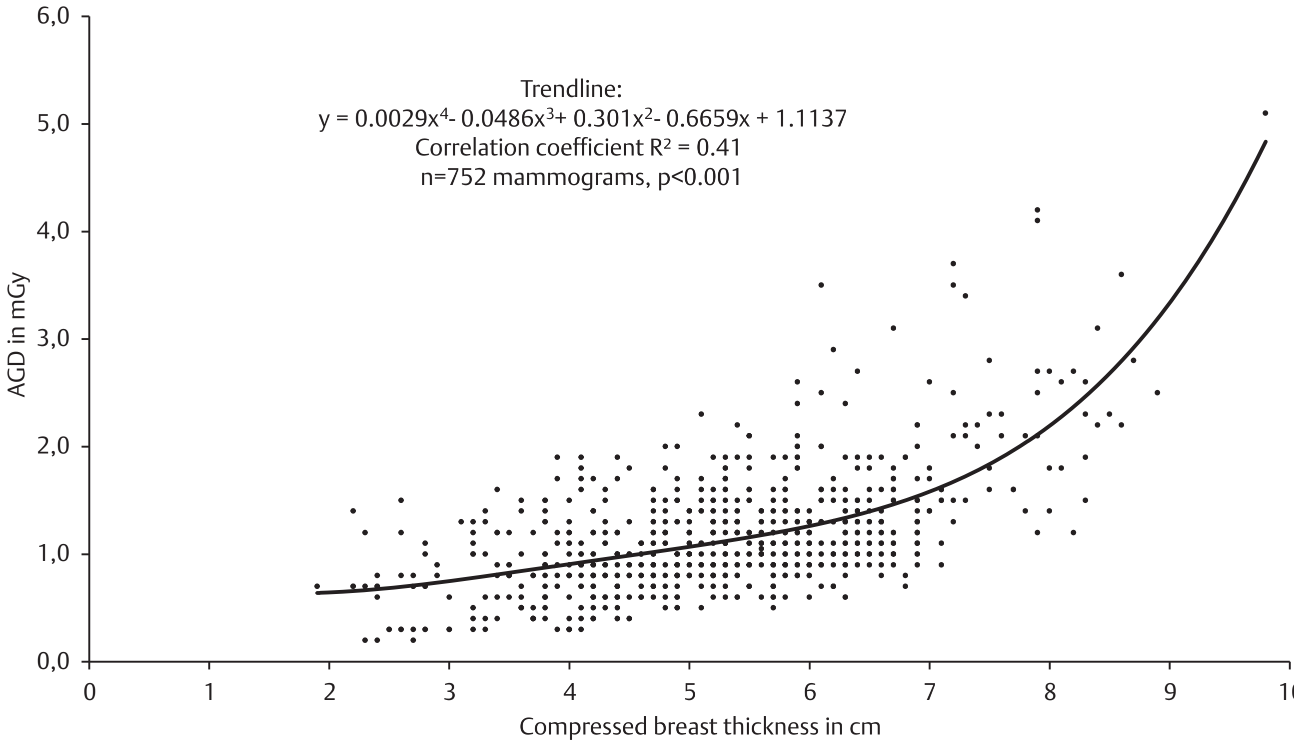
▶ **Table 1** Definition of the particular classes and distribution of the number of mammograms in relation to the different categories (projections, pain, compression force, surface area of the breast, density of the breast (ACR) and previous surgery).

patients 199			
mammograms 765			
projections			
RCC	LCC	RMLO	LMLO
number of mammograms (total = 765)			
188	192	191	194
pain (x in 0 – 10 according to the numeric rating scale)			
low	medium	strong	
x < = 3	3 > x < = 5	x > 5	
number of mammograms (total = 765)			
265	245	255	
compression force (F in daN)			
low	medium	great	
F < 9	9 > = F < 11	F > = 11	
number of mammograms (total = 765)			
256	243	266	
surface area (A in cm^2)			
small	medium	large	
A < 143	143 > = A < 206	A > = 206	
number of mammograms (total = 765)			
255	255	255	
ACR classification			
ACR 1	ACR 2	ACR 3	ACR 4
number of mammograms (total = 765)			
137	168	372	88
previous surgery (with/without radiation)			
PE	lumpectomy	ablation	
number of patients (total = 52)			
17	25 (24 with radiation)	10	

