The Basics of Breast MRI

8

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Introduction

Magnetic resonance imaging of the breast has been well established as a supplemental imaging modality with proven benefit in breast cancer screening and diagnosis. Dynamic contrast-enhanced MRI of the breast has been shown to be the most sensitive imaging modality in the detection of breast carcinoma. A review of the currently accepted as well as some additional less commonly used indications that have not been rigorously validated is presented. The protocols, techniques of examination, and the artifacts encountered in a breast MRI examination are discussed. The role of MRI in the assessment of breast implants is briefly described. The BI-RADS terminology for breast MRI is presented. Breast MRI in the staging and diagnosis of breast cancer is discussed in Chap. 9.

Clinical Applications of Breast MRI

The role of MRI in the diagnosis of breast cancer has been well established. MRI depicts cancers that are occult on screening mammography, breast ultrasound, and clinical breast examination [1]. This advantage has to be balanced with a less than perfect specificity resulting in high false positives that may be higher in certain patient populations. Cost of exam, lack of widespread availability and expertise in interpretation, significantly longer examination time, need to use intravenous contrast with its attendant complications, and a cumbersome biopsy procedure for lesions that are seen on MRI are additional drawbacks to be borne in mind. Judicious utilization of this modality is therefore required [1]. And for these reasons despite the high sensitivity of MRI in detection of breast cancer it is not recommended for routine screening in women with an average risk for breast cancer. Use of breast MRI should be dictated by scientifically proven accuracy for any particular indication. Box 8.1 lists the currently utilized common indications for the use of breast MRI.

Breast MRI as a Supplemental Screening Modality in Women with an Elevated Risk for Breast Cancer

The value of breast MRI in screening for breast cancer in women at an elevated risk has been shown in several observational studies [1–15]. Currently the American Cancer Society recommends annual screening with MRI for women with a 20–25 % lifetime risk of developing breast cancer [2]

Box 8.1 Appropriate Indications for the Use of Breast MRI

1. As a supplemental modality to screen for breast cancer in women at an elevated risk for breast cancer
2. Known breast cancer patient
   (a) Staging of breast cancer to determine extent of disease to aid in treatment planning
   (b) Monitoring patients undergoing neoadjuvant chemotherapy
3. As a supplemental modality to diagnostic mammography and/or ultrasound in:
   (a) Diagnosis of occult breast cancer in patients metastatic axillary adenocarcinoma with an unknown primary
   (b) Problem-solving assessment in:
      (i) Lesion characterization
      (ii) Sonographically occult one-view-only mammographic finding
4. To assess integrity of breast implants

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Box 8.2 American Cancer Society Guidelines for Breast Screening with MRI as an Adjunct to Mammography

Recommend annual MRI screening (based on evidence*)
- *BRCA* mutation
- First-degree relative of *BRCA* carrier, but untested
- Lifetime risk ~20–25 % or greater, as defined by BRCAPRO or other models that are largely dependent on family history

Recommend annual MRI screening (based on expert consensus opinion)
- Radiation to chest between age 10 and 30 years
- Li-Fraumeni syndrome and first-degree relatives
- Cowden and Bannayan-Riley-Ruvalcaba syndromes and first-degree relatives

Insufficient evidence to recommend for or against MRI screening
- Lifetime risk 15–20 %, as defined by BRCAPRO or other models that are largely dependent on family history
- Lobular carcinoma in situ (LCIS) or atypical lobular hyperplasia (ALH)
- Atypical ductal hyperplasia (ADH)
- Heterogeneously or extremely dense breast on mammography
- Women with a personal history of breast cancer, including ductal carcinoma in situ (DCIS)

Recommend against MRI screening (based on expert consensus opinion)
- Women at less than 15 % lifetime risk

Used with permission from Saslow et al. [2]
*Evidence from nonrandomized screening trials and observational studies

[Box 8.2]. There is insufficient evidence showing benefit in screening women with a 15–20 % lifetime risk, and MRI is not recommended for those with a less than 15 % lifetime risk of developing breast cancer [2]. Women with a genetic BRCA1 and BRCA2 mutations account for about 3 % of all breast cancers. These women and their untested relatives may have a 50–60 % lifetime risk of breast cancer. There is insufficient evidence for routine screening with MRI in women with a personal history of breast cancer, in those diagnosed with atypical ductal or lobular hyperplasia or DCIS, or in those with extremely dense breast. About 5–10 % of breast cancers are truly hereditary [3].

