MRI of the Breast

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Uwe Fischer

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12.1 Tumorangiogenesis

Probably all invasive breast cancer and many of the intraductal carcinomas are associated with increased vascularization due to tumor neoangiogenesis. MRI allows the visualization of breast cancer because these tumors are associated with signal enhancement after peripheral administration of a contrast material. Thus, MRI gives information on hemodynamic as well as morphologic aspects of a tumor. The provision of hemodynamic information by MRI of the breast is the relevant difference in comparison to X-ray mammography and ultrasonography, which give primary information on the morphologic changes based on radiation absorption and ultrasound reflection, respectively.

12.2 Technique and Methods

Indispensable equipment for MRI of the breast is a magnetic resonance tomography diagnostic unit and a dedicated bilateral breast surface coil. For performing a MRI of the breast, a field strength of 1.5 T or more is recommended. The breast surface coil should be open bilaterally to allow MR-guided interventions such as a percutaneous biopsy or pretherapeutic localization. Moreover, dedicated tools are available to perform an examination at a high comfort level for the patient. A dedicated headrest is helpful to place the patient's head and neck in a comfortable position (Fig. 12.1). For MR-guided interventions, special MR-compatible equipment is necessary to calculate the required coordinates of unclear findings. Usually, these tools are integrated into the lateral parts of an open surface coil (Fig. 12.2).

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Fig. 12.1 Devices for the comfortable positioning of the patient during MRI of the breast. A dedicated headrest with an integrated mirror allows the patient to look out, e.g., at a postcard or a picture of her own choice

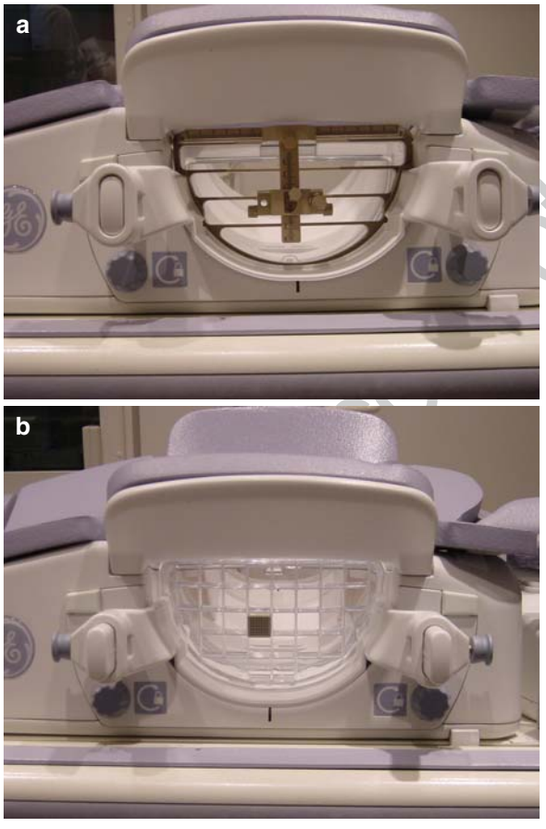

Fig. 12.2 Compression devices for MR-guided interventions. Two different systems available for use in open breast surface coils for the performance of percutaneous biopsy or wire localization. Post-and-pillar system (**a**) and grid system with a puncture cube (**b**)

The patient history must be collected before beginning MRI. Special questions that should be asked are

- Personal history, especially with respect to previous breast cancer (type, stage, age at diagnosis, treatment) or biopsies with benign histology
- Family history of breast or ovarian cancer (degree of relationship, age at diagnosis)
- Abnormalities, suspicion of malignancy (e.g., palpable mass, skin retraction, nipple discharge)
- Hormonal status (e.g., premenstrual/menopausal/postmenopausal, hormonal-replacement therapy)
- Previous allergic reaction after administration of MR contrast material

Moreover, previous imaging studies such as mammography and/or sonography, and their findings should be available.

Before starting the MRI, the patient must be informed about the general conditions during MRI of the breast and the requirements made of her. These include the following aspects:

- MR study is accompanied by unpleasant, loud noises.
- Patient movement must be prevented during the entire examination.
- Measurements are announced by the radiographer.
- An announcement will be made before application of the contrast material.
- Measurement will be stopped immediately if the patient indicates indisposition. (In this case, however, the study cannot be repeated on the same day.)

For application of the contrast material, a venous line (18–20 G) must be inserted, preferably in the antecubital vein, before starting the examination. Use of peripheral veins (e.g., on the back of the hand) should be avoided because the inflow time of the contrast material will be lengthened significantly. An extension tube of 2–2.5 m is used to connect the patient with the injector while the patient is positioned in the MRI system.

MRI must be performed with the patient in the prone position. It is recommended that the arms be placed alongside the body. It is helpful to use something like a bathrobe in order to fix the arms to the body with the belt raising the arms up above the head runs the risk of the breast partially slipping out from the surface coil. Moreover, the inflow of the contrast material could be impeded.

In the past, two different philosophies existed concerning the performance of MRI of the breast: either high temporal resolution with measurement times of less than 1 min per sequence, or high spatial resolution with voxels of 1–2 mm^3 or less were preferred. Modern high-performance MR systems today allow the imaging of the breast with a high temporal as well as a high spatial resolution. If there is spare capacity to modify the examination further, an increase in spatial resolution is recommended.

The most relevant prerequisite for attaining a high-quality MRI of the breast is patient comfort. To achieve this, the patient must be sufficiently informed about the conditions expected during the performance of the examination. This includes information about the prone positioning, the necessity of breast compression, and the possible reactions to the application of contrast material. In this context, practical experience of the personnel is as relevant as the surrounding conditions such as room temperature and music. The best imaging technique will not result in a high-quality MRI of the breast if patient comfort is absent.

For 1.5 T systems, the following image parameters are adequate: transversal (alternative: coronal, sagittal), T1-W 3D (alternative: 2D), gradient-echo (GRE) pulse sequences once before and repetitively 4–6 times after bolus injection of 0.1 mmol/kg gadopentetate dimeglumine. In our protocol, we use TR/TE/FA 8.4 ms/4.1 ms/10° with a non-interpolated 512 x 512 imaging matrix. Depending on the field strength, TE is selected so that in-phase settings of fat and water resonance frequencies are warranted. The field of view (FoV) typically ranges from 280 to 320 mm, depending on the breast size. The slice thickness should be 3 mm or less, and without gaps. With these parameter settings, about 30 slices are needed to visualize the entire breast parenchyma. With this protocol, 40–50 slices should be acquired within an examination time of 2 min per dynamic scan. There is no need for higher temporal resolution. If there is more scanner capacity, it should be used for better spatial resolution, i.e., a slice thickness of 2 mm. It could be demonstrated that MRI of the breast is feasible on a 3.0 T system, whereas 0.5 and 1.0 T systems are no longer recommended.

Today, technical developments allow an examination of both breasts in axial, coronal, or sagittal angulation with a high temporal and spatial resolution. Therefore, the angulation of MRI of the breast depends on the user's preference. Many users prefer the axial orientation because radiologists are accustomed to this view from CT examinations. Moreover, it allows a better assessment of the retroareolar as well as the prepectoral regions, and it allows a reduction of the slice thickness when cranio-caudal compression devices are used.

In all protocols for breast MRI, the signal from fatty tissue must be suppressed to improve the detection and delineation of contrast-enhancing lesions. Fat suppression can be effectively achieved by two different approaches: (1) active fat saturation using a frequency- or spectral-selective prepulse (American way) or (2) passive subtraction of pre and postcontrast images (European way). Notably, it is also possible to use the passive subtraction method on active fat-saturation images to allow better differentiation between signal-intense parenchymal tissue and enhancing lesions. When using the European method of fat suppression, it is recommended that the precontrast images be subtracted from the second postcontrast measurement images ("early subtraction"). If the parenchyma shows a strong contrast enhancement in the early subtraction, an additional "earliest subtraction," that is, the subtraction of the precontrast images from the first postcontrast measurement images, may be performed. There is no need for a later subtraction.

After image subtraction, it is useful to obtain a maximum intensity projection (MIP) of the early postcontrast subtraction images. This makes it easier to assess the topographic aspects of a breast lesion. Moreover, diffusely enhancing structures, such as an intraductal tumor component (EIC), are sometimes better visualized in the MIP image.

Prior to T1-WIs, the recommended practice is to obtain water-sensitive T2-w images using T2-w turbo spin-echo (TSE) or T2-w inversion recovery (IR) sequences with geometric parameters (thickness, slice position) equivalent to those of the dynamic contrast-enhanced series. T2-w images are helpful to better characterize solid enhancing masses. Moreover, it improves the detection of interstitial edema (e.g., radiation therapy, diffuse inflammatory disease, lymphangiosis).

MRI of the breast using a dedicated breast surface coil is usually not adequate for the staging of the locoregional lymph nodes. Occasionally, however, enlarged axillary or internal mammary lymph nodes can be depicted on precontrast T1-W, as well as on T2-w images, and assessed to be suspicious for metastases.

For documentation and communication purposes, the recommended practice is to present the complete AQ2

data set of precontrast T1-weighted, early postcontrast subtraction images, and earliest postcontrast subtraction images, if calculated. In addition, prepared signal-to-time intensity curves and selected T2-weighted images should be documented together with the corresponding lesion.

12.3 Evaluation

The evaluation criteria for MRI of the breast take into account information presented in the precontrast, postcontrast, and T2-w images. Some specific findings may already be seen on the precontrast T1 images, for example lymph nodes with a fatty hilus, macrocalcifications in regressive fibroadenomas, and sanguineous or protein-rich content of complicated cysts. The detection of, especially, a fat-equivalent signal within an unclear mass should be assessed as a sign of benignity.

The contrast uptake of the breast parenchyma should be described to define the reliability of the individual examination. In analogy to the BI-RADS reporting system for X-ray mammography, four categories are differentiated (MRM-density types I-IV). MRM-density type I is associated with a high sensitivity for the detection of breast cancer. MRM-density type IV is associated with a highly limited sensitivity. In this case, an earliest image subtraction (1. postcontrast – precontrast) should be performed in addition to the routinely performed early image subtraction (2. postcontrast – precontrast) (Table 12.1).

The extent of motion artifacts is another aspect that should be included in the written report. Usually, there are four categories for image quality, ranging from MRM artifact category I to artifact category IV. MRI with artifact category I has the highest sensitivity for the detection of breast cancer. Accuracy is reduced with increasing artifacts. MRI with artifact category IV is insufficient, and should be repeated after correcting the causes of bad quality (Table 12.2).