Results

Breast thickness while compressed and radiation dose

The ratio of AGD to breast thickness under compression is shown in ▶ **Fig. 1** for 752 of the 765 mammograms as a scatter plot and a 4th order polynomial as a trend line ($y = 0.0029x^4 – 0.0486x^3 + 0.301x^2 – 0.6659x + 1.1137$, n = 752). The trend line points to an exponential relationship between the average glandular dose displayed in the mammogram and breast thickness while compressed. The correlation coefficient was 0.41 ($p < 0.001$).



▶ **Fig. 1** Average glandular dose (AGD in mGy) in relation to the thickness of the compressed breast (cm) as a scatter-plot with a 4th degree polynomial as a trendline.

Breast thickness while compressed and compression force

▶ **Fig. 2** shows the percentage thickness of the breast under compression relative to the initial uncompressed value for 30 patients and four projections. The course of compression was broken down into three phases. After an initial phase with a steeper progression to a compression force of 4 daN to 78.4 % of the initial value, the curve becomes shallower, to flatten again after 10 daN. Likewise, using compression with more than 10 daN compression force, additional reduction of breast thickness was possible. This applied particularly to the first RCC projection. Thus with a compression of 10 daN, the breast could be reduced to an average thickness of 65.2 % of the initial value for all four projections. If compression was increased to 15 daN, breast thickness could be further reduced to 57.8 % of its initial value.

The average baseline value of the thickness of the non-compressed breast for these 30 patients and four projections was 8.2 cm. Accordingly, at a compression force of 10 daN, the average breast thickness was reduced to 5.4 cm (65.2 % of the initial thickness of 8.2 cm). Compression force of 15 daN resulted in a reduction to 4.7 cm (57.8 % of the initial thickness of 8.2 cm). Comparing these breast thickness values after compression with the breast thickness value-dependent average glandular dose (AGD) values of the 752 mammograms documented in our study, we obtained average dose values per mammogram of 1.2 mGy for 5.4 cm breast thickness and 1.0 mGy for a breast thickness of 4.7 cm. An increase of compression force from 10 to 15 daN resulted in an average dose reduction of 17 % (0.2 mGy from 1.2 mGy).

Pain indications, compression force, surface area of the compressed breast, breast thickness (ACR), projection and prior surgery