Table 8.1 compares the sensitivity of mammography to breast MRI in screening for breast cancer in high-risk women. MRI is clearly the winner; mammography performs poorly mainly due to reduced sensitivity resulting from dense breast tissue that is more prevalent in these young women who are being screened. One of the initial large observational studies examining the benefits of screening for breast cancer in women at high risk was the Dutch Magnetic Resonance Imaging Screening study undertaken in 2004. Since most women at high risk refused consent for randomization, the study population was compared with a control group of non-screened women from an external source [4]. The multicenter study included 1,909 women of whom 358 were gene carriers, 1,052 had a lifetime risk of 30–50 % [high-risk group], and 499 women had a lifetime risk between 15 and 30 % [moderate-risk group]. There were 19 malignancies in mutation carriers, in the high-risk group there were 15 cancers, and in the moderate-risk group there were 11 cancers. The sensitivity of MRI in this study was 79.5 % and that of mammography was 33.3 %, clearly showing the superiority of breast MRI over screening mammography [4]. The Magnetic Resonance Imaging Breast Screening [MARIBS] trial was a prospective study of 649 high-risk women; in this study, mammography was shown to have a sensitivity of only 40 % compared to 77 % with breast MRI. Combined sensitivity for the two modalities was high at 94 %, justifying the use of both modalities to screen for breast cancer. The High Breast Cancer Risk Italian trial [HIBCRIT] included 278 women, all of whom were BRCA1 and BRCA2 carriers; the sensitivity of MRI was 94 % compared to 59 % with mammography. A recent large trial including 609 women demonstrated a sensitivity of 17 % for whole breast ultrasound, 33 % for film-screen mammography, 39 % for digital mammography, and 71 % for MRI. These studies have also shown the value of MRI in detecting cancer at a more favorable tumor stage. The Dutch trial showed that MRI-screened patients had a significantly higher percentage of small cancers, 10 mm or less in 43 % of women compared with 12.5 % in age- and risk-matched women, and had positive lymph nodes in 21.4 % of women compared to 56.4 % in the non-MRI-screened women. There is, therefore, indirect evidence of a beneficial effect on prognosis; however, in the absence of randomized clinical trials, it is not possible to reach conclusions regarding

Table 8.1 Comparison of sensitivity of screening MRI and mammography for detection of breast cancer in women with an elevated risk

Study	MRI sensitivity	Mammography sensitivity
Kreige et al. [4] *N* = 1,909	71.1 %	40
Warner et al. [7]	77.3	36.4
Leach et al. [6] *N* = 649	77	40
Saridenelli et al. [8] *N* = 278	93.8	58.8
Weinstein et al. [9] *N* = 609	71	39
Lehman et al. [12] *N* = 171	100	33.3
Morris et al. [11] *N* = 365	100	
Podo et al. [10] *N* = 105	100	12.5 %

mortality rate reduction or even improved disease-free survival [1].

The role of MRI as a supplement to mammography and whole breast ultrasound has been reported by Berg and others. The supplemental yield of additional cancers was 14.7 per 1,000 women screened using breast MRI. Among women screened with MRI, 2.6 % were diagnosed with breast cancer [15]. The sensitivity and value of MRI has been therefore clearly proven in these studies. The number of screens needed to detect one cancer was 127 for mammography, 234 for supplemental breast ultrasound, and 68 for MRI after a negative mammogram and ultrasound. The sensitivity and PPV3 [positive predictive value] for combined mammography and ultrasound were 44 and 18 %; for combined MRI, mammography, and ultrasound, they were 100 and 19 % [15]. Among the 612 women who had MRI in addition to mammography and ultrasound, the rate of biopsy increased from 6.2 to 13.2 % because of the addition of MRI. The PPV3 for MRI was 19 % [15]. The increased cancer detection rate varied between 1.2 and 6.7 % and was accompanied by a positive predictive value ranging from 23.7 to 60 %. MRI will lead to increased biopsies; the reported range is from 4.6 to 16.1 % [1].

Role of Breast MRI in a Patient with Known Breast Cancer

Indications for use of breast MRI in a patient diagnosed with breast cancer for staging and to assess response to chemotherapy are discussed in detail in Chap. 9.

Breast MRI to Assess Integrity of Implants

There are many different types of breast implants that complicate imaging assessment. About 14 types have been described [16]. Approximately 80 % of the implants are placed for cosmetic reasons and about 20 % are placed as a part of reconstructive surgery. A large majority of breast implants are single-lumen silicone gel implants, about 80 % in a series of nearly 10,000 implants. Saline-filled, dextran-filled, and PVP-filled implants have similar appearances on MR imaging. An understanding of the various types of implants and their component features improves accuracy in assessment of these implants [16]. There are three common types of implants: the single-lumen silicone gel, which consists of an outer silicone capsule containing viscous silicone gel, the single-lumen inflatable saline implant with greater chances of deflation when ruptured, and the double-lumen implants. The latter are of two types, one in which the inner lumen is filled with silicone and the other in which there is a saline-filled inner lumen and silicone-filled outer lumen [17].