According to the BI-RADS Lexicon of the American College of Radiology, enhancing areas in the breast are differentiated into focus/foci, masses, and non-mass-like lesions. Moreover, associated findings are described. A *focus* is a small isolated spot of enhancement, generally less than 5 mm in size, that is so tiny that no definitive morphologic descriptors can be applied. Foci describe several such tiny spots, separated widely by normal tissue. Although commonly a normal finding, a very small carcinoma can appear as a focus. A *mass* is a three-dimensional space-occupying lesion that may or may not displace or otherwise affect the surrounding normal tissue. For the evaluation of masses, different criteria are described. The so-called Fischer score contains morphologic and dynamic criteria for a multimodal analysis of enhancing masses in the breast. Criteria include shape, border, endotumoral type of contrast material distribution, and the initial and post-initial signal behavior in relation to the precontrast signal. Other authors describe defined types of signal curves. Apart from the above named criteria, other "signs" on MRI of the breast are recognized. *Non-mass-like lesions* on MRI of the breast are enhancing areas that are neither a focus nor a mass. Depending on the distribution of the enhancement, it can be described as a focal area, linear, ductal, segmental, regional, multiple regions, or diffuse. Additionally, internal characteristics of the enhancing area, like homogeneous, heterogeneous, stippled/punctuate, clumped, or reticular/dendritic, can be evaluated. Typically, non-mass-like lesions are associated with normal findings, mastitis, ductal carcinoma in situ (DCIS), and invasive lobular carcinomas (Fig. 12.3).

Information from T2 images is important if there are unclear enhancing lesions seen on T1 images. In this case, the T2 signal is helpful to increase the specificity of MRI. High endotumoral signal in a solid mass, for example, is often associated with benign lesions,

Table 12.1 Density types in MRI of the breast

MRM density	Description	Sensitivity
Type I	No enhancement	Excellent
Type II	Spotty enhancement	Good
Type III	Patchy enhancement	Moderate
Type IV	Strong diffuse enhancement	Poor

Table 12.2 Artifact categories in MRI of the breast and the corresponding sensitivity for the detection of breast cancer

MRM artifacts	Description	Sensitivity
Category I	No artifacts	Excellent
Category II	Little artifacts	Good
Category III	Moderate artifacts	Moderate
Category IV	Unacceptable artifacts	Poor

AQ12 **Table 12.3** Fischer score for evaluation of masses in MRI. The total number of points defines the score and the MRM-BI-RADS category (MRM-BI-RADS 1: 0 points, MRM-BI-RADS 1: 1 point, MRM-BI-RADS 2: 2 points, MRM-BI-RADS 3: 3 points, MRM-BI-RADS 4: 4–5 points, MRM-BI-RADS 5: 6–8 points)

Criteria	Points		
	0	1	2
Shape	Round, oval	Irregular	–
Border	Well-defined	Ill-defined	–
CM distribution	Homogeneous	Inhomogeneous	Rim sign
Initial signal increase (%)	<50	50–100	>100
Postinitial signal	Continuous increase	Plateau	Washout

while malignant tumors usually have low water content. This is, however, not a reliable criterion, because mucinous tumors as well as other carcinomas may also be associated with a high T2 signal. Moreover, T2 images are helpful in recognizing endotumoral dark septations, which are sometimes better visualized on water-weighted images than on postcontrast images. Uncomplicated cysts also have a high signal on T2 images, as expected.

12.4 BI-RADS for MRI of the Breast

In 2003, the American College of Radiology defined a Breast Imaging MRI Lexicon and a Reporting System including seven categories for findings of the breast on MRI. While the category MRM-BI-RADS 0 describes an incomplete assessment and the category MRM-BI-RADS 6 is given to a histological verified breast carcinoma, the other five categories give a practical assessment of MRI findings:

Category MRM-BI-RADS 1: "negative"

No abnormal enhancement is found, and routine follow-up is advised.

Category MRM-BI-RADS 2: "benign"

MRI shows a benign finding, for example a hyalinized nonenhancing fibroadenoma, cysts, and old nonenhancing scars, fat-containing lesions such as oil cysts, lipomas, galactoceles, or mixed-density hamartomas.

Category MRM-BI-RADS 3: "probably benign"

Changes that are highly unlikely to be malignant, i.e., those that have a very high probability of being benign, are placed in this category. The consequences resulting for a finding in this category will likely undergo modifications in the future.

Category MRM-BI-RADS 4: "suspicious"

These are lesions that do not have the characteristic morphology of breast carcinoma, but do have a definite low to moderate probability of being malignant. Biopsy should be considered for these lesions.

Category MRM-BI-RADS 5: "highly suggestive of malignancy"

Lesions categorized as MRM-BI-RADS 5 have a high probability of being cancerous. They show the typical findings of a malignant breast tumor, and appropriate action should be taken.

12.5 Normal Findings

Enhancement of normal breast tissue after i.v. administration of contrast material depends especially on the hormonal stimulation of the parenchyma. As a consequence, significant intraindividual and interindividual variability may be seen. For premenopausal women, the contrast material uptake is usually stronger in the premenstrual than in the postmenstrual phase. For this reason, a highly recommended practice is to perform a MRI examination of the breast in the second (or third) week of the cycle, while the first and fourth week should be avoided. For postmenopausal women, there is usually a stronger parenchymal enhancement in patients with hormonal replacement therapy than in women without hormonal substitution (Fig. 12.4). An extremely high uptake of the contrast material is found during lactation.

In contrast to the hormonal stimulation, the breast parenchymal density on X-ray mammography does not correlate with enhancement after administration of contrast material. Even very dense breast tissue (i.e., ACR type IV) is often associated with absent or very low enhancement (Fig. 12.5).

12.6 Benign Findings

A *fibroadenoma* is the most common breast tumor found in young women. The presentation in MRI varies strongly, and depends essentially on the tumor age and the degree of fibrosis. A myxoid fibroadenoma in

a young patient is usually characterized as a round or oval mass, with well-defined borders. Myxoid fibroadenomas frequently show a very strong initial enhancement – often stronger than in breast cancer – and a post-initial plateau (Fig. 12.7). A washout phenomenon is rare and should be a cause to reconsider the diagnosis. If there is any doubt, percutaneous biopsy is recommended to confirm the diagnosis. Myxoid fibroadenomas typically have a high signal on T2 images due to their gelatinous matrix. They often show endotumoral dark lines on subtraction and/or T2 images, corresponding to small fibrotic septations. Some authors assess endotumoral dark septations as pathognomonic for a fibroadenoma. The differential diagnoses for a myxoid fibroadenoma include the phyllodes tumor, papilloma, and mucinous carcinoma. Within increasing tumor age, a fibroadenoma becomes increasingly sclerotic. This is characterized by decreasing enhancement after administration of contrast material and decreasing signal intensity in the T2 images. A completely sclerotic fibroadenoma shows no enhancement on subtraction images and is hypointense on water-sensitive T2 images. In this stage, diagnosis is clear, and there is no differential diagnosis for a sclerotic fibroadenoma.

A *cyst* is a fluid-filled lesion and characteristically shows a high signal on T2 images and a low signal on precontrast T1 images. It is typically round and well-defined (Fig. 12.6). Sometimes, the cyst wall is inflamed, and a corresponding enhancement of the thin wall after contrast material administration is seen. In the case of a *complicated cyst*, intracystic proliferation with increased enhancement is seen on the postcontrast image.

Inflammatory changes of the breast are characterized by non-mass-like enhancement in the area of increased vascularization. Sometimes, skin thickening, increased edema of the subcutaneous area, and enlarged axillary lymph nodes are seen. MRI, however, does not allow a reliable differentiation between nonpuerperal mastitis and inflammatory breast cancer.

Postoperative scars typically show spiculated or ill-defined signal alterations on T1-WIs. Normally, there is no more increased enhancement in the scar area 6 months after open biopsy (Fig. 12.8). However, unspecific uptake of the contrast material will be visible if there are granulomatous inflammatory changes accompanying the scarring. In patients with postoperative radiation therapy after breast conserving therapy (BCT), a minimum interval of 12 months is recommended before performing a MRI of the breast.

12.7 Borderline Lesions

Borderline lesions are defined as benign findings with an increased risk of malignant transformation or coincidence with a malignant tumor. Borderline lesions of the breast include papillomas, radial scars, and lobular intraepithelial neoplasia (LIN).

Papillomas are benign proliferative epithelial breast lesions with a papillary architecture. They may occur at any site in the ductal and lobular system, from the nipple to the terminal ductal-lobular unit. Solitary (central) papillomas are distinguished from multiple (peripheral) papillomas. The risk for malignant transformation is as high as 30% for peripheral papillomas, while it is rare in central papillomas. MRI shows round or oval foci or masses, with increased uptake of contrast material and unspecific signal-time curves. Typical for papillomatos is a linear or segmental distribution of tumors.

A *radial scar* is a variant of sclerosing adenosis and has a coincidence with breast cancer ranging from 5 to 30%. In MRI, it is usually most conspicous on precontrast T1 images, presenting as a stellate hypointense lesion with a defined central area. Enhancement after administration of contrast material is unspecific, sometimes missing (Fig. 12.10).

The generic term “lobular intraepithelial neoplasia” refers to the entire spectrum of noninvasive, atypical epithelial proliferations of the lobular type. LIN is associated with an increased relative risk of developing invasive breast cancer in either breast. Usually, there is no corresponding lesion in mammography and ultrasound. MRI sometimes demonstrates a small focus or foci, with a signal increase after administration of contrast material. Signal-to-time curves are unspecific. AQ5

12.8 Malignant Findings

Malignant tumors of the breast are differentiated into intraductal carcinomas and invasive breast cancer. While DCIS is considered a localized disease within the breast ducts, invasive tumors have the potential for

systemic tumor dissemination (systemic disease). In the diagnostic MRI of the breast, the criteria used for recognizing invasive breast cancer may not be transferred to the diagnosis of DCIS.

In the past, DCIS was usually detected on the basis of ductal microcalcifications on mammography. Clinical and ultrasound examinations show a very low sensitivity for the detection of intraductal proliferative processes. There is also enough evidence confirming that microcalcifications are not directly visible on MRI. Nevertheless, there are reports in the current literature stating that DCIS can be seen on high resolution MRI examinations more reliably than on mammography. This is especially true for lesions with a high tumor grade. Study data suggest that low grade DCIS is associated with a lower angiogenetic potential and a stronger disposition for developing intraductal microcalcifications. High grade DCIS, on the other hand, seems to have a stronger angiogenetic activity and is therefore better visualized on MRI.

For detection of DCIS, the typical tumor growth within the intramammary ducts and the anatomy of the ductal system of the breast must be taken into account. In analogy to the distribution of microcalcifications on mammography, the enhancement pattern on MRI is usually characterized as a non-mass like lesion with linear, dendritic, or segmental uptake of contrast material. In order to detect such enhancement patterns, a high spatial resolution with a noninterpolated matrix of a least 512 x 512 is a prerequisite. For the reliable detection of small DCIS lesions, a high spatial resolution is much more important than kinetic aspects such as initial signal increase or post-initial signal behavior (Fig. 12.11; 12.12). Multimodal evaluation protocols including dynamic criteria are, therefore, not helpful in the analysis of ductal enhancement patterns. In a few cases, DCIS may present as a focal lesion with strong and rapid enhancement, with or without washout phenomenon, indistinguishable from an invasive breast cancer.

Recent study data show that the sensitivity for the detection of DCIS by mammography ranges from 52 to 56%, while state-of-the-art high resolution contrast-enhanced MRI depicted 89–92% of all DCIS, especially high grade tumors. DCIS was missed by breast MRI in approximately 10–15% of all detected cases. For this reason, a recent state-of-the-art mammogram must be available when a breast MR study is performed. Moreover, a negative breast MR study cannot, at the current state of experience, negate the necessity for biopsy if a mammogram shows suspicious microcalcifications.

There are many different histopathologic subtypes of *invasive breast cancer*: ductal invasive cancers, not otherwise specified (NOS; approximately 80% of invasive cancers), lobular invasive cancers (10–15%), and rare invasive cancers (e.g., medullary, mucinous, or tubular cancers).

The typical appearance of *ductal invasive breast cancer* on MRI is a focal mass with irregular morphology, indistinct margins, and an inhomogeneous internal architecture. These morphologic criteria are, as expected, equivalent to those that have been found useful in mammography and ultrasonography. In addition, peripheral tumor enhancement (ring-enhancement, rim sign) is almost pathognomonic for breast cancer. The rim corresponds to the growing tumor periphery, while the central tumor areas of fibrosis or necrosis show less or no uptake of the contrast material. The dynamic characteristics typically shown by ductal invasive carcinoma are a moderate to strong initial signal increase and a post-initial plateau or washout. When a rim sign is observed, a centripetal enhancement spread is especially suspicious of malignancy. The T2 signal of breast cancer is unspecific. Invasive ductal carcinoma, however, often shows an intermediate or hypointense signal in comparison to the adjacent parenchyma (Fig. 12.9; 12.14; 12.15; 12.16; 12.17).

The growth pattern of *lobular breast cancers* effects a typically non-mass, non-space-occupying enhancement pattern on MRI. This type of tumor grows more or less diffusely, with displacement of the surrounding breast parenchyma. Lobular carcinoma is an important differential diagnosis for non-mass-like lesions (beside other changes, like DCIS, radial scar, mastitis, or circumscribed areas of adenosis). Most invasive carcinomas show typical signal-to-time curves, with strong initial enhancement followed by a plateau or washout (Fig. 12.13). Some lobular cancers, however, may differ and show a gradual and/or low enhancement.

Medullary breast cancer is typically characterized as a hypervascularized, well-circumscribed lesion with microlobulated borders, and an increased signal intensity on T2-WIs. This tumor entity is more frequent in patients with a strong family history of breast cancer and in BRCA1 or BRCA2 mutation carriers.

In contrast to ductal or lobular type of breast carcinoma, high signal intensity on T2-WIs is also seen in *mucinous cancer*. This tumor type is histopathologically characterized by small islands of tumor cells within

large mucus-filled areas. Mucinous tumors are usually round and well-circumscribed.

Another histopathologically well-differentiated malignant tumor of the breast is the *tubular breast cancer*. MRI typically shows a spiculated tumor with increased contrast enhancement. T2 signal is low and signal-to-time curves are unspecific.

Inflammatory breast cancer is characterized by the clinical trio of swelling, erythema, and pain. Imaging demonstrates cutaneous edema and hypervascularization. MRI typically shows enhancement of the thickened skin. The associated intramammary lymphangiosis often shows low or no uptake of the contrast material. If there is an underlying cancer, a strong enhancement will usually be detectable within solid tumor manifestations. MRI cannot, however, distinguish puerperal or nonpuerperal mastitis from inflammatory breast cancer.

12.9 Indications

Appropriate indications for breast MRI are:

Preoperative staging in breast cancer	In patients with a proven breast carcinoma, MRI is superior to all other imaging modalities in the depiction of additional intramammary tumor lesions, e.g., peritumoral extensive intraductal component (EIC), multifocality, multicentricity, and contralateral tumor manifestations
Follow-up after BCT	MRI allows the differentiation between scar and tumor relapse, with a high degree of reliability. Postoperative scar tissue usually demonstrates no or very low perfusion and shows no contrast enhancement. In contrast, a tumor relapse is typically associated with a strong uptake of contrast material. In the case of accompanying inflammatory changes, a postoperative scar may demonstrate an unspecific enhancement pattern
Screening in high-risk women	A high-risk profile for the development of breast cancer is defined as an increased lifetime risk of ≥30%. Women with such a high-risk profile include those with a positive test for a BRCA gene mutation, or increased number of young relatives with breast or ovarian cancer. The mean age of these women at the time of breast cancer diagnosis is approximately 40 years. Several studies have shown that for this group of young women, MRI is the most sensitive method for the detection of breast cancer
Monitoring of neoadjuvant chemotherapy	The tumor response in patients with breast cancer primarily undergoing chemotherapy can be monitored reliably by MRI. Criteria for evaluation of the effectiveness of the neoadjuvant therapy are a reduction of tumor size and a decrease in vascularization
Search for primary in CUP syndrome	MRI is indicated to search for the primary tumor in patients with a histopathologically proven metastasis of an axillary lymph node if mammography and ultrasound are inconspicious. In this constellation, even semi-suspicious findings on MRI should be evaluated by percutaneous biopsy
Diagnostic evaluation of breast implants	In women with breast implants, MRI is the method of choice to rule out or detect complications like herniation, migration, gel bleeding, and intra- or extracapsular rupture. For this indication, special exam protocols, with selective presentation of saline- and silicone signal, are recommended

12.9.1 Optimized Imaging Concept for Early Detection of Breast Cancer (Optipack-Concept)

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The combination of digital full-field mammography in the MLO-view with contrast-enhanced high resolution MRI of the breast is currently the best concept for the early detection of breast cancer. It offers the highest sensitivity for the detection of breast carcinoma, using the lowest radiation dosage. In this combination, mammography allows the detection of microcalcifications with very high reliability, while MRI depicts noncalcifying breast cancer., MRI, especially within dense parenchyma, shows a higher sensitivity in detecting such tumors by visualizing pathologic tumor neoangiogenesis that is found in many high grade intraductal tumors and all invasive breast cancers. This combination of digital 1-view mammography and MRI was introduced as the so-called Göttinger Optipack in 2003.

12.9.2 Breast Cancer Screening with MRI

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Summarizing all data on the sensitivity and specificity of MRI of the breast in the detection of breast cancer, this method seems to be the perfect tool for breast cancer screening: Its high sensitivity is superior to that of all other imaging modalities. The specificity is

acceptable and equivalent to that of mammography and ultrasonography. Moreover, there is no radiation exposure in MRI. Considering only these medical aspects, MRI should be the method of choice for screening (Fig. 12.20). Unfortunately, however, there are still problems with image quality, especially concerning motion artifacts and spatial resolution. Moreover, costs are generally too high to perform a population-based screening with MRI.

12.10 MR-Guided Interventions

MR-guided interventions are indicated for the histologic work-up of lesions classified as MRM-BI-RADS 4 and 5 that have no corresponding findings in mammography or ultrasound. A targeted ultrasound examination (second-look US) should always be performed in knowledge of the exact localization and size of the suspicious lesion on MRI.

In comparison to US-guided or stereotactic interventions, there are some additional specific aspects to be considered when performing a MR-guided biopsy or localization. First, the equipment must be compatible with a strong magnetic field. Second, the target of intervention is usually visible for only a short period of time, lasting 3–5 min. This is due to the washout of contrast material from the tumor and the increasing signal of the surrounding breast tissue in postcontrast imaging.

Another prerequisite for MR-guided interventions is an open dedicated breast surface coil, and additional perforated compression plates or post-and-pillar tools to access the breast from the lateral and/or medial aspect after the calculation of appropriate coordinates of the lesion. For MRI-guided percutaneous biopsy of unclear findings, vacuum biopsy in coaxial technique is recommended. Six to twelve specimens should be acquired, depending on the gauge of the needle. Available needle sizes range from 12 to 8 gauge (Fig. 12.18; 12.19).

For MR-guided vacuum biopsy, hand-held-systems that have to be removed after acquisition of each specimen (e.g., VACORA), as well as systems that remain at the biopsy site during the excision of the specimens (i.e., ATEC, MAMMOTOME), are available. After termination of the percutaneous vacuum biopsy, it is possible to place a small marker coil or clip within the resection cavity for later identification.

Findings seen only on MRI should be localized preoperatively, using a wire or coil/clip technique. The assortment of localization wires ranges from permanent hook and double hook types to repositionable j-like configurations and threaded hooks.

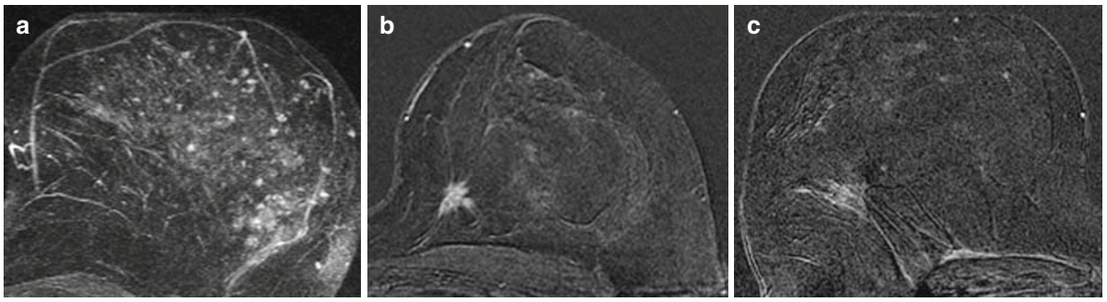
Study data demonstrate that MR-guided interventions can be performed in an acceptable time, with high reliability (Table 12.4).