Compression force and breast surface area

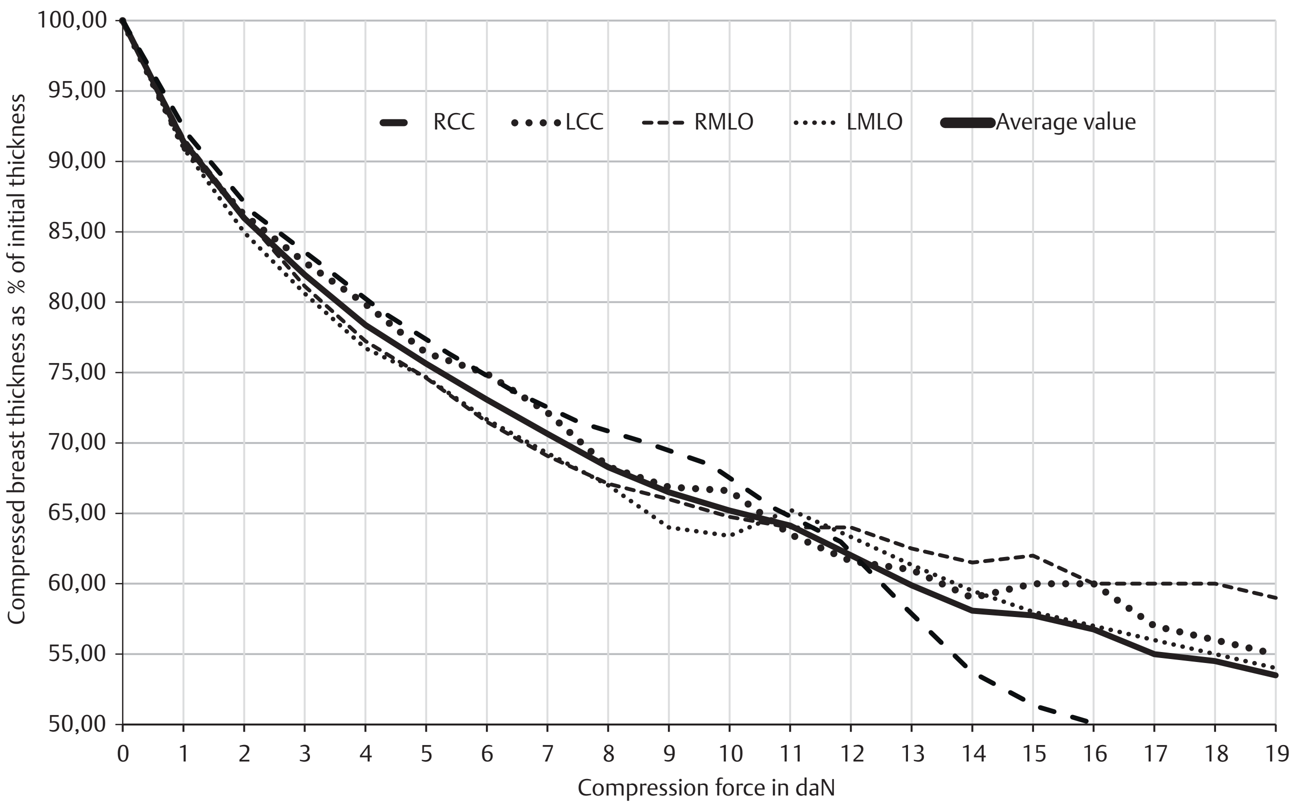
The compression force tolerated by the patients correlated positively with the surface area of the compressed breast (▶ **Fig. 3**). In the course of the individual mammography, women with a small breast surface had a decreasing acceptance of great compression force ($p < 0.001$, ▶ **Table 2**). This applied particularly to the LMLO projection which was performed last. On the other hand, women with a large breast surface area more frequently tolerated great compression force.

Pain and compression force

The patients indicated greater pain in more than half of mammograms with low compression force (▶ **Fig. 4**). The results were highly significant ($p < 0.001$, ▶ **Table 2**). There was no recognizable positive correlation between tolerated compression force and indicated pain.

Pain and previous surgery

In their medical history, 52 of the 199 patients indicated breast surgery (24 patients with radiation). In 39 of these 52 patients (18 with radiation), compression-related pain on the operated



▶ **Fig. 2** Thickness of the breast under compression in percentage of the thickness of the uncompressed breast relating to compression force in 30 patients.

side could be compared to the non-operated side (patients with bilateral lumpectomy and those with ablation were therefore not included in the analysis). Six patients (craniocaudal projections) and six patients (oblique projections) indicated a stronger experience of pain during compression of the operated side compared to the non-operated side (▶ **Table 3**). A lower sensation of pain on the operated side compared to the non-operated side was reported for one craniocaudal projection and for 3 oblique projections. In the majority of patients (32 craniocaudal and 30 oblique projection images), no change in pain perception resulting from prior surgery with or without radiation could be observed. Statistical significance with respect to the influence of previous surgery on pain indication was not evident ($p > 0.05$, Dixon and Mood staircase method for related samples, ▶ **Table 2**).