Table 8.2 MR signs of breast implant rupture

Definite sign of implant rupture	Possible rupture	Not indicative of a rupture
Linguine sign	Teardrop sign	Irregular margin
Subcapsular line	Noose sign, keyhole sign	Lobulated contour
Train sign	Droplets in silicone	Simple radial folds
Salad oil sign		Complex radial folds
Extracapsular silicone		

Gel leaking or leeching refers to microscopic leakage of silicone through semipermeable membrane leading to capsule formation and contracture [17]. To minimize the chances of this happening decreasing the gel concentration and placement of silicone barriers on the inner surface of the envelope has been tried. Implants may be placed subglandular or subpectoral. The incidence of capsular contraction is higher with the subglandular implants and is likely due to direct contact of the implant with breast tissue. MR imaging is performed to identify implant rupture and has been shown to be the most reliable modality to diagnose implant-related complications [16–23]. The diagnosis of an implant rupture is important because the release of silicone gel and fluid into tissues can lead to local complications [18]. The incidence of implant rupture is 1–2 %; the rate of silent rupture is considerably higher [16]. Rupture may be suspected due to symptoms such as tenderness, palpable nodules, asymmetry, or infection. Implant rupture may be asymptomatic and be discovered during clinical examination, particularly when the rupture is intracapsular, where free silicone remains inside the fibrous capsule that develops around the implant. In an extracapsular rupture, free silicone is seen in the breast tissue outside the implant. Mammography is of limited use in the assessment of implant rupture and is able to diagnose extracapsular rupture only in which case free silicone is seen in the breast parenchyma [17]. Ultrasound is more useful in the assessment of breast implants but is less accurate than is MRI. Diffuse low-level echoes when seen is suggestive of an implant rupture [19]. A contour abnormality is an unreliable sign of implant rupture [19]. Common implant-related complications include hematoma in the early postoperative period, infection, capsule contracture, rupture, and formation of silicone granulomas [19]. More recent studies have reaffirmed the accuracy of MR imaging in assessment of implants [22, 23]. An accuracy of 90–92 %, sensitivity of 89–96 %, specificity of 77–97 %, positive predictive value of 90–99 %, and a negative predictive value of 79–90 % have been reported [22, 23]. The linguine sign and the salad oil signs were statistically the most significant signs [23]. Presence of silicone granulomas, free silicone, and silicone in axillary lymph nodes are suggested as signs that require immediate explantation (Table 8.2) [23]:

- *Linguine Sign/Subcapsular Line*: These two signs are the most reliable signs of an implant rupture and appear as

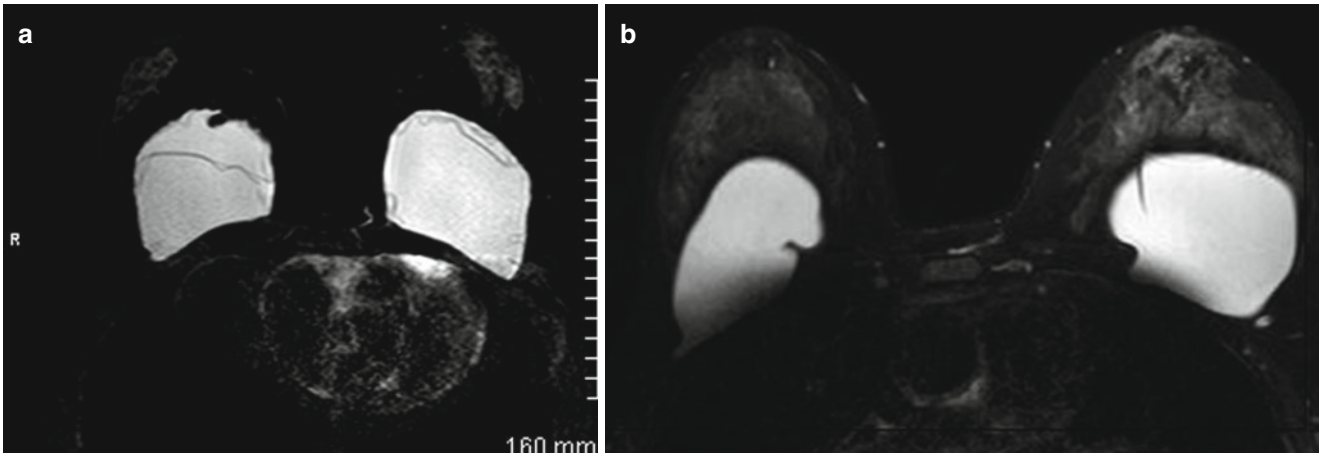

Fig. 8.1 (**a**) A silicone-excited sequence shows bilateral implant rupture with typical "linguine sign" within the implants representing collapsed implant shell. (**b**) A silicone-excited sequence shows normal infolding of the implant shell simulating a "linguine sign"