12.11 MRI Summary and Perspectives

All current data document that contrast-enhanced MRI of the breast is the most sensitive method for the detection of intraductal as well as invasive breast cancer. In all studies published in the last 10 years, MRI is shown to be superior to other imaging modalities. The specificity of MRI is within the range of that attained by mammography and ultrasonography. MRI is thus the best diagnostic tool for the detection of breast cancer at all stages if a high technical standard, appropriate methodical strategy, and a high level of experience on the part of the performing radiologist prevail. Further improvements should aim to optimize the examination protocols by reducing the study to the basic essentials and decreasing the examination costs.

Table 12.4 MR-guided vacuum biopsies. Results, time required, and complication rates in different working groups

Author	Liberman	Perlet	Orel	Kuhl	Fischer
Number of biopsies	112	538	85	316	389
Malignant findings (%)	25	27	61	43	27
Borderline lesions (%)	20	3	21	5	13
Benign findings (%)	52	70	18	52	60
Accuracy (%)	97	96	98	99	99
Time required (min)	33	38	30–60	34	39
Complication rate (%)	5	<1	0	3	<1



AQ9 **Fig. 12.3** Focus, mass, and non-mass-like lesion. Types of enhancement after administration of contrast material in MRI of the breast: multiple foci, each under 5 mm in size (**a**), enhancing mass (**b**), and non-space-occupying non-mass-like lesion (**c**)

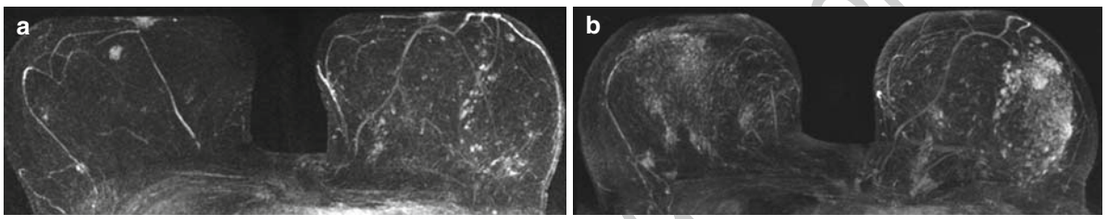


Fig. 12.4 Intraindividual variability of enhancement in a premenopausal woman. MIP of subtraction images in a 38-year-old woman. Low uptake of the contrast material 7 days after the beginning of the menstrual cycle (**a**). Stronger enhancement 1 year later, on the 11th day of menstrual cycle (**b**). Accompanying finding: hypervascularized fibroadenoma behind the nipple of the right breast

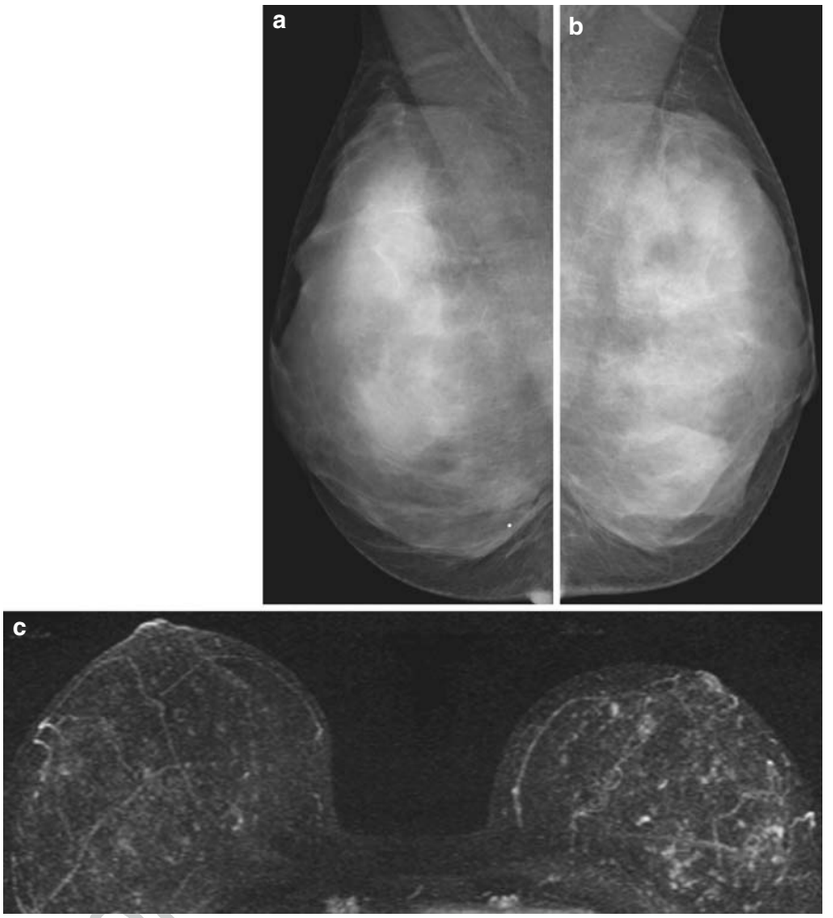


Fig. 12.5 High parenchymal density in digital mammography in comparison to CE-MRI of the breast. Digital mammography in MLO view demonstrates high parenchymal density type IV according to the American College of Radiology. MRI after administration of contrast material shows high transparency of the parenchyma (MIP; MRI-density type I)

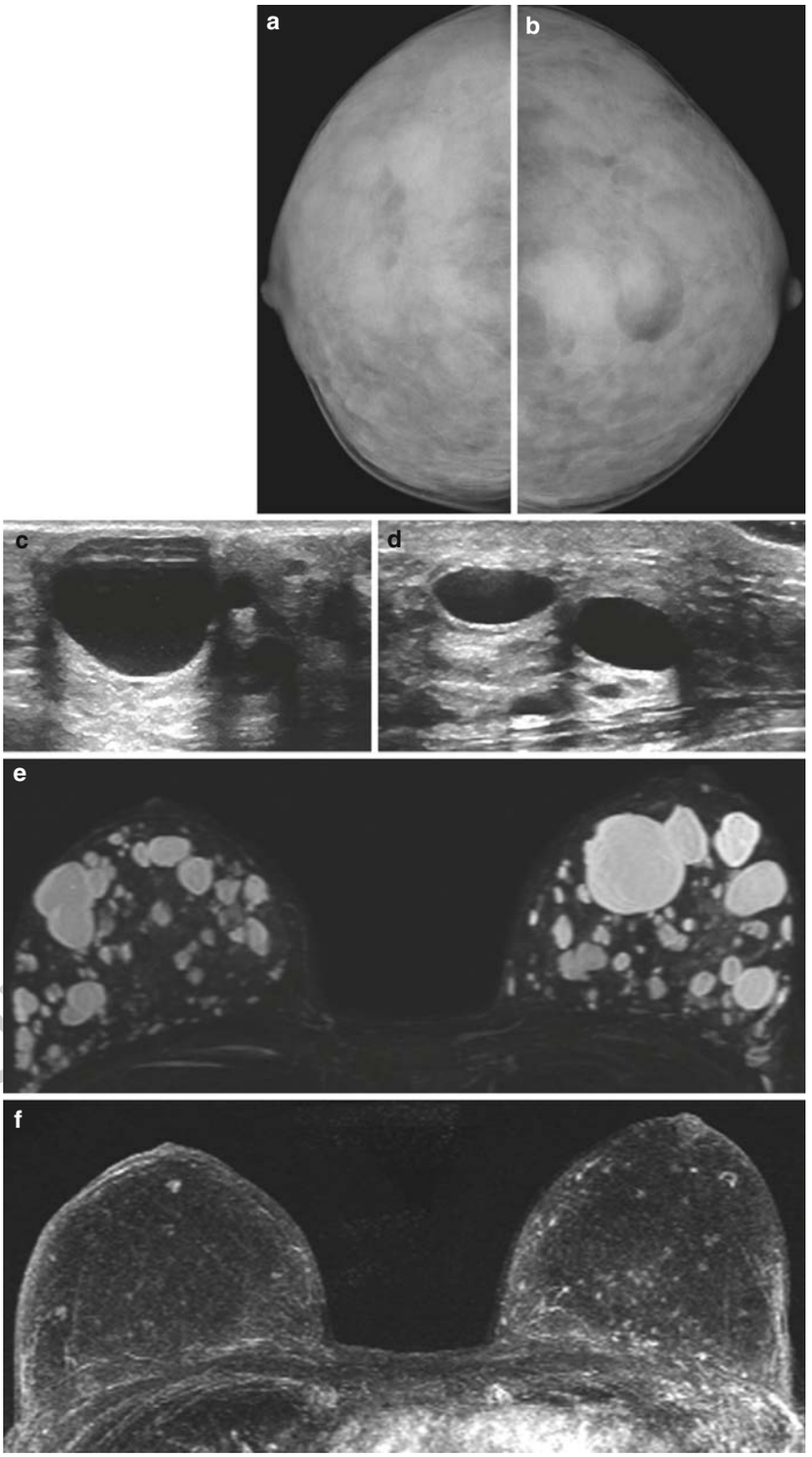


Fig. 12.6 MRI in a patient with extreme fibrocystic changes. Digital mammography in CC view shows extremely high density type IV according to the American College of Radiology and clearly reduced sensitivity (**a**, **b**). Multiple micro- and macro-cysts in both breasts on ultrasound (**c**: right breast, **d**: left breast). Demonstration of the multitude of cysts in both breasts in the MIP presentation of water-sensitive IR images (**e**). High reliability for the detection of breast cancer in the MIP of the MRI subtraction images demonstrating only few small foci (MRM-density type I)

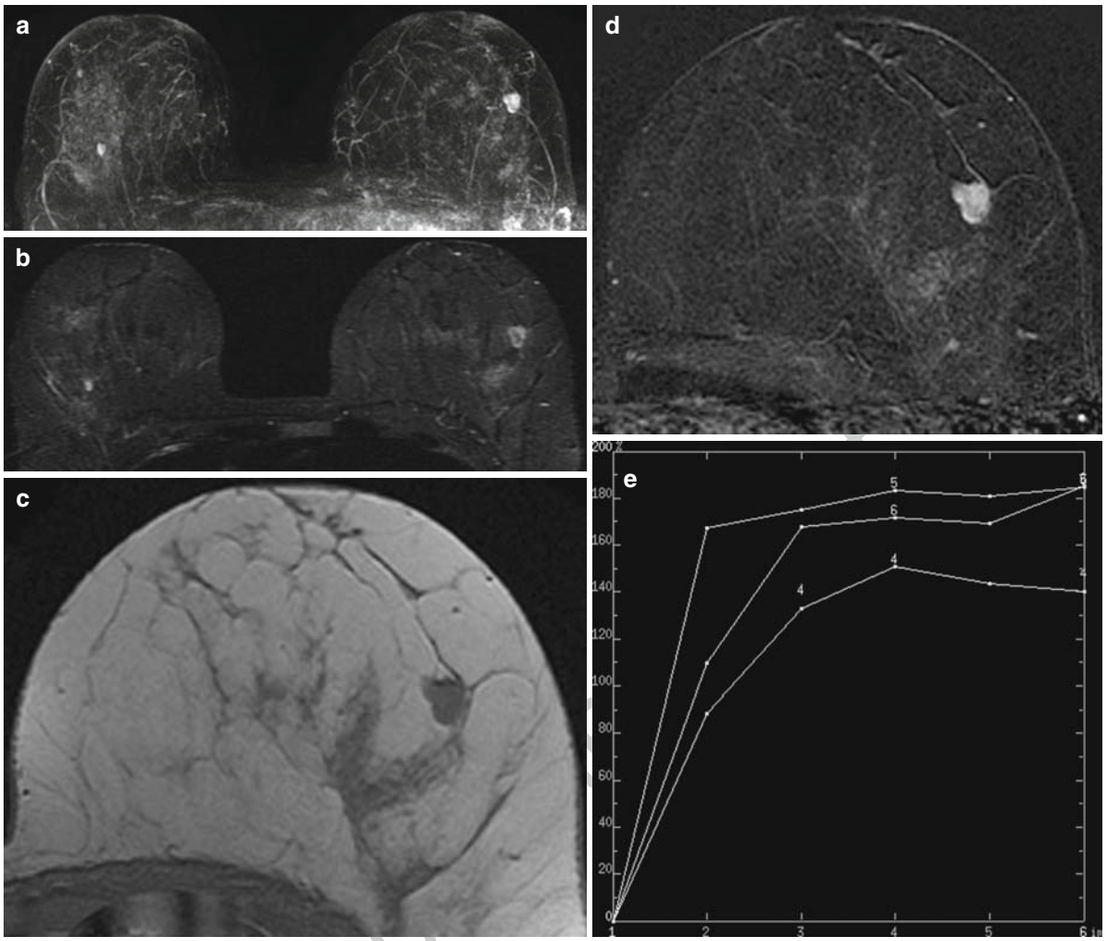


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Fig. 12.7 Myxoid fibroadenoma of the breast on MRI. Lobulated, well-defined mass with endotumoral septation in the lateral aspect of the left breast. Additional small tumor with similar signal behavior in the center of the right breast. Presentation in MIP technique (**a**). High water content of both tumors in T2-IR single slice with improved visualization of the endotumoral septations (**b**). Left tumor in precontrast T1-WI (**c**) and in single slice subtraction image (**d**). Signal-to-time curve in the tumor, with strong initial increase (>160%) and post-initial plateau (**e**). Histology after percutaneous core biopsy: myxoid fibroadenoma

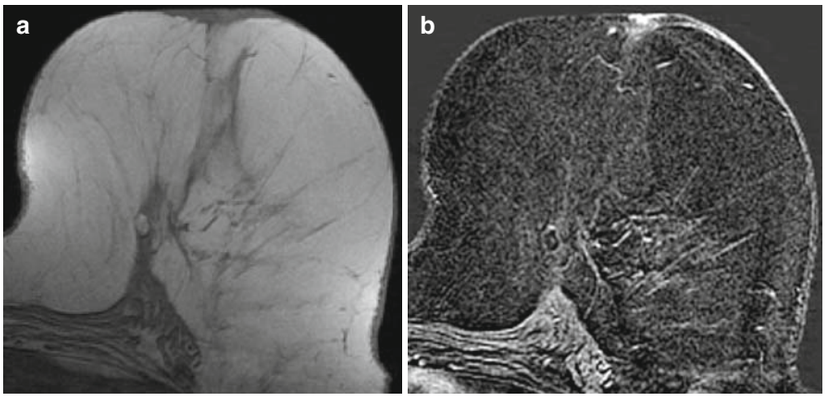

Fig. 12.8 Postoperative scarring in MRI. MRI after breast conserving therapy in a patient with a history of a small breast cancer 3 years ago. The T1-W precontrast image showed a scar with an architectural distortion accompanied by a fat necrosis (**a**). Subtraction image after administration of contrast material demonstrated no enhancement within the scar (**b**). Follow up over more than 2 years confirmed the diagnosis of a postoperative scar

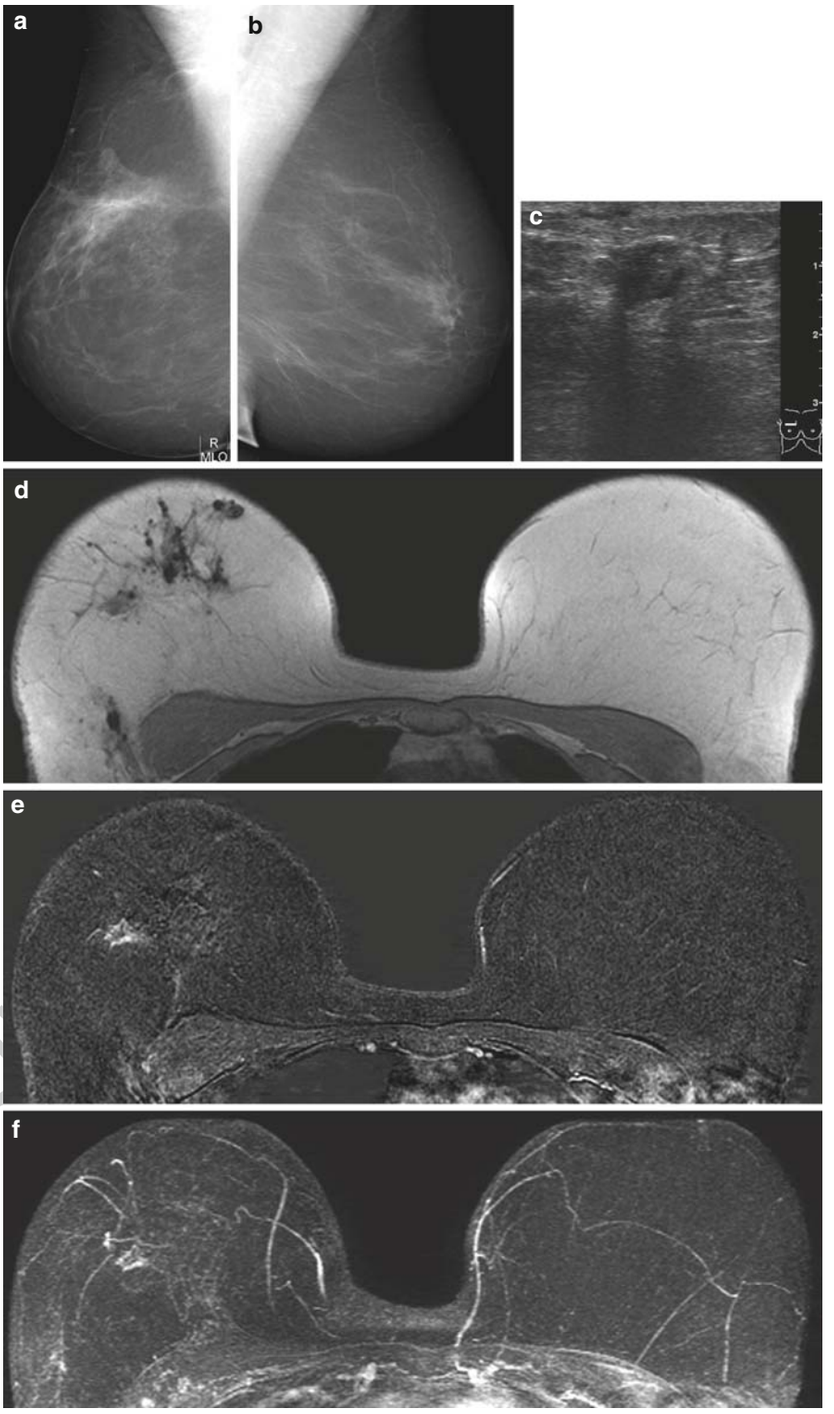

Fig. 12.9 Tumor relapse after breast conserving therapy (BCT). Digital mammography of both breasts in MLO view 3 years after BCT on the right side (**a**, **b**). Architectural distortion in the right breast compatible with a postoperative scar (**a**). Ultrasound in the region of tumorectomy demonstrates a circumscribed signal alteration compatible with fat necrosis (**c**). The precontrast T1-W GE sequence shows multiple susceptibility artifacts due to electro-cautering during surgery (**d**). The single slice subtraction image demonstrates an irregular enhancement within the scar region (**e**). Presentation of the non-mass-like enhancement in MIP technique (**f**). Histology after MR-guided vacuum biopsy revealed invasive ductal carcinoma (tumor recurrence)

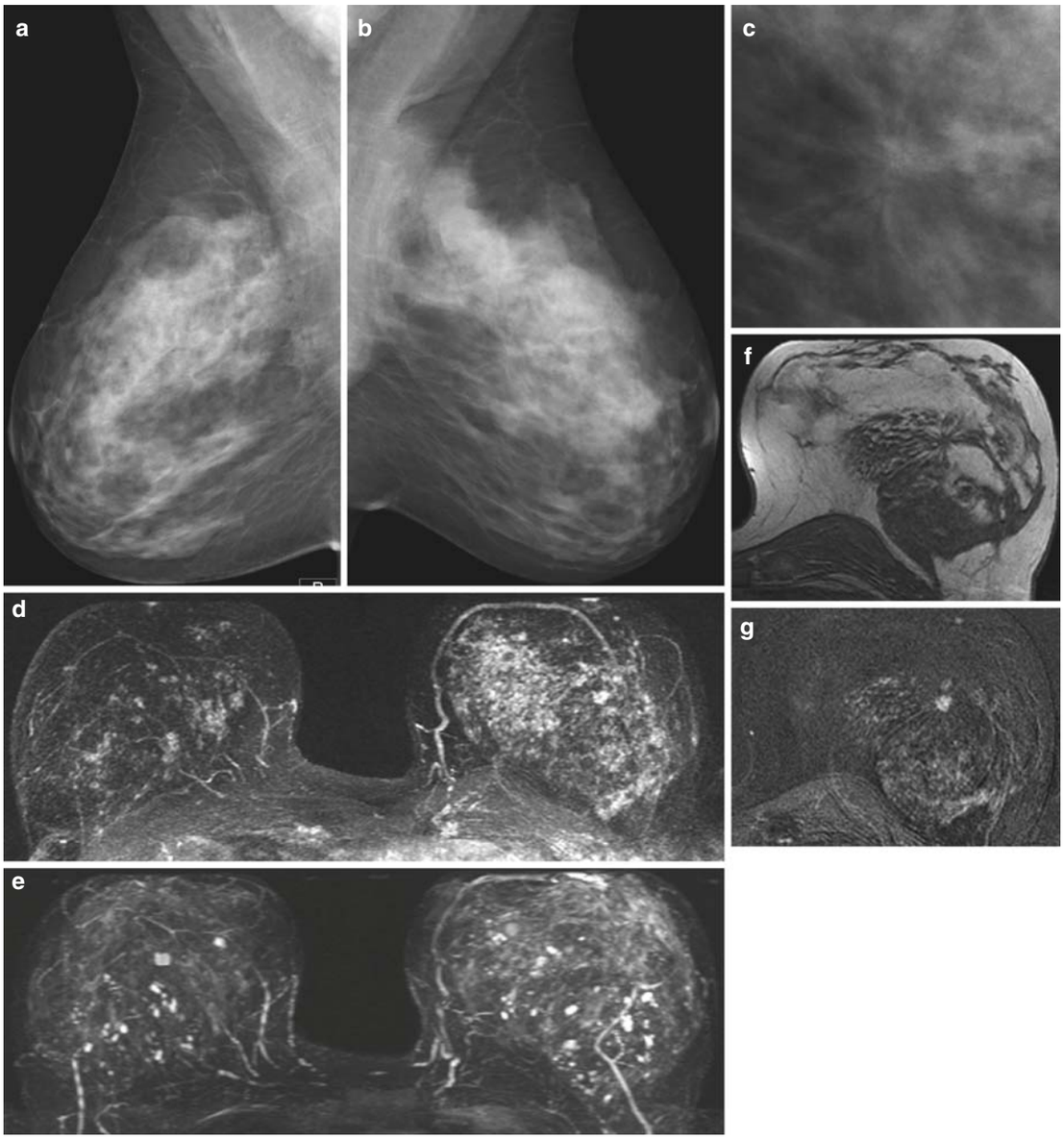

Fig. 12.10 Radial scar with associated small breast cancer. Digital mammography in MLO projection (**a**, **b**). Density type ACR IV. Architectural distortion in the center of the left breast (**b**), better seen on magnification mammogram (**c**). MRI demonstrates asymmetric uptake of the contrast material (left > right). Small hypervascularized nodule in the center of the left breast (**d**), without water signal on T2 IR image (**e**, MIP technique). Reproducibility of the architectural distortion on precontrast T1-W gradient echo sequence (**f**), with the enhancing ill-defined lesion in the center of the distortion (**g**, single slice subtraction image). Histology after MR-guided vacuum biopsy: 3 mm invasive ductal carcinoma within a radial scar

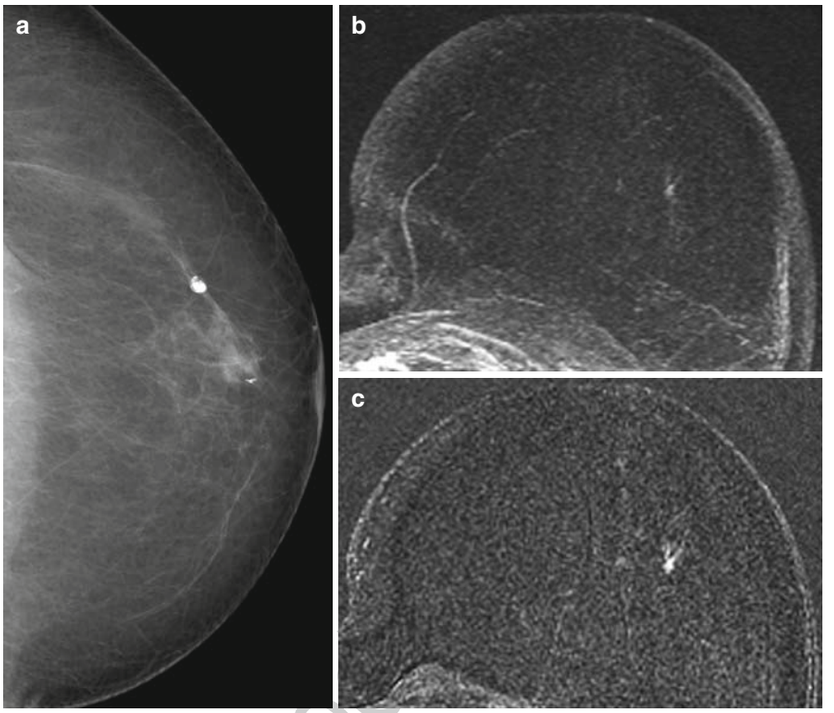

Fig. 12.11 Small high-grade DCIS in MRI. Digital mammography of the left breast in CC view. No suspicious findings. Macrocalcification (**a**). Small dendritic enhancement (non-mass-like lesion) in the lateral part of the left breast in MIP technique (**b**) and on single slice subtraction image (**c**). Histology after preoperative MR-guided needle localization: high-grade DCIS of 24 mm size

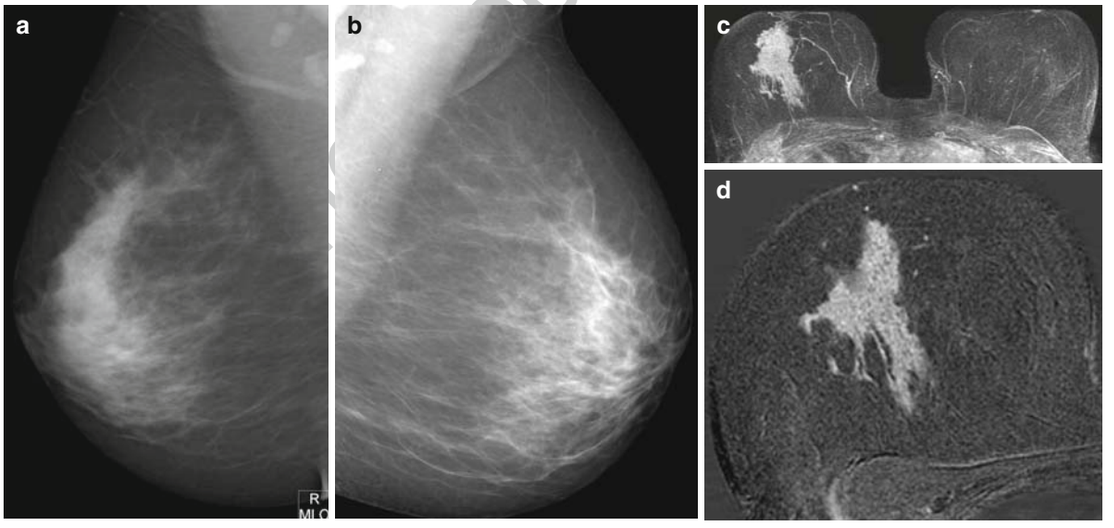

Fig. 12.12 Large high-grade DCIS in MRI. Digital mammography of both breasts in medio-lateral view. Shrinking sign of the parenchymal structures of the right breast without any associated microcalcifications (**a**, **b**). Large non-mass-like enhancement in the center of the right breast in MIP technique (**c**) and on single slice subtraction image (**d**). Histology after open biopsy (mastectomy): high-grade DCIS size

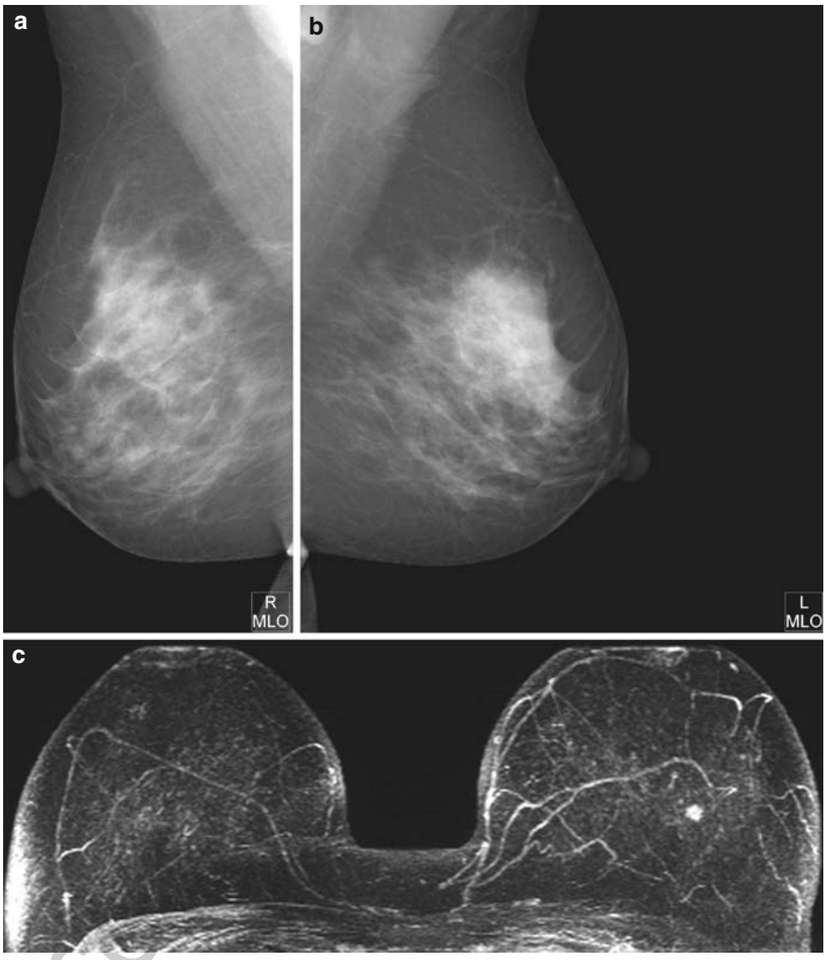

Fig. 12.13 Small invasive lobular breast carcinoma in mammographically dense breasts. Digital mammography of both breasts demonstrates normal findings. Density ACR type III. BI-RADS right 1, left 1 (**a**, **b**). Demonstration of an 11 mm lesion in the center of the left breast. MR-density type I. Histology after MR-guided vacuum biopsy and open biopsy: ILC, pT1b, pN0, G2, R0

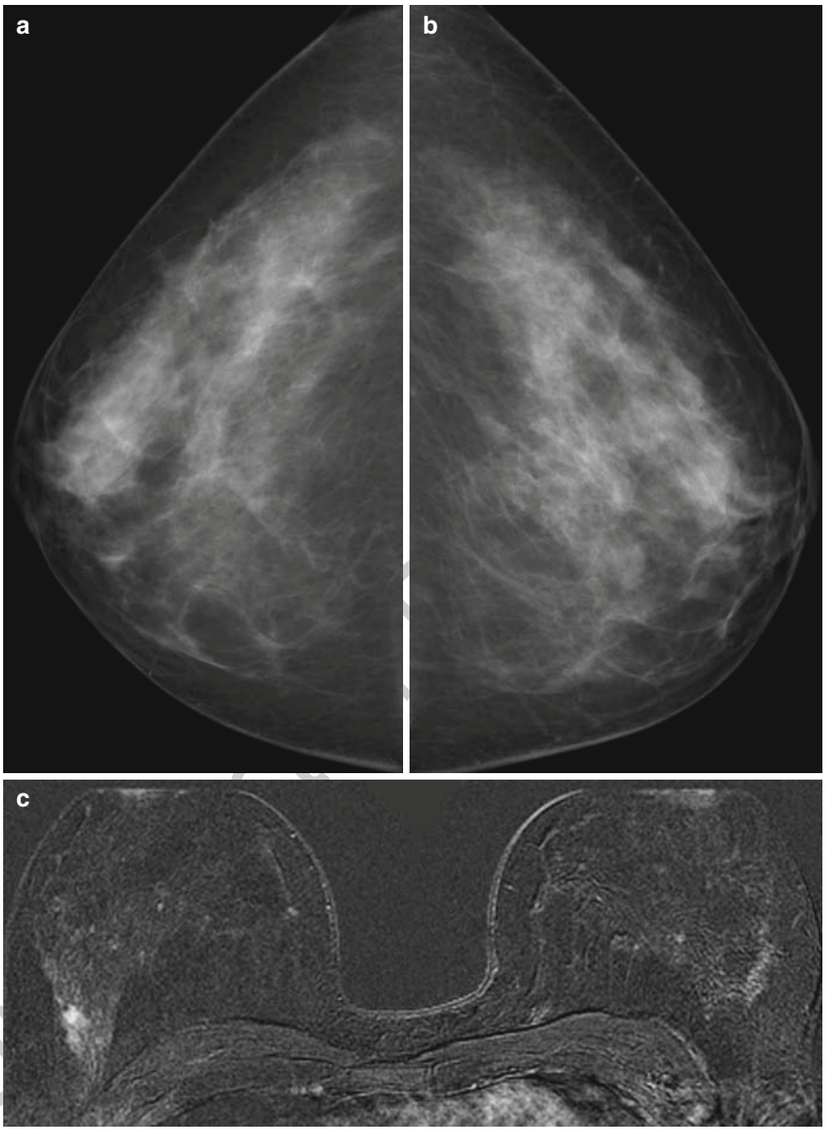

Fig. 12.14 Small invasive ductal breast carcinoma in mammographically dense breasts. Digital mammography of both breasts demonstrates normal findings. Density ACR type III. BI-RADS right 1, left 1 (**a**, **b**). Depiction of an 8 mm invasive ductal breast cancer in the lateral parts of the left breast with surrounding non-mass-like enhancement, suspicious for extensive intraductal component (EIC). MR-density type I. Histology after US-guided core biopsy (second-look) and open biopsy: IDC, pT1b, pN0, G2, R0

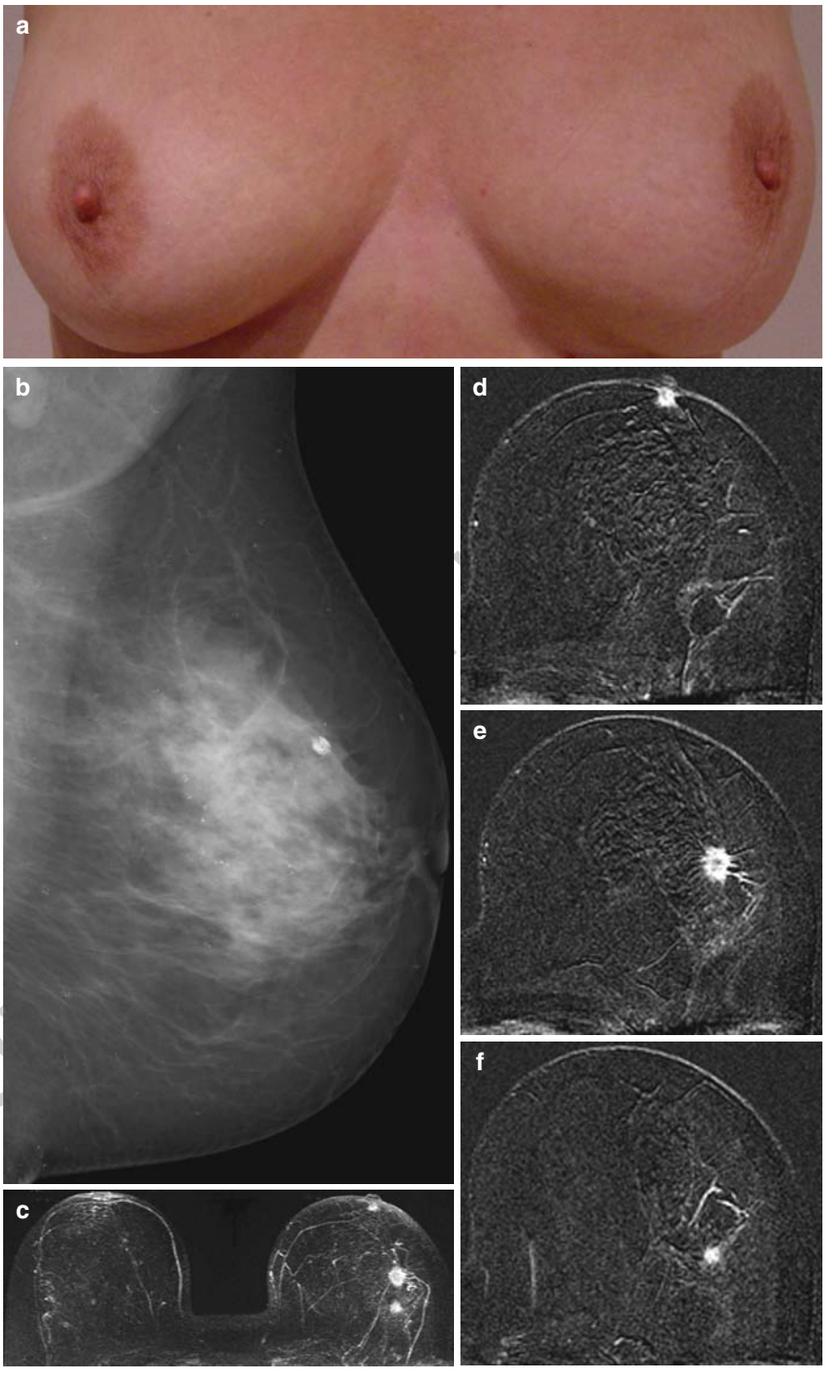

Fig. 12.15 Preoperative local staging in a patient with a trifocal breast cancer. Digital mammogram of a patient with left-sided nipple retraction (**a**) demonstrates dense parenchymal tissue (ACR type IV), unsuspicious diffuse calcifications, and nipple retraction (**b**). MRI depicted a small enhancing lesion directly behind the left nipple (**d**), the index tumor in the lateral part of the left breast (also seen on ultrasound, **e**), and a third enhancing nodule in the lower outer quadrant (**f**). Visualization of all three tumors in MIP technique (**c**). Histology revealed invasive ductal carcinoma of 13 mm (index tumor), and further cancer manifestations in the retromamillary region (6 mm) and in the lower outer quadrant (12 mm; pT1c, pN1a, G2)

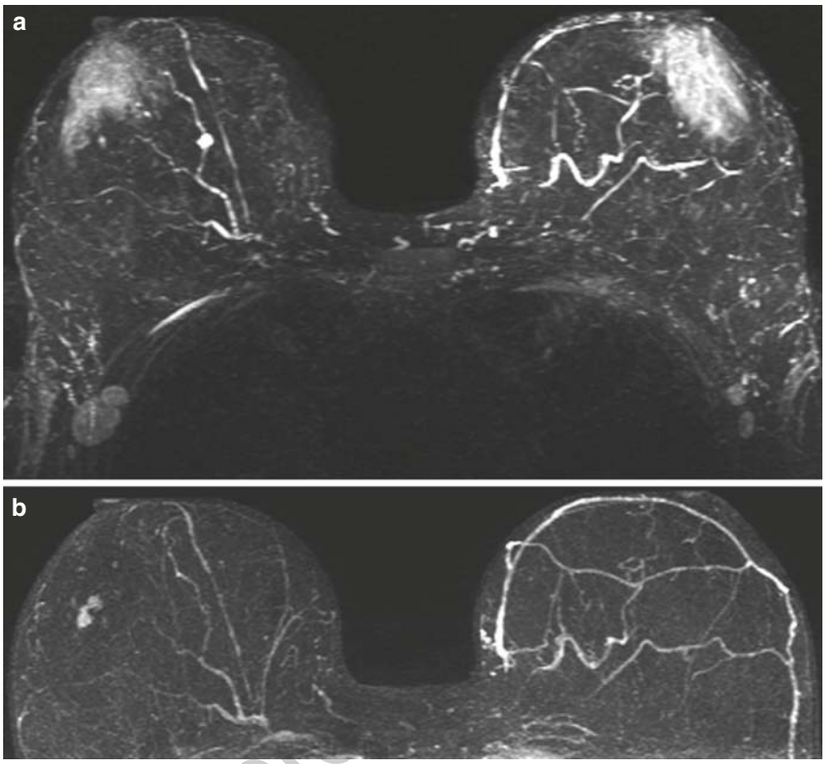

Fig. 12.16 MRI in patient with CUP syndrome (carcinoma of unknown primary). Pathologic enlargement of a lymph node in the right axilla was noticed by this patient. Histopathology after US-guided core biopsy revealed a metastasis of an adenocarcinoma. Mammography and ultrasound did not show any suspicious lesion. T2-W MR imaging demonstrated lymph node metastasis in the right axilla (**a**, MIP of T2 images). MIP of subtraction images depicted the primary carcinoma of 8 mm size in the lateral parts of the right breast (**b**). Open biopsy after needle localization confirmed this diagnosis (IDC, pT1b, pN2)

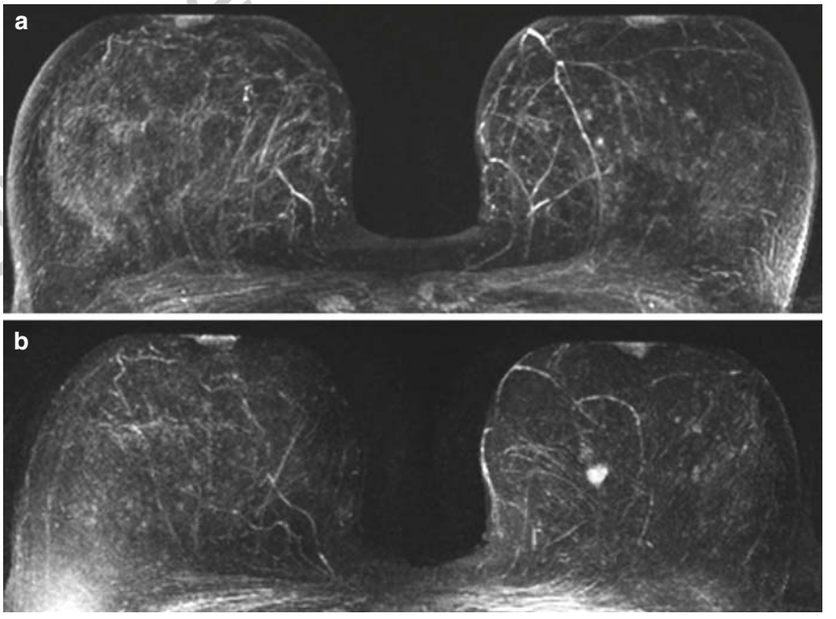

Fig. 12.17 Goettinger Optipack – follow–up. MRI in a woman with high familial risk profile. MIP of subtraction images demonstrates several foci in both breasts (**a**). No suspicious findings were diagnosed (MRM BI-RADS 1). Eighteen months later, MRI depicts an 8 mm enhancing mass in the center of the left breast (**b**). This lesion was occult in mammography and ultrasound. MR-guided vacuum biopsy verified an invasive ductal carcinoma (pT1c, pN0)

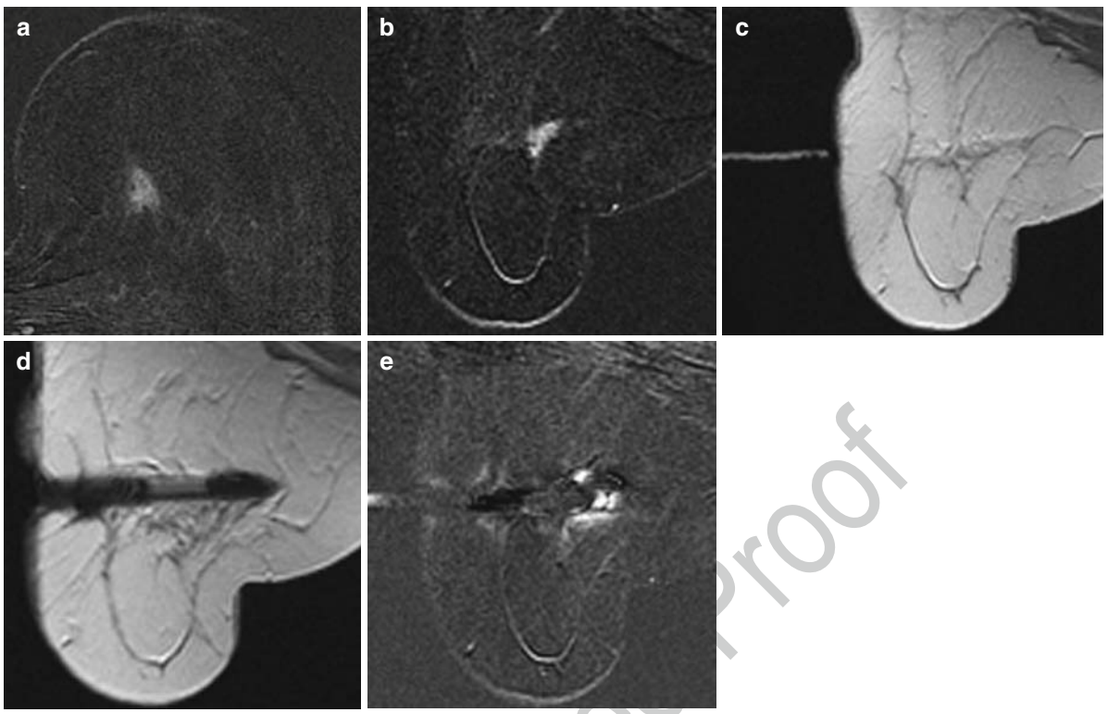

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Fig. 12.18 MR-guided vacuum biopsy of the breast. Suspicious non-mass-like lesion on diagnostic MRI of the breast, categorized as MRM-BI-RADS IV (**a**; single slice subtraction image). Reproduction of the enhancing lesion during the MR-guided interventional procedure (**b**). Confirmation of the correct needle position after calculation of appropriate coordinates (**c**). Documentation of the coaxial cannula with the notch in the center of the lesion (**d**). Final documentation of the successful biopsy after renewed application of contrast material and subtraction image (**e**). Histology revealed a radial scar without associated carcinoma

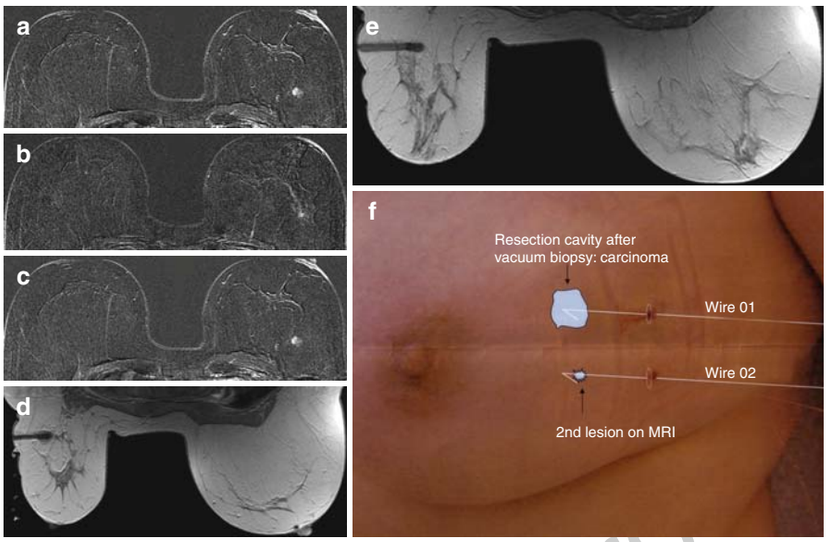

Fig. 12.19 MR-guided preoperative wire localization of two lesions. Diagnostic contrast-enhanced MRI of the breast with an enhancing mass (index tumor) in the outer upper quadrant of the left breast (**a**) and another enhancing focus 2 cm caudally from the first (**b**). Demonstration of both findings in MIP projection (**c**). Histology of the index tumor after percutaneous vacuum biopsy: invasive lobular breast cancer. Precise preoperative wire localization of the cavity after vacuum biopsy (**d**) and the second lesion (**e**). Photo documentation after intervention with presentation of the wire positions. Final histology: invasive lobular carcinoma pT1b, pN0 (index tumor); lobular carcinoma in situ (second lesion)

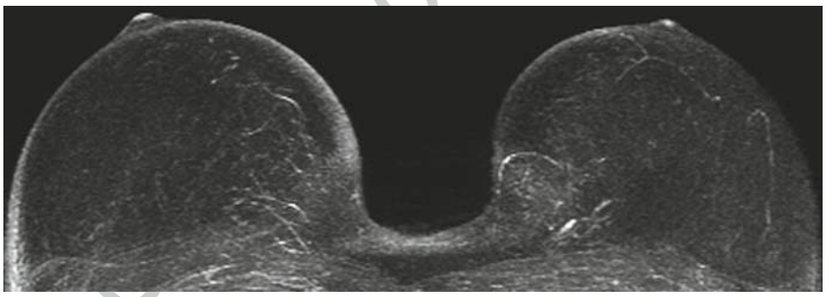

Fig. 12.20 MRM-BI-RADS 1 in superior quality MRI – do we need more diagnostics? High resolution MRI of the breast without any motion artifact (MRI artifact type I) demonstrating no parenchymal enhancement after administration of contrast material (MRI density type I) and no enhancing lesion (MRI-BI-RADS 1). In this situation, a relevant breast tumor can be excluded with extremely high reliability. In this constellation, two questions are important: Can additional mammography give more information than MRI has already given? Is it ethical to perform an additional mammography, considering the radiation exposure?

Further Readings

Berg W et al (2004) Diagnostic accuracy of mammography, clinical examination, US, and MR imaging in preoperative assessment of breast cancer. Radiology 233:830–849

Fischer U (1999) Lehratlas der MR-mammographie. Thieme, Stuttgart. ISBN 3131185813

Fischer U et al (2006) Preoperative MR imaging in patients with breast cancer: preoperative staging, effects on recurrence rates, and outcome analysis. Magn Reson Imaging Clin N Am 14:11–12

AQ7

AQ8 Fischer U et al (2008) MR-gesteuerte interventionen. In: Interventionen der Mamma. Thieme, Stuttgart, pp 86–126

Ikeda D et al. ACR-imaging and reporting system - magnetic resonance imaging?: illustrated BI-RADS?-MRI?. American College of Radiology, Reston, VA (in press)

AQ9

Kriege M et al (2004) Efficacy of MRI and mammography for breast-cancer screening in women with a familial or genetic predisposition. NEJM 352:427–437

Kuhl CK (2007a) The current status of breast MR imaging. Part I: choice of technique, image interpretation, diagnostic accuracy, and transfer to clinical practice. Radiology 244: 356–378

Kuhl CK (2007b) The current status of breast MR imaging. Part II: clinical applications. Radiology 244:672–691

Kuhl CK et al (2007) MRI for diagnosis of pure ductal carcinoma in situ: a prospective observation study. Lancet 370:485–492

Orel SG (2001) MR imaging of the breast. Magn Reson Imaging Clin N Am 9:273–288

Sardanelli F (2004) Sensitivity of MRI versus mammography for detecting foci of multifocal, multicentric breast cancer in fatty and dense breasts using the whole-breast pathologic examination as a gold standard. AJR 183:1149–1157

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