Pain and projection, breast surface area and ACR classification

Pain perception was unrelated to the projection (RCC, LCC, RMLO and LMLO) as well as breast area (▶ **Table 2**). In addition, radiologically-measured breast density following classification of the American College of Radiology (ACR) [23] did not affect pain sensation. Patients with radiopaque glandular tissue (ACR 4) more frequently tolerated only lower force in craniocaudal projections (RCC, LCC) ($p > 0.05$, ▶ **Table 2**).

Compression force and projection

In the course of each individual mammographic examination, increased compression force was increasingly less tolerated (▶ **Fig. 5**). Although the relative proportion of mammograms in which the patients tolerated greater force in the initial RCC projection was 47.3 %, the relative proportion declined to 23.7 % in the final LMLO projection ($p < 0.001$, ▶ **Table 2**).

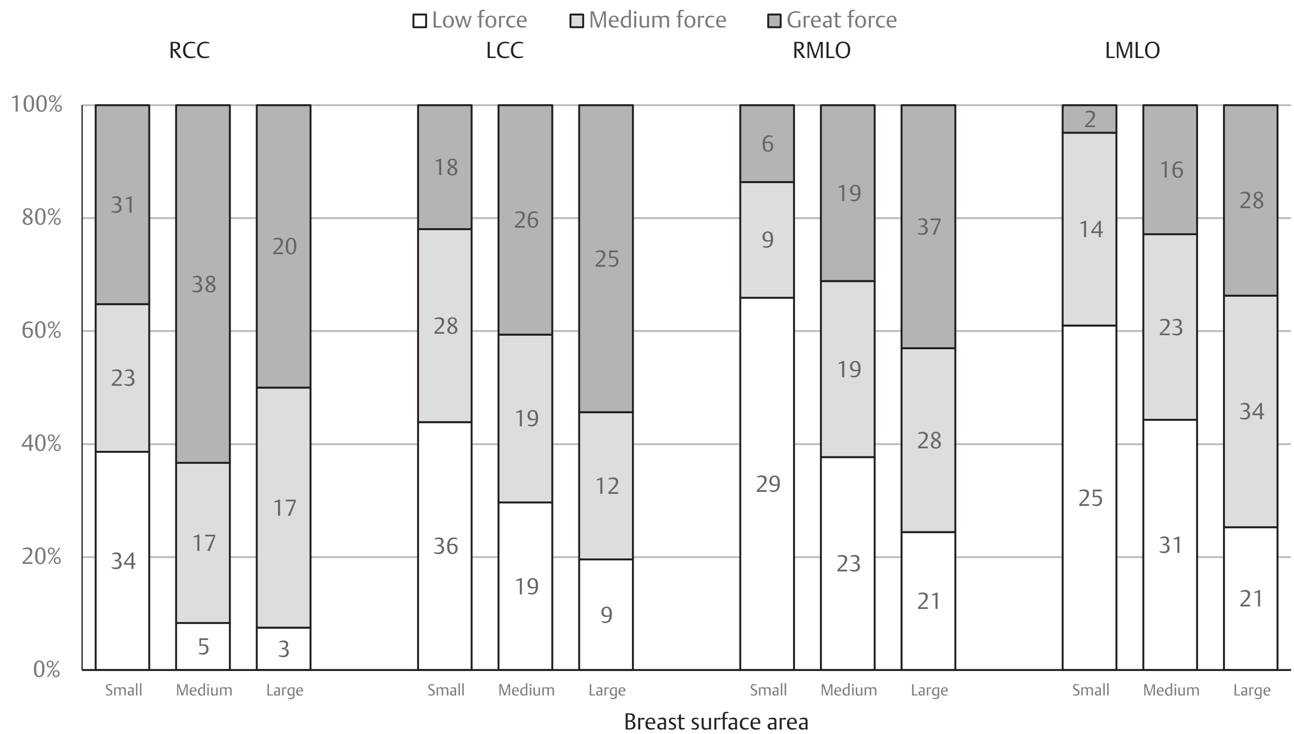
Topographical distribution of compression-related pain

Less than half of the women indicated their breast as the location where the pain was greatest during the mammogram (▶ **Table 4**). During oblique projections, 60 % of the women named the axilla as the site with the greatest pain. During craniocaudal projections, the upper thoracic wall area was named as the maximum pain point by more than 40 % of patients.