hypointense lines that are wavy and appear folded within the silicone gel and lie parallel to the fibrous capsule; these represent the ruptured silicone shell floating within the fibrous capsule (Fig. 8.1a, b). Subcapsular line is a prelude to the linguine sign when the detachment from the fibrous capsule is not complete [22].

- *Teardrop Sign*, *Noose Sign*, *or Keyhole Sign*: These signs are a result of invagination of the silicone membrane containing a drop of silicone; hence, the membranes are not opposed or touching each other as in folds. This finding depending on the shape may appear as a teardrop, noose, or a keyhole. When such an appearance is seen in more than one image, it is suggestive of an implant rupture.
- *Droplet Sign or the Salad Oil Sign*: Dot-like hypointensity within silicone represents the presence of water or serum droplets within the silicone gel. By itself this sign cannot be considered diagnostic of an implant rupture and may even represent a normal finding if saline steroids or antibiotics are directly injected into the silicone chamber in the perioperative period [23]. When larger this sign is called as the salad oil sign, a finding that is diagnostic of an implant rupture [23].
- *Train Rail Sign*: Two hypointense parallel lines are seen in close proximity forming a double-contoured subcapsular line within the silicone gel indicating that both membranes in a double-lumen implant have ruptured [22].
- *Simple and Complex Radial Folds*: Radial folds represent normal infolding of the implant shell and may simulate the linguine sign of implant rupture; these are normal findings that represent uninterrupted hypointense lines, and these extend almost perpendicularly into the lumen and end blindly (Fig. 8.1b). Complex folds are longer and have a multidirectional course. Use of orthogonal planes and reduced slice thickness or volumetric acquisitions help. Patient motion artifacts can also sometimes cause curvilinear hypointense lines within the implant simulating the linguine sign [22, 23].
- *Contour Change/Irregular Margin*: Contour changes and irregular margin when by itself is not a sign of implant rupture and may indicate herniation of the fibrous capsule. Rupture without collapse has been attributed to some cases of implant rupture that was missed on MR imaging [20]. The ruptured surface elastomer in these cases adhered to the fibrous capsule without producing the linguine sign. The homogenous high signal was maintained within the ruptured implant.
- *Extracapsular Silicone*: This is a sign of extracapsular rupture of an implant. There is free silicone in the soft tissue or a silicone granuloma which may appear as dense rounded or irregular mass.

Breast MRI as a Problem-Solving Tool

MR imaging is not recommended for routine use as a problem-solving tool to supplement diagnostic mammography. There have been studies that have examined the value of MRI as a supplemental modality for equivocal findings on mammography [24–27]. MRI is not recommended for lesion characterization or biopsy avoidance. However, in routine practice occasional use of breast MRI is made to further assess suspected abnormal findings. Judicious use of MRI is important due to the cost and potential for false positives. The ACR Practice Guideline for the Performance of Contrast-Enhanced MRI of the breast includes "additional evaluation of clinical or imaging findings" as one of the indications for performing breast MRI. The guideline specifically states that "breast MRI may be indicated when other imaging examinations, such as ultrasound and mammography, and physical examination are inconclusive for the presence of breast cancer, and biopsy could not be performed." The guideline goes on to caution, however, that "MRI should not supplant careful problem-solving mammographic views or ultrasound in

the diagnostic setting" and "should not be used in lieu of biopsy of a mammographically, clinically, and sonographically suspicious finding" [28].

In one series problem solving was an indication for 3.9 % of MRI exams of the breast performed over a 6-year period; there were 115 exams performed for inconclusive findings that represented 0.14 % of the total number of mammograms performed [24]. The most common indication was focal asymmetry [85 %] followed by architectural distortion [10 %] and scar at site of benign breast biopsy [4 %]. A majority of cases were classified as BI-RADS 0 prior to MRI [68 %]; in 19 % an assignment of BI-RADS 4 was made and MRI was performed as a biopsy avoidance tool. Ultrasound was performed in 65 of these 115 cases with no malignancies found. MRI of the breast identified six malignancies and had a sensitivity of 100 %; two of these six cancers were seen on one mammographic view. The positive predictive value of MRI was 14 % [24]. The role of MRI in downgrading BI-RADS 3 lesions has been reported but is not a cost-effective approach for this indication. The negative predictive value of MRI in reported studies for noncalcified BI-RADS 3 lesions was 100 %. For probably benign calcifications, the negative predictive value was 76–97 % for BI-RADS 3 microcalcifications [25]. For this reason there is no justification for use of MRI downgrading BI-RADS microcalcifications. A report on use of MRI as an adjunct to mammography found that MRI had the most benefit in lesions that were characterized as BI-RADS 0 or 3. A significant higher sensitivity was achieved with the use of MRI with nearly similar specificity [26]. Cost-effectiveness remains an issue despite the beneficial findings shown in these few studies and was not addressed. MRI should generally not be used for lesion characterization or for biopsy avoidance since percutaneous biopsy under imaging guidance is relatively safe, less expensive, and readily available [1]. Moreover, for this indication to be valid, MRI has to have a greater than 98 % negative predictive value which has not been the case. A large series of 821 patients with a suspicious mammographic or clinical finding found an NPV of only 85 % with cancer missed in 48 of 329 negative MR examinations [27]. Based on lack of robust data and issue of cost-effectiveness, it seems prudent to use MRI occasionally as a problem-solving tool in cases such as lesions seen on one view and sonographically occult [13].

Breast MRI to Diagnose an Occult Breast Cancer

Uncommonly, adenocarcinoma is identified in axillary lymph nodes with no mammographic evidence of a primary in the breast. Such a presentation is seen in less than 1 % of breast cancer cases [1]. Such metastasis is usually from the ipsilateral breast. Identifying a tumor may result in less radical surgical procedures and/or radiation depending on tumor size, characteristics, and extent [1]. MRI successfully identifies occult primary cancer in 61 % of cases [1]. The European Society of Breast Imaging recommends use of MRI in case of localized metastatic disease such as axillary adenopathy when clinical and conventional imaging fail to identify a breast primary [5]. When metastasis is extensive and prognosis is poor and will not be affected by site of primary tumor, there is no role for the use of breast MRI [5].

MRI BI-RADS Lexicon

Dynamic contrast-enhanced MR mammography is now an accepted modality for screening, diagnosing, and staging of breast cancer. With increasing utilization of breast MRI, there was a need to standardize terminology, reporting, and final assessments to fall in line with what had already been established and used for mammography and breast ultrasound. The American College of Radiology incorporated the BI-RADS™ MRI lexicon into its Breast Imaging and Data System Atlas in 2003 [29]. An updated version is nearly complete and due to be released later this year with significant changes made to the original lexicon [30].

The descriptors are for types of enhancement, location of the lesion, the kinetic time-intensity information, and associated findings [31, 32]. There are two main categories of descriptors of enhancing lesions, namely, the morphology and the enhancement kinetics. There are three morphologic types of enhancing lesions that will be discussed next.

Focus or Foci

Focus or foci are enhancing lesions that are small and typically less than 5 mm; these are often related to hormonal changes and are benign (Fig. 8.2a, b). The finding of a focus or foci is often stable on follow-up examination. Foci may be challenging to assess for enhancement kinetics due to volume averaging effect. The differential diagnosis of such foci includes focal fibrocystic change, small fibroadenoma, papilloma, benign lymph node, or rarely DCIS or a small invasive ductal cancer [32]. In a retrospective study of 666 MR-only detected lesions that underwent histological confirmation, the incidence of cancer among foci was less than 3 %; for this reason biopsy is rarely needed for foci particularly when there are more than one such finding [33].

Masses

A mass is larger than 5 mm and is three dimensional and visible on precontrast images. This may indicate an invasive breast cancer or a benign entity such as a fibroadenoma. The shape, margins, and internal enhancement characteristics are described next.

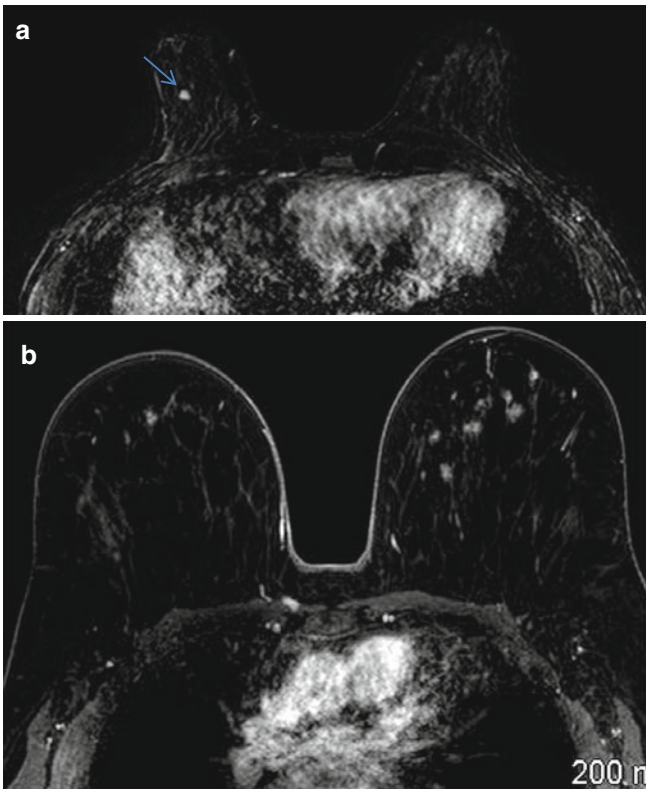

Fig. 8.2 (**a**) Axial postcontrast fat-suppressed T1-weighted subtraction image shows a 4 mm enhancing focus in the right breast. (**b**) Axial postcontrast fat-suppressed T1-weighted subtraction image shows multiple bilateral enhancing foci

Shape of a Mass

This may be described as round, oval, or lobulated when the border is undulating. The shape is considered irregular when it has an uneven shape and cannot be categorized as round, oval, or lobulated. A round mass is circular or ball shaped, an oval mass is elliptical, a lobulated mass can have a scalloped contour.

Margins of a Mass

This feature can be described as being smooth, irregular, or spiculated. The latter is suspicious for cancer or a radial scar. Smooth margin is well defined with sharp demarcation from surrounding tissue (Fig. 8.3a–c). An irregular margin is uneven, ill-defined, or indistinct and can have jagged edges. A spiculated margin has spicules radiating from the surface. An irregular mass or one with an irregular or spiculated margin is commonly associated with invasive breast cancer.

Internal Enhancement Characteristics

There are six patterns of internal enhancement that are encountered: homogenous, heterogeneous, rim, dark internal septations, enhancing internal septations, and central enhancement. They are described as follows:

- A homogenous enhancement pattern is associated with uniform enhancement within the mass.
- A heterogeneous enhancement refers to an inhomogeneous internal enhancement pattern resulting in variable signal intensity.
- Rim enhancement refers to a peripheral rind of enhancement. Dark internal septations are nonenhancing linear areas within a mass.
- Enhancing lines within a mass indicate the presence of internal enhancing septations.
- A central enhancement is when there is more pronounced enhancement at the center of a mass.

Smooth margins, poorly enhanced lobulated masses, and presence of nonenhancing internal septations are predictors of benignity in a mass (Fig. 8.3a–c). The degree of enhancement in a fibroadenoma is variable depending on the fibrotic component and hormonal stimulation of the breast. Myxoid fibroadenomas enhance strongly but tend to washout slow unlike invasive cancers. Phyllodes tumors can show heterogeneous enhancement and may have nonenhancing internal septations (Fig. 8.3c). Although a fibroadenoma can typically demonstrate homogeneous enhancement, this can also be associated with invasive breast cancer.

A lobulated mass without septations or with enhancing septations and moderate to intense enhancement and with washout kinetics is highly suggestive of malignancy and may be characteristically seen in medullary and colloid cancers and also in some invasive ductal and lobular cancers. Rim enhancement has a high predictive value for malignancy, although not a frequent finding (Fig. 8.4a–c). This finding is commonly associated with invasive ductal cancer of a higher grade [32]. Spiculated margins are often seen in invasive ductal cancers and in radial scars; enhancement kinetics may help in the differential diagnosis (Fig. 8.5). Spiculated margins less commonly may be associated with tubular cancers, DCIS, and invasive lobular cancer.

Non-Mass-Like Enhancement [NMLE]

Non-mass-like enhancement refers to areas of enhancement that do not correspond to a defined 3-dimensional mass. Features in such areas of enhancement that are described include the distribution, the internal characteristics or patterns of enhancement, and the presence of symmetry or asymmetry in appearance when bilateral. These areas of enhancement are distinct from the surrounding breast tissue. In general NMLE may be associated with DCIS, invasive lobular cancer, adenosis, fibrocystic change, or inflammation. It is not associated with estrogen receptor-positive cancers [32].

Distribution of NMLE

- Focal enhancement is a single small area of NMLE confined to less than 25 % of a quadrant of the breast (Fig. 8.6a–d).

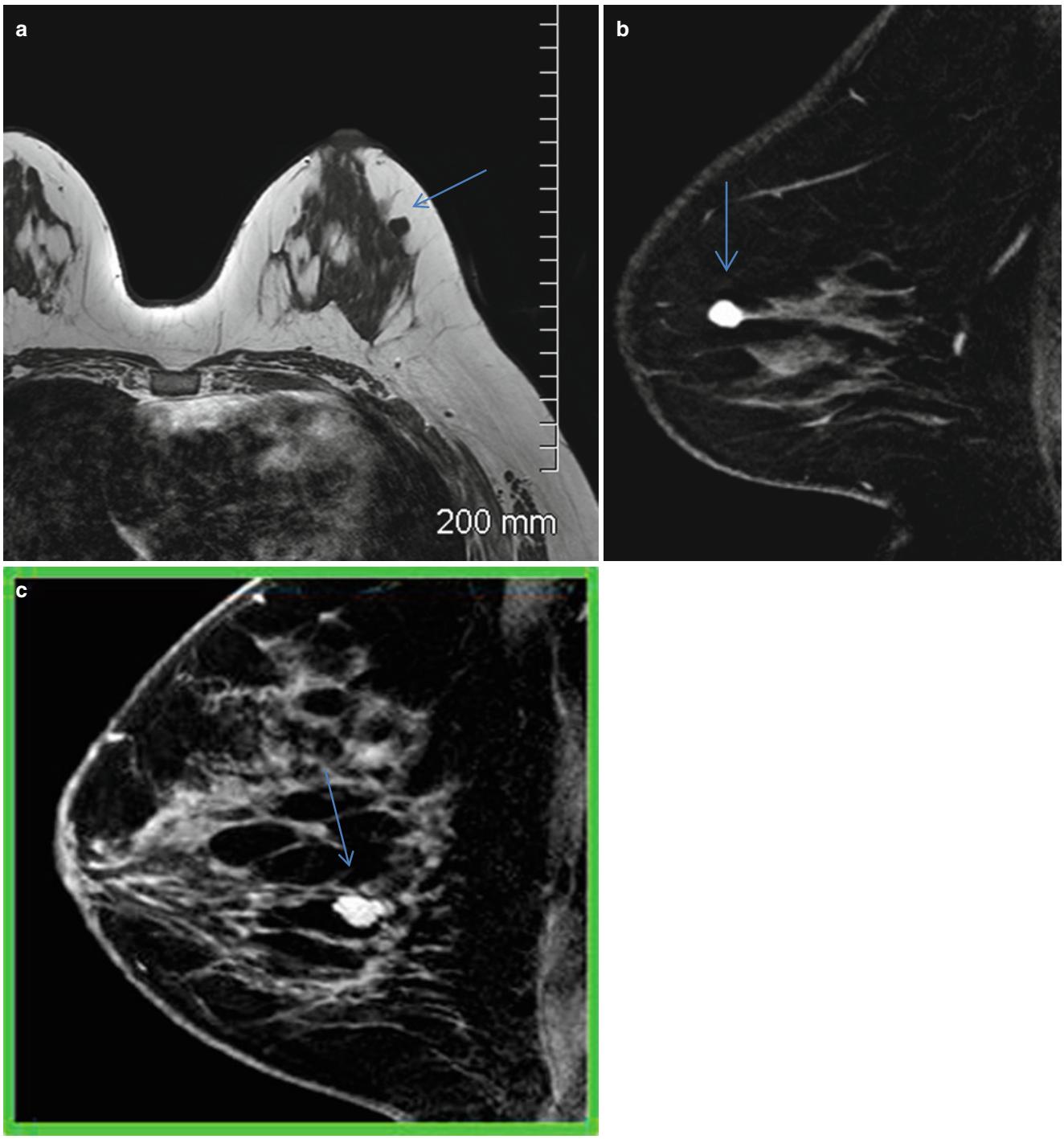

Fig. 8.3 (**a**) Axial T1-weighted image shows an isointense mass with smooth borders in the outer central left breast. (**b**) Sagittal postcontrast fat-suppressed T1-weighted image shows homogenous enhancement and smooth margins suggestive of a benign mass. Histological diagnosis: fibroadenoma. (**c**) Sagittal postcontrast fat-suppressed T1-weighted image shows enhancing mass with dark internal septations and smooth margins suggestive of a benign mass. Histological diagnosis: fibroadenoma

- Linear enhancement is seen along a line but not conforming to a ductal distribution, it may appear sheet like in an orthogonal plane.
- Ductal enhancement occurs along a single duct or in a branching pattern and usually toward the nipple. This pattern of non-mass-like enhancement is highly predictive of malignancy. It is frequently associated with DCIS. It is sometimes associated with benign histology such as atypical ductal hyperplasia and lobular carcinoma in situ (Fig. 8.7).

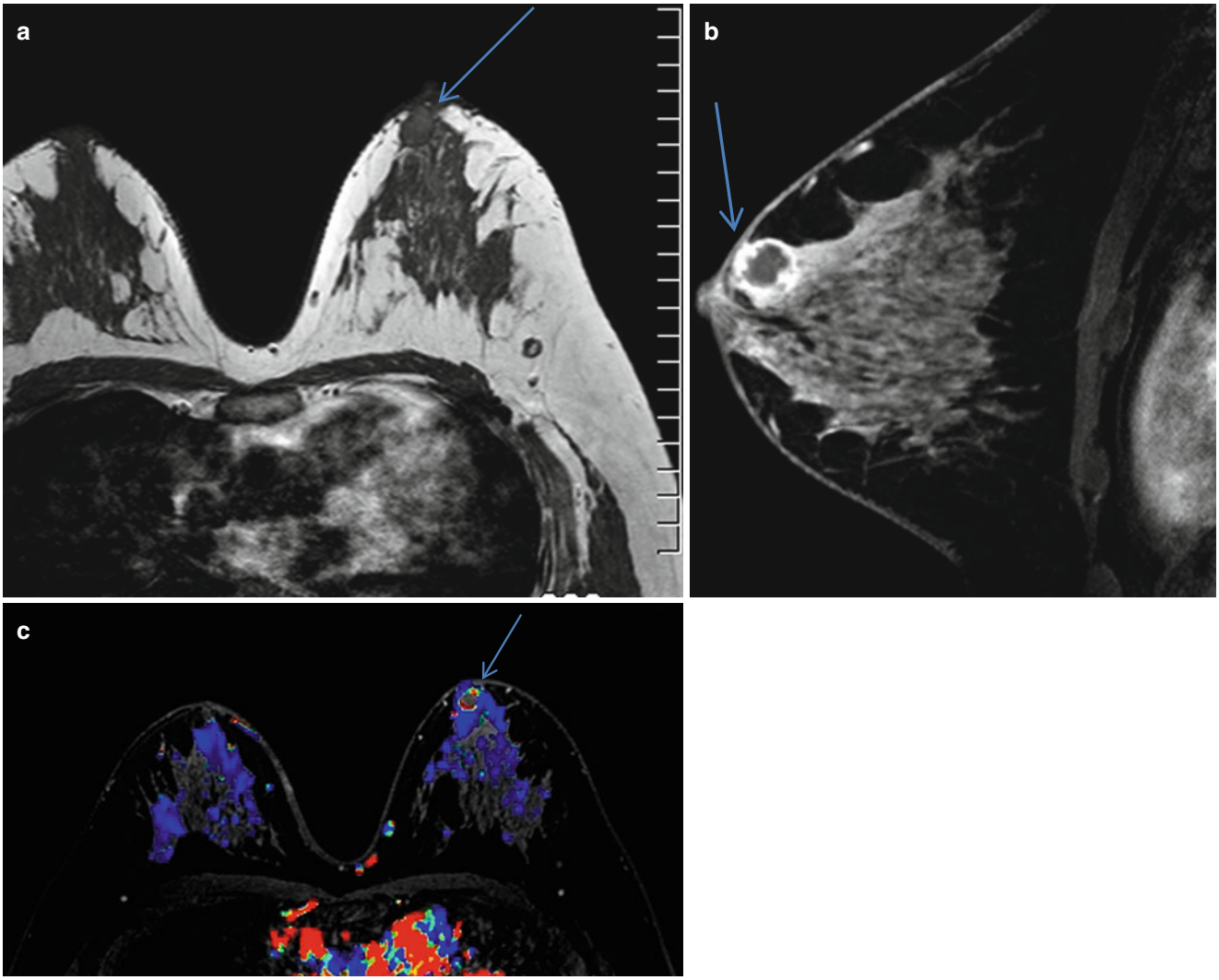

Fig. 8.4 (**a**) Axial T1-weighted image shows an isointense mass with lobulated borders in the subareolar left breast. (**b**) Axial postcontrast fat-suppressed T1-weighted image shows an enhancing lesion with irregular thick rim enhancement suspicious for malignancy. (**c**) Axial postcontrast subtraction image with color overlay demonstrates washout kinetics in the thick irregular rim of the subareolar mass. Histological diