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Radiological Assessment of Response to Neoadjuvant Chemotherapy in Breast Cancer Females, Using Standard and Spectral Mammography

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Abstract

Background

Morphological assessment and measurement of the residual mass of the breast tumour following neoadjuvant chemotherapy (NACT) is the key to successful surgical treatment. The objective of our study was to evaluate the efficiency of contrast-enhanced spectral mammography (CESM) and conventional mammography (MMG) in detecting CR (complete response) following NACT, as well as to compare the efficiency of conventional mammography and contrast-enhanced spectral mammography is assessing the therapeutic response to NACT in breast cancer patients.

Methods

A retrospective analysis included 63 breast cancer subjects who had undergone neoadjuvant chemotherapy in the years 2016-2019. The inclusion criteria for the study included diagnosed breast cancer based on a core needle biopsy, a complete set of imaging examinations before the procedure consisted of digital mammography, contrast-enhanced spectral mammography and surgery performed before and after completed neoadjuvant chemotherapy.

Results

The average size of the tumours prior to neoadjuvant chemotherapy amounted to 34.37 mm for MMG and 34.34 mm for CESM, as well as 17.61 mm for MMG and 8.48 mm for CESM following NACT. The average size of the lesions in histopathological examination was 11.06 mm. Spearman's analysis revealed a high level of correlation ($R=0.89$, $p<0.01$) upon comparing the maximum tumour dimensions prior to neoadjuvant chemotherapy on MMG and CESM, and a moderate level of correlation ($R=0.57$, $p<0.01$) upon comparing the maximum tumour dimensions post-NACT on MMG and CESM. While comparing the measurements of the maximum dimensions on MMG and CESM following NACT, with the maximum dimensions in histopathological examination, we can observe a low level of correlation for MMG ($R=0.26$, $p<0.04$) and a high level of correlation for CESM ($R=0.67$, $p<0.01$). The sensitivity of MMG in forecasting CR amounted to 33.33% and its specificity to 92.86%, whereas the same parameters for CESM were 85.71% and 71.42% respectively.

Conclusions

CESM demonstrates significantly higher sensitivity than MMG in forecasting CR in female patients receiving NACT due to breast cancer. CESM correlates well with the size of residual lesions in histopathological examination. However, it tends to underestimate the tumour size. In the assessment of post-NACT residual lesions, conventional mammography is an insufficient diagnostic tool.

Background

Breast cancer is the most common carcinoma in females, affecting approximately 2.1 million patients a year and representing the leading cause of cancer deaths in this group [1]. Neoadjuvant chemotherapy (NACT) is dedicated to cases where the objective is to reduce the mass of tumour and micrometastasis prior to radical surgery (reducing the staging of primary tumours).

Neoadjuvant chemotherapy also allows for reducing the extent of surgery in the axilla, as the response of the primary tumour to chemotherapy entails the response of axillary lymph nodes [2]. Preoperative chemotherapy, besides limiting the extent of operative treatment, allows for observing the efficiency of the drugs used immediately during the surgical procedures, which is impossible in the case of subsequent application of postoperative chemotherapy alone. As a result, neoadjuvant therapy can also be applied to clinical studies aimed at evaluating the efficiency and approving new drugs on the market [3].

A tumour response to neoadjuvant therapy may also provide valuable prognostic information. Achieving complete response upon completion of neoadjuvant therapy (pCR) and surgical resection is associated with improved survival rates. This correlation, to a certain extent, depends on the molecular subtype and is the strongest in patients with triple-negative breast cancer (TNBC) (oestrogen receptor (ER)-negative, progesterone receptor (PR)-negative and no expression for human epidermal growth factor receptor type 2 (HER2)), as well as with HER2-positive breast cancer [4]. In-depth morphological assessment and adequate measurement of the residual mass of the tumour following neoadjuvant chemotherapy is the key to successful surgical treatment.

The response to preoperative chemotherapy is evaluated on the basis of the RECIST 1.1 criteria (Response Evaluation Criteria in Solid Tumors), which are used for the assessment of therapeutic response based on radiological examinations. The classification of the particular therapeutic responses is based on the difference between the dimensions before and after the application of neoadjuvant chemotherapy, and it consists of the following options: complete response (CR), partial response (PR), stable disease (SD) and progressive disease (PD). For the purposes of this article, PR, SD and PD have been classified as “non-CR” [5, 6].

There are several imaging methods that allows for evaluating the impact of neoadjuvant therapy on breast cancer, with the most popular still being the conventional mammography (MMG) [7]. Physical examination may not be used for this evaluation, since it is less efficient – it reaches merely 57% of efficiency compared to mammography (74%) and ultrasonography (79%) [8].

Underestimating the size of residual lesions may result in incomplete resection of the tumour during surgery, and involves the risk of recurrence or second surgery. Overestimation, on the other hand, may lead to too radical surgical intervention, bringing about unsatisfactory cosmetic effects and other complications. Currently, the most effective method for evaluating the response of cancer lesions to neoadjuvant chemotherapy is the magnetic resonance imaging (MRI) [9]. This solutions is particularly useful in assessing multifocal lesions, where its sensitivity amounts to more than 90% and specificity – 60–100% [10]. Earlier studies indicate good correlation between the size of the tumour evaluated on MRI

and the size of the postoperative neoplasm [11]. Unfortunately, some research shows that MRI may under- as well as overestimate the size of residual lesions in 18% of cases [12].

Contrast-enhanced spectral mammography (CESM) is a novel, valuable tool in the diagnostics of primary breast cancer. This method, like MRI, involves imaging the neoangiogenesis of the tumour using a contrast medium (a chelated iodinated contrast agent). CESM sensitivity (over 90%) is similar to that of MRI, which means that both methods are the most sensitive solutions used in breast cancer diagnostics [13, 14]. Unfortunately, the specificity of CESM is considerably lower than its sensitivity – 58–60% [13, 15]. Taking into account the shortcomings of the imaging techniques currently in use, new better methods are constantly being searched for.

Obtaining pathological complete response (pCR) translates into better EFS (Event Free Survival) and OS (Overall Survival) rates. Therefore, pCR has been approved by the US Food and Drug Administration (FDA) in July 2020 as the final point of clinical studies in the neoadjuvant therapy of early breast cancer with a high recurrence risk [23].

For this reason, we decided to evaluate the efficiency of CESM in assessing the complete pathological response (pCR) following NACT.

The aim of our study was to evaluate the efficiency of contrast-enhanced spectral mammography (CESM) and conventional mammography (MMG) in detecting CR (complete response) following NACT (neoadjuvant chemotherapy), as well as to compare the efficiency of conventional mammography and contrast-enhanced spectral mammography is assessing the therapeutic response to NACT in breast cancer patients.

Methods

We carried out a retrospective analysis of 63 female medical records with breast cancer, who had undergone neoadjuvant chemotherapy in the years 2016–2019.

Full description of the study group is presented in Table 1.

Table 1
Patient demographics.

Characteristics	Number	Percentage
Number of Patients	63	100%
Age (median of years)	53.32 ± 9.47	
Menopause		
Before	27	42.86
After	36	57.14
Molecular characteristics		
LumA	5	8.06
LumB	34	54.84
TNBC 1-Jan	24	38.71
Type of tumour		
Invasive ductal	52	82.54
Invasive lobular	7	11.11
Ducto-lobular	4	6.35
TNM stage upon diagnosis		
T1N+	2	3.17
T2N0	13	20.63
T2N+	13	20.63
T3N0	11	17.46
T3N+	16	25.40
T4N0	3	4.76
T4N+	5	7.94

The inclusion criteria for the study included diagnosed breast cancer (based on a core needle biopsy), a complete set of imaging examinations before the procedure consisted of digital mammography, contrast-enhanced spectral mammography and surgery performed after completed neoadjuvant chemotherapy.

After completing the diagnostics, the final therapeutic decision was made on the basis of breast cancer unit team (BCU) with the participation of the patient and a team of specialists, including oncological

surgeon, a clinical oncologist, a radiotherapist, a radiologist, and a pathomorphologist. The patient was able to ask questions and expressed informed consent to the proposed treatment.

Following the decision by BCU, 98% of patients received chemotherapy based on anthracyclines and taxanes, including 30% in the “dose-dense” regimen. Only one patient did not receive anthracyclines due to earlier treatment of Hodgkin’s disease and limited doze of anthracyclines Due to the lack of public funding of trastuzumab in this centre in the years 2016–2019 (no drug prescription programme), all the cancer patients with positive HER2 were treated outside our centre and were not included in this analysis.

Before finish of neoadjuvant chemotherapy (2–4 weeks), all the patients received a follow-up CESM to assess the effects of the treatment.

Due to the retrospective nature of this study, the local ethics committee of the Medical University of Silesia repealed the requirement of informed consent (decision number PCN/0022/KB/157/20). All the test procedures were carried out in compliance with the ethical principles of the 1964 Helsinki Declaration and its subsequent amendments.

Imaging Procedures

All the CESM examinations were performed in our centre while MMG examinations we performed on an outpatient’s basis (in most cases as a screening test), and then checked by two consultant radiologists from our centre. Before qualifying for CESM all patients completed a questionnaire which was the basis for disqualifying those women with pregnancy or allergy to contrast agents (iodine-based contrast used in CESM). eGFR less than 30 mL/min excluded patients from the study.

Cesm And Mmg Protocols

All CESM examinations were carried-out with a digital mammography device dedicated to perform dual-energy CESM acquisitions (Seno Bright, GE Healthcare). An intravenous injection of 1.5 ml/kg of body mass of non-ionic contrast agent was performed using a power injector at a rate of 3 ml/s with a bolus chaser of 30 ml of saline. In CESM mode, the device automatically performed a pair of exposures (low- and high-energy) in each view. Specific image processing of low-energy and high-energy images was done to obtain subtraction images to highlight contrast enhancement and suppress structured noise due to fibroglandular breast tissue. The total examination time was usually 10 minutes. After examination, the patients were observed for approx. 30 minutes for any adverse reactions that may occur after administration of the contrast agent [30, 31].

The conventional MMG and spectral CESM images were assessed according to the BI-RADS scale (Breast Imaging-Reporting and Data System). On both examinations (MMG and CESM), 3 measurements were taken in the CC and MLO projections, while the statistical analysis encompassed one – I.e. the biggest dimension of the tumour.

The tumour dimensions were compared, analysing:

- subtraction images from two consecutive contrast-enhanced spectral mammograms (taken prior to and before completion of neoadjuvant chemotherapy)
- images from standard mammogram taken before therapy and low-energy images of contrast-enhanced spectral mammograms, performed before completion of the systemic treatment). The morphological information obtained from low-energy images of CESM is identical to the morphological information given by standard mammography.

According to the RECIST 1.1 guidelines, based on comparative analysis of all the examinations performed, all the patients had the type of their therapeutic response determined from amongst such options as: CR, SD, PR, and PD.

After the surgery, comparison was made of the type of response specified on MMG and CESM to the postoperative histopathological material.

Histopathological Examination

The histopathological examination was conducted in the Histopathology Laboratory of our centre by 2 pathologists with extensive experience in breast cancer diagnostics. The greatest dimension of the tumour necessary for determining the T descriptor in the pTNM classification, besides the macroscopic measurement, was verified histopathologically by means of a microscope and the Cell Sens Dimension® software by Olimpus from 2013. Tumours up to 2 cm were excised in whole, serially, on a cross-sectional basis with a margin of 0.2 to 0.4 cm and embedded in a paraffin block, after each cross section. Tumours measuring over 2 cm, not fitting within a single paraffin block, were divided into 2 or more parts by making parallel cuts of the lesion. Next, they were marked in pairs with ink of the same colour and the individual layers were given numbers to allow for restoring the entire largest section of the tumour. The T value of the tumour was the total of the parallel measurements of the particular parts of the lesion.

Statistical analysis

Histopathology-derived size of the tumours was used as the “gold standard” and compared to the tumour sizes derived from MMG and CESM. The normality of the distribution was assessed using the Shapiro-Wilk test and the continuous variables were summarized using an arithmetic mean with standard deviation for data following normal distribution or a median with a quartile 1 and 3 for data demonstrating the non-normal distribution. Comparison of four respective aspects, constituting the maximal tumour dimension (defined as the maximal of three dimensions measured in mammography, CESM and histopathology) included Pearson’s correlation coefficient (R-value) to measure the strength of the relationship between the mammography and CESM measurements. Paired t-tests were used to assess mean differences between each analysed study participant. The correlations of data are illustrated by plotting the actual measurements, while all paired measurements for each patient are

summarized using paired linear plots. A p-value of < 0.05 was considered statistically significant. The diagnostic performance indexes for mammography and CESM for complete response and non-complete response were tested using Clopper-Pearson test with 95% confidence intervals. Statistical analyses were carried out using The STATISTICA 10 (StatSoft Inc., Tulsa, Oklahoma) and MedCalc Statistical Software 16.4.3 (MedCalc Software bv, Ostend, Belgium) software.

Results

The study included a group of 63 breast cancer female patients. The average size of the tumours prior to neoadjuvant chemotherapy amounted to 34.37 mm for MMG and 34.34 mm for CESM. After neoadjuvant chemotherapy, their average size was 17.61 mm for MMG and 8.48 mm for CESM. The average size of the lesions in histopathological examination was 11.06 mm (Table 2). The average reduction of the tumours amounted to 52.22% of the initial tumour mass based on MMG, while 78.76% – in the case of CESM.

Table 2
Dimensions and volumes of the lesions prior to and following neoadjuvant chemotherapy for MMG, CESM and histopathological examination.

	Min.	Max.	Mean ± SD
PMMG (mm)	15.00	77.00	34.37 ± 12.58
NMMG (mm)	0.00	80.00	17.61 ± 15.43
PCESM (mm)	8.00	100.00	34.34 ± 17.42
NCESM (mm)	0.00	66.00	8.48 ± 12.01
NHP (mm)	0.00	65.00	11.06 ± 12.80

Comparing the maximum tumour dimensions prior to neoadjuvant chemotherapy on MMG and CESM, one can notice a high degree of correlation in the Spearman's analysis ($R = 0.89$, $p < 0.01$). While comparing the maximum tumour dimensions after neoadjuvant therapy on MMG and CESM, the correlation between the results can be described as moderate ($R = 0.57$, $p < 0.01$) (Fig. 1). A certain correlation, defined as moderate ($R = 0.44$, $p < 0.01$), can also be observed upon comparison of the maximum tumour reduction on MMG and CESM. While comparing the measurements of the maximum size on MMG and CESM following NACT, and of the maximum size in histopathological examination, we can observe a low level of correlation for MMG ($R = 0.26$, $p < 0.04$) and a high level of correlation for CESM ($R = 0.67$, $p < 0.01$) (Fig. 2).

Both methods tend to imprecisely estimate the size of residual lesions. In the case of MMG, the size of these lesions is overestimated (the average overestimation value is 6.28 mm), whereas in the case of CESM, residual lesions are underestimated (the average underestimation value is 2.75 mm).

According to the RECIST 1.1 guidelines, MMG revealed 15.87% of CR (10/63) and 84.13% of non-CR (53/63). In the case of CESM, these parameters were 47.62% (30/63) and 52.38% (33/63) respectively. Histopathological examination demonstrated CR in 33.33% (21/63), whereas non-CR in 66.67% (42/63). Detailed description of the particular responses to NACT can be found in Table 3.

Table 3
Individual therapeutic responses to NACT assessed by means of MMG and CESM.

	MMG	CESM
CR	10/63 (15.87%)	30/63 (47.62%)
PR	43/63 (68.25%)	31/63 (49.2%)
SD	9/63 (14.29%)	2/63 (3.17%)
PD	1/63 (1.59%)	0/63 (0%)

Comparing these two methods to histopathological examination, Table 4 presents the sensitivity, specificity, negative predictive value (NPV) and positive predictive value (PPV) of both in forecasting CR. The sensitivity of MMG in forecasting CR amounted to 33.33%, while its specificity – 92.86%. In the case of CESM, the sensitivity amounted to 85.71% and the specificity – 71.42%. Figure 3 presents the differences in ROC curves for MMG and CESM in detecting CR. Figure 4 presents assessment of therapeutic response in MMG and CESM

Table 4
Diagnostic performance indexes for the assessment of complete (CR) and non-complete response (pPR, pSD, pPD) according to RECIST criteria 1.1, using CESM and conventional mammography, compared to histopathological analysis.

Assessment				
CESM	RECIST 1.1	Histopathological pCR	Histopathology non-pCR (pPR, pSD, pPD)	
	CR	18	12	PPV 60.00% (95% CI:) 0.4060–0.7734
	non-CR (PR, SD, PD)	3	30	NPV 90.90% (95% CI:) 0.7567–0.9808
		Sensitivity 85.71% (95% CI:) 0.6366–0.9695	Specificity 71.42% (95% CI:) 0.5542–0.8428	
Mammography	CR	7	3	PPV 70.0% (95% CI:) 0.3475–0.9333
	non-CR (PR, SD, PD)	14	39	NPV 73.58% (95% CI:) 0.5967–0.8474)
		Sensitivity 33.33% (95% CI:) 0.1459–0.5697	Specificity 92.86% (95% CI:) 0.8052–0.9850	

Discussion

Currently, neoadjuvant chemotherapy (NACT) is widely used as first of multidisciplinary management of breast cancer without distant metastases [16, 17, 18, 19]. Besides reducing the tumour mass and thereby offering better conditions for local treatment (BCT – breast conserving therapy), NACT provides professionals with unique opportunities for *in vivo* chemotherapeutic evaluation of cancer cells' sensitivity and for the quest of new biomarkers of therapeutic response, and – in the event of poor response and progression of the disease – it offers a chance to alter the treatment scheme or refer a given patient for surgical treatment [20, 21]. Apart from the predictive and prognostic factors known to date, including staging, grading, HER2 status, hormone receptors status, and Ki 67%, the therapeutic response of the tumour to NACT provides information about the patient's prognosis. Obtaining complete pathological response (pCR) defined as ypT0/Tis, ypN0 translates into better EFS and OS [22, 23, 24, 25, 26]. This served as the basis for the US Food and Drug Administration in July 2020 to accept pCR as the final point of clinical studies in the neoadjuvant therapy of early breast cancer with a high recurrence risk [23]. Evaluating the tumour response to NACT is key to planning further therapy.

To the best of our knowledge, our study is one of the few attempts to evaluate the efficiency of CESM in determining the CR of breast cancer following NACT and the only one to compare the efficiency of CESM with conventional MMG.

The precision of treatment evaluation on MMG depends on the breast structure and morphology of the infiltration itself. The efficiency of evaluation upon MMG, similarly to physical examination, decreases if the tumour is a spiculated or an irregularly limited mass, and the breast has a glandular structure, which may cause the full image of the tumours to be masked by the glandular tissue [27]. The presence of microcalcifications does not correlate with the post-NACT tumour size, as their presence and image may result from tumour necrosis. Earlier studies revealed that even as much as 44% of microcalcifications presence after breast cancer treatment does not correlate with the presence of malignancy [28].

In a Swedish retrospective study, Skarping et al. demonstrated that, in the majority of patients, the breast density on mammography decreased during NACT. However, this value was not a direct predictor of pCR for the treatment applied, which confirms the insufficiency of standard mammography for evaluating post-NACT residual lesions (29).

In our study, nearly half of the subjects had a highly glandular or glandular/adipose breast tissue structure, and 20.63% of cases (13/63) demonstrated multifocal lesions. The arguments above account for such a low sensitivity of MMG in detecting CR – 33.33%.

Contrast-enhanced spectral mammography provides a double amount of information:

1. morphological information (as in standard mammography) – in low-energy images;
2. functional information – in subtraction images that visualise the vascularisation of breast lesions.

CESM is characterised by very high sensitivity in detecting focal breast lesions, and the tumour size on CESM correlate well with histopathological examination in non-NACT patients [30, 31].

In our study, the sensitivity of CESM in a group of NACT patients was 85.71%, its specificity – 71.42%, the PPV – 60%, and the NPV – 90.90%. In the assessment of the prognostic factor, i.e. CR following NACT, CESM reaches significantly higher sensitivity than MMG, but unfortunately its specificity is much lower. Similar values, especially in the assessment of specificity, were obtained by Patel et al. (sensitivity: 95%, specificity: 66.7%, PPV: 55.9%, NPV: 96.7%) and by Iotti et. al. (sensitivity: 100%, specificity 84%, PPV 57%, and NPV 100%) [32, 33]. These results demonstrate that imaging techniques, even after intravenous administration of a contrast agent, do not allow for differentiation between residual infiltration lesions and co-existing inflammatory/reactive lesions.

In our study, the largest pretreatment tumour dimensions on MMG and CESM were similar and there is essential difference between these modalities ($R = 0.89$, $p < 0.01$). However, these differences become significant following neoadjuvant chemotherapy ($R = 0.55$, $p < 0.01$).This is due to the fact that post-NACT tumours reduce their density and then become difficult to be distinguished from a glandular tissue based

on morphological images alone. On the other hand, the functional information provided by CESM on subtraction images, the residual infiltration is clearly visible, and the type of breast tissue does not affect its visualisation.

Our study showed that standard MMG has a tendency to overestimate the dimensions of residual lesions following NACT, while CESM tends to underestimate them. Different results were obtained by Łuczyńska et al., were CESM overestimated the results by 1.7 mm [34]. However, this difference may arise out of the fact that Łuczyńska analysed tumours prior to treatment, while our analysis concerned tumours following NACT, which caused damage to the tumour's vessels and, as a consequence, could account for the underestimation of results. The study by Iotti et al., which was focused on NACT female patients, revealed that CESM tends to underestimate the dimension of residual lesions by 4.1 mm, which is comparable to our results [32]. It must also be emphasised that the underestimation of the dimensions of residual lesions in our study has no impact on the scope of surgical treatment. Since CESM is a method involving vascularisation of the tumour focus, the effect of excessive reduction in vascularisation around the tumour during NACT may account for the weaker enhancement of the residual tumour mass on follow-up CESM, and thereby underestimating the actual dimension of residual lesions. A similar problem concerns MRI, which also tends to underestimate residual lesions in follow-up examinations [32, 35].

The sensitivity of CESM in detecting breast cancer is comparable to that of MRI, with the former modality being cheaper, as well as quicker to perform and interpret. In the group of NACT patients, CESM significantly outperforms standard mammography in evaluating residual lesions following NACT.

A limitation of our study is the small number of participants, which results from the national qualification guidelines for female patients supposed to receive NACT. However, the initial results are encouraging enough to continue this study with more subjects.

Conclusions

CESM demonstrates significantly higher sensitivity than MMG in forecasting CR in female patients receiving NACT due to breast cancer.

CESM correlates well with the size of residual lesions in histopathological examination. However, it tends to underestimate the tumour size.

In the assessment of post-NACT residual lesions, conventional mammography is an insufficient diagnostic tool.

Breast Cancer Research

Abbreviations

NACT

Neoadjuvant chemotherapy

pCR

Pathological complete response

pPR

Pathological partial response

pSD

Pathological stable disease

pPD

Pathological progressive disease

CR

Complete response

PR

Partial response

SD

Stable disease

PD

Progressive disease

MMG

Mammography

MRI

Magnetic resonance imaging

CESM

Contrast-enhanced spectral mammography

TNBC

Triple-negative breast cancer

ER

Oestrogen receptor

PR

Progesterone receptor

HER2

Human epidermal growth factor receptor 2

RECIST 1.1 criteria

Response Evaluation Criteria in Solid Tumors

EFS

Event Free Survival

OS

Overall Survival

FDA

US Food and Drug Administration

BCU

Breast Cancer Unit team

BI-RADS

Breast Imaging-Reporting and Data System

CC

Craniocaudal view

MLO

Mediolateral oblique view

T

Tumour size

N

Nodal status

M

Distant metastasis

pTNM

Pathologic T, N and M status

BCT

Breast Conserving Therapy

PPV

Positive Predictive Value

NPV

Negative Predictive Value

LumA

Luminal A breast cancer

LumB

Luminal B breast cancer

PMMG

MMG prior to neoadjuvant chemotherapy

NMMG

MMG following neoadjuvant chemotherapy

PCESM

CESM prior to neoadjuvant chemotherapy

NCESM

CESM following neoadjuvant chemotherapy

NHP

histopathological examination

Declarations

CONTRIBUTION STATEMENT

KSR, IG and AL conceived the idea for study. KSR, IG, ABG, AL contributed to the design of the research.

KSR, AG, IG conceived the idea for the analysis.

KSR, AB, ABG, JSC were involved in data collection.

KSR, AG, KO, ZL, IM, WU, AB analyzed the data.

KSR, ABG, AG, KO, ZL, IM, WU, IG drafted the manuscript.

All authors edited and approved the final version of the manuscript.

Ethics approval and consent to participate

Due to the retrospective nature of this study, the local ethics committee of the Medical University of Silesia repealed the requirement of informed consent (decision number PCN/0022/KB/157/20).

Consent for publication

Not applicable

Availability of data and materials

The datasets during and/or analysed during the current study available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

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Figures

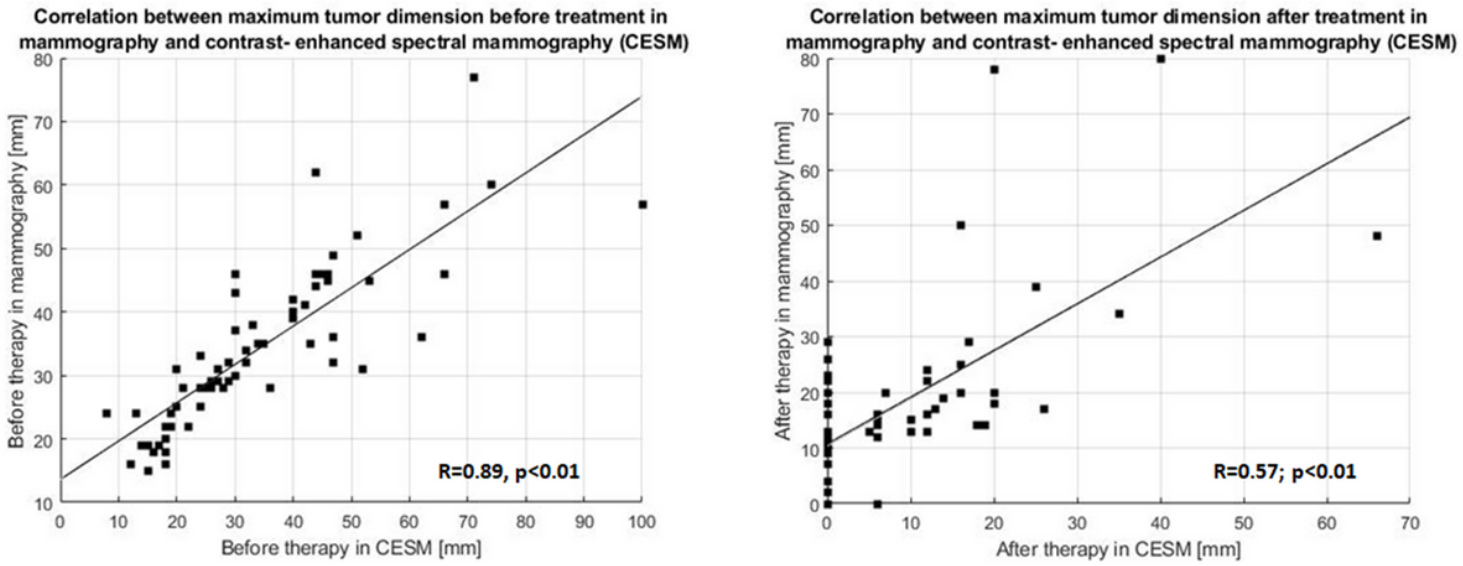

Figure 1

Correlations between the maximum tumour size prior to and following neoadjuvant chemotherapy on mammophraphy and contrast-enhanced spectral mammography

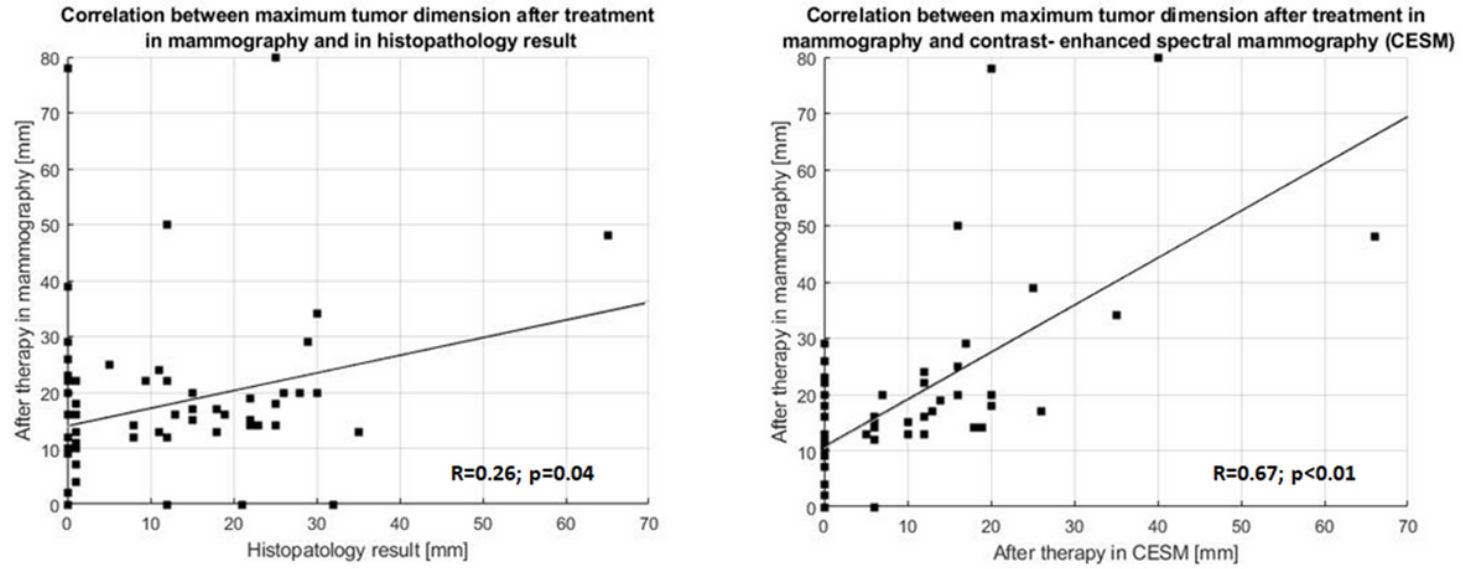

Figure 2

Correlations between the maximum tumour size following neoadjuvant chemotherapy assessed using MMG and CESM, and the result of the histopathological examination.

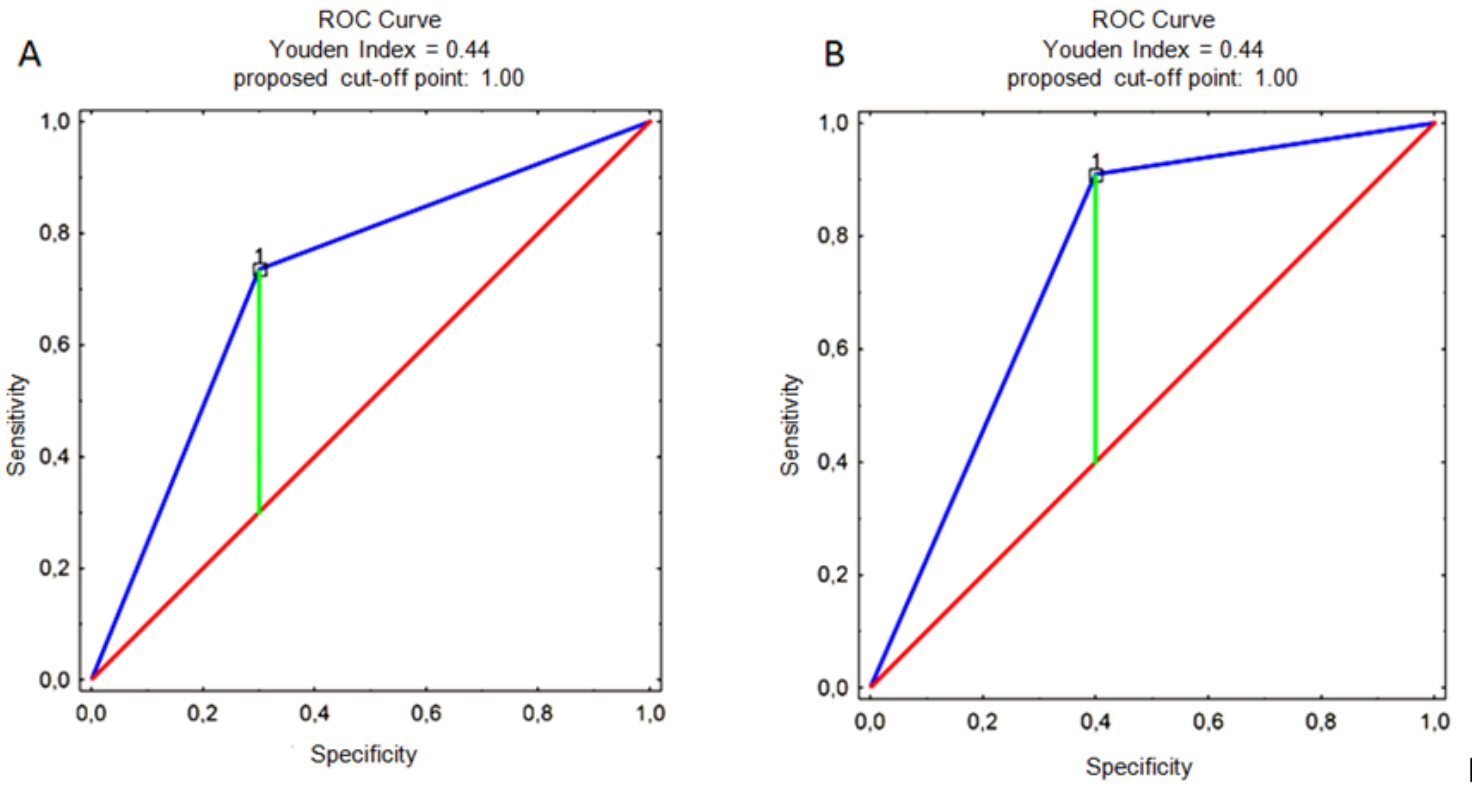

Figure 3

A - ROC curve for MMG – the value of the AUC field was 0.718 at a standard error of 0.091 and p<0.0172; B – ROC curve for MMG – the value of the AUC field was 0.755 at a standard error of 0.064 and p<0.0001.

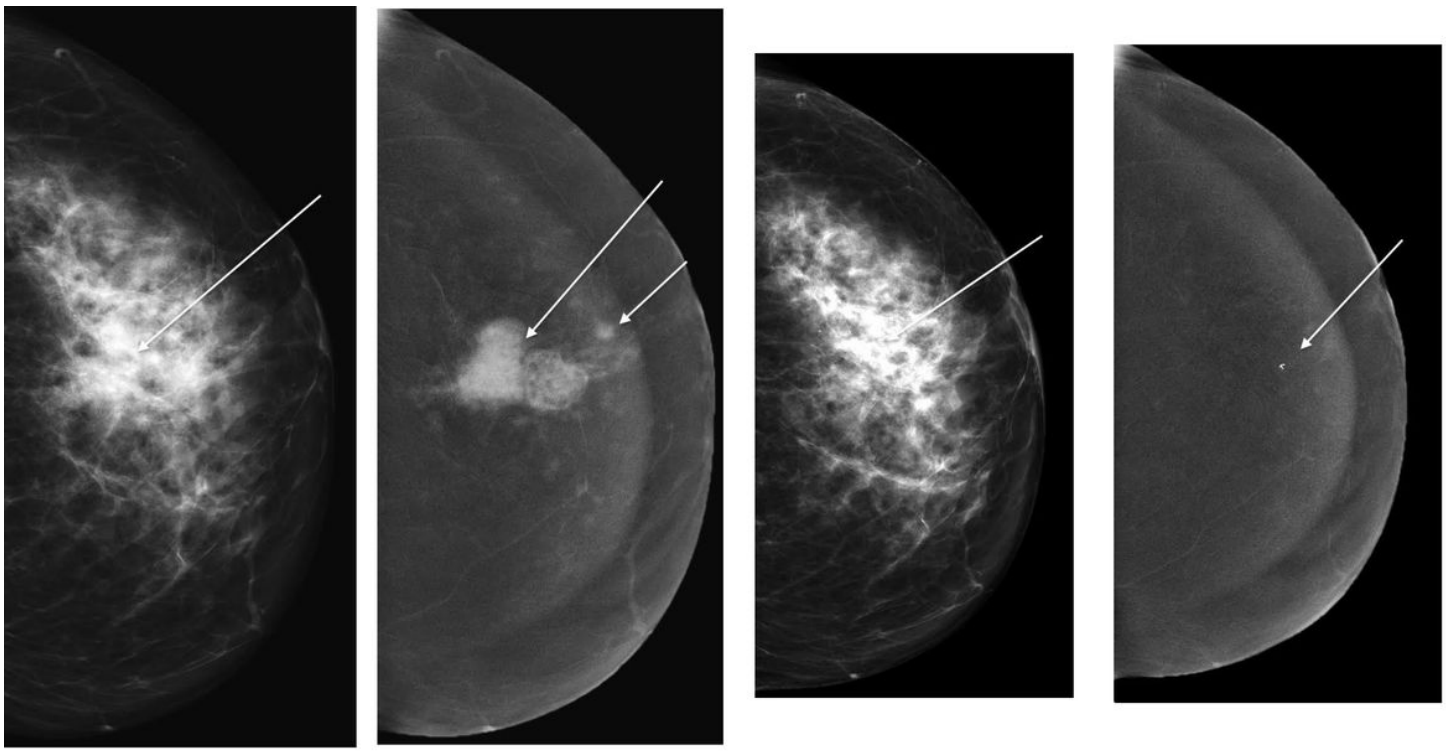

Figure 4

Assessment of therapeutic response in MG CC (0, 2) and CESM CC (1, 3) prior to NACT (NST Lum B, G2 T3N1) irregular infiltration on the border of the outer quadrants of the left breast with high density, (0), revealing pathological contrast enhancement on CESM(1). Additionally, satellite foci visible in CESM, confirmed in core-needle biopsy (smaller arrow) (1) following NACT visible focal asymmetry, with a density slightly lower than the infiltration prior to NACT (2), without pathological contrast enhancement (3). Based on MG – the therapeutic response was classified as SD (stable disease). Based on CESM – the therapeutic response was classified as CR (complete response), which was acknowledged in HP examination.