Discussion

Breast compression during mammography and average glandular dose

Adequate compression of the breast during mammography reduces the radiation dose with an exponential relation between dose and breast thickness [3]. In the examinations under study, the average glandular dose for a 6 cm breast thickness with



▶ **Fig. 3** Relationship between breast-surface area and compression-force. The numbers represent mammograms, where 100 % corresponds to the sum of mammograms with small, medium or great surface area respectively in each of the four projections.

▶ **Table 2** Overview of the results of statistical tests regarding the relationship of the parameters (projections, pain, force of compression, surface area of the breast, breast density (ACR) and previous surgery).

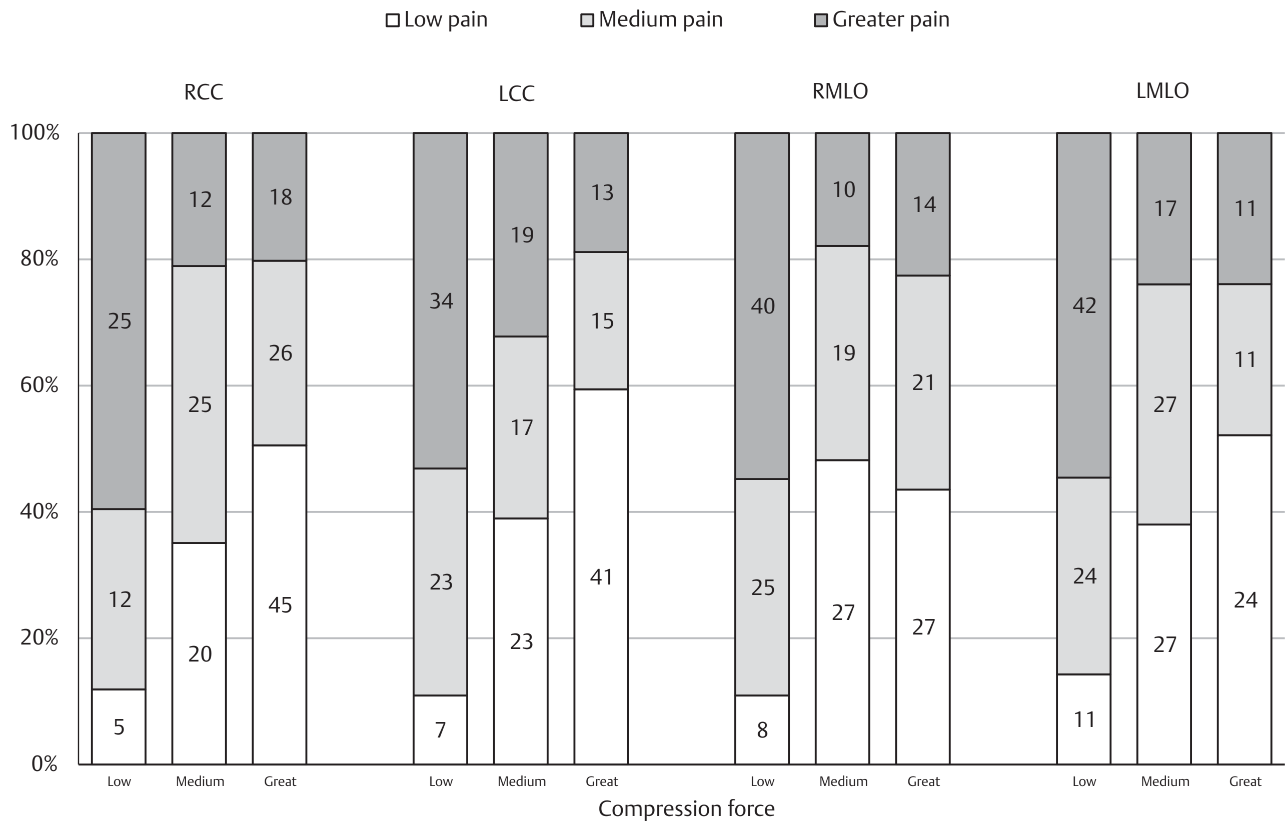
projections versus pain	n.s. (not significant)			
projections versus force	$p < 0.001$			
	craniocaudal projection (CC)		**mediolateral-oblique projection (MLO)**	
surgery versus pain	n.s.		n.s.	
	RCC	**LCC**	**RMLO**	**LMLO**
force versus pain	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
surface area versus force	$p < 0.001$	$p < 0.01$	$p < 0.001$	$p < 0.001$
pain versus surface area	n.s.	n.s.	n.s.	n.s.
ACR versus pain	n.s.	n.s.	n.s.	n.s.
ACR versus force	$p < 0.05$	$p < 0.05$	n.s.	n.s.

1.1 mGy was only 55 % of the average dose for a breast thickness of 8 cm with 2 mGy. These results underscore the significance of compression-related breast thickness reduction with respect to radiation protection.

In our study the effectiveness of breast thickness reduction decreased with increasing compressive force. Forced compression using 15 daN resulted in an average reduction of breast thickness of 57.8 % of the original thickness of the uncompressed breast, thus allowing an average dose reduction of 17 % compared to that achieved using 10 daN. De Groot et al. [26] describe similar curve progressions for the mammographic compression process. They divided breast compression into a "deformation" and a "clamping" phase. Concurring with our results, the authors describe only minimal reduction of breast thickness in the clamping phase and recommend shortening this phase in the interest of pain reduction.

Breast compression, pain sensation and compression force

Contrary to expectations, greater pain was more frequently reported when low compression force was used. It should therefore be presumed that the pain indicated by these women was less the



▸ **Fig. 4** Relationship between pain and compression-force. The numbers represent mammograms, where 100 % corresponds to the sum of mammograms with lower, medium or greater compression-force respectively in each of the four projections.

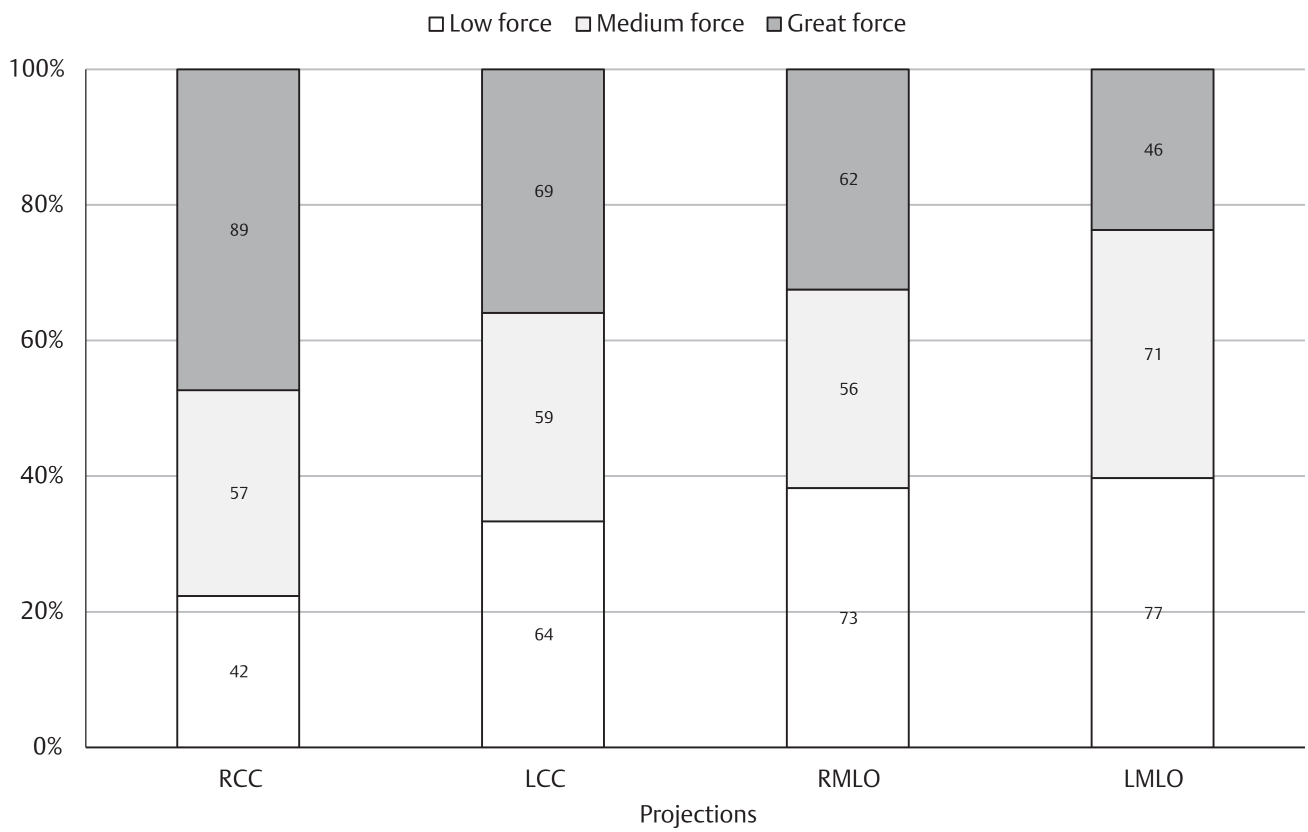
▸ **Table 3** Comparison of compression pain: operated breast vs. contralateral side without operation in 39 patients (p > 0.05).

projection	cranio-caudal	medio-lateral-oblique
compression-related pain same on both sides	32	30
compression-related pain greater in operated breast	6	6
compression-related pain less in operated breast	1	3

result of the physical extent of compression but rather was influenced by their individual sensitivity to pain [21]. Women with heightened pain sensitivity consequently terminated the compression procedure earlier. This concurs with studies investigating women's psychological experience of pain during mammography [9 – 19]. Pain is thus less suitable as a parameter for inter-individual optimization of breast compression during mammography since individual factors independent of the breast have significant influence on feeling pain. This likewise explains why in our study, the projection, surface area of the breast as well as relation of glandular and fat tissue according to the classification of the American College of Radiology (ACR) [23] exhibited no significant influence on experienced pain. Markle et al. could also demonstrate no relationship between breast tissue composition and compression-related pain [27]. On the other hand, Kornguth et al. have described a corresponding correlation [28].

Our larger-breasted patients tolerated greater compression force. This applied particularly to both oblique projections. If, therefore, the same compressive force were used as the criterion for optimal compression of all breasts, large breasts would tend to be insufficiently compressed, whereas smaller breasts would be subjected to excessive compression. Using the same compression force, higher intramammary pressure is produced in a smaller breast compared to a large breast as a function of the compressed breast surface area [21]. Our results suggest that during breast compression, intramammary pressure as a quotient of compressive force and breast surface area is a better measure of compression tolerance than the patients' pain indication. De Groot et al. likewise refer to the significance of intramammary pressure as a parameter for applying individualized compression independent of breast size. Consequently they developed a device for mammography units to continuously display intramammary pressure during compression [20, 21]. This allowed standardization of the compression procedure as well as a reduction of compression-related pain.

In our investigations, escalating compression force was increasingly less tolerated during the course of each individual mammo-



▶ **Fig. 5** Relationship between the compression-force and the four projections (RCC, LCC, RMLO und LMLO). The numbers represent mammograms, where 100 % corresponds to the sum of mammograms in each of the four projections.

▶ **Table 4** Topographic distribution of point of maximum pain during mammographic compression (n = number of patients).

projections		breast	axilla	thoracic wall, upper	thoracic wall, lower	row sum n = number of patients
RCC	n	18	0	22	7	47
	%	38.3	0.0	46.8	14.9	100.0
LCC	n	20	0	21	8	49
	%	40.8	0.0	42.9	16.3	100.0
RMLO	n	7	30	12	1	50
	%	14.0	60.0	24.0	2.0	100.0
LMLO	n	7	31	13	1	52
	%	13.5	59.6	25.0	1.9	100.0

graphic examination. The proportion of mammograms during which patients tolerated greater force declined by half from 47.3 % in the first projection (RCC) to 23.7 % in the final LMLO projection. Therefore, not only past painful mammograms, but also a position causing pain in the course of the current examination can adversely affect the examination procedure. Therefore mammography should not begin with that breast which due to prior surgery, radiation or unilateral mammalgia is particularly sensitive. Several authors discuss the positive effect of psychological guidance during the examination, with explanations of the course of the examination as well as closer observation of the patient's sensations by the examiner [1, 11 – 13, 15, 17].

Some women with lumpectomies and radiation complained of greater pain during compression of the operated side as compared to the non-operated side. This was also observed by de Groot et al. [7]. However, the majority of our patients did not report any difference with respect to pain.

Breast compression during mammography and topographical distribution of pain

For more than half of the women we queried, the breast was not the site that was the most painful during compression. This particularly related to oblique projections during which 60 % of patients experienced the greatest pain in the axillary region. Consequently, pain directly in the breast is not solely responsible for discomfort during the mammogram. This should be taken into account during the performance of the mammogram as well as by the manufacturers of mammography units when designing these devices. Several authors report a reduction of compression-related pain as a result of technical modifications to the compression plate [20, 29 – 32].

Limitations of the study

Our investigations were based on mammograms of symptomatic patients. The results therefor have limited applicability to early detection examinations of asymptomatic women (screening mammography). A further limitation of the study is the absence of a specified minimum value for compression force to guide the examiners when evaluating patients' pain indications. In some cases, the desired compression force of at least 10 daN could not be realized due to patient pain. This can result in inter-individual differences in the examiners' procedure. In contrast to mammographic screening of asymptomatic women, mammography of symptomatic patients requires closer attention to the patient's individual situation, taking into account pre-existing conditions and previous breast surgery.

Direct measurement of intramammary pressure during compression would not be possible without technical modifications of the mammography equipment and consequent loss of operating authorization. We had to limit ourselves to detection of compression force and breast surface which allowed only an indirect statement regarding intramammary pressure. A further limitation was the varying numbers of cases in the analyses, which possibly influenced statistical evaluation. Therefore further studies of individualized pressure-related compression during mammography are required. Such studies would employ pressure-sensitive compression plates [20] and include mammographic screening of asymptomatic women.

CLINICAL RELEVANCE

- Forced compression using 15 daN, compared to application of 10daN, resulted in an additional average reduction of average glandular dose of 17 %.
- Pain during a mammogram is not exclusively due to the physical extent of compression, but also related to individual differences in sensitivity to pain.
- Compression force should be made dependent on breast size since women with larger breasts frequently tolerate greater compression force.
- During breast compression, intramammary pressure as a quotient of compressive force and breast surface area is a better measure of compression tolerance than the patients' pain indication.
- Mammography should not begin with that breast which is particularly sensitive, since a painfully experienced position can have a negative influence on the further course of the examination.
- The presence of mammography-associated pain outside of the breasts should be taken into account both in positioning the images as well as in the design of mammography units.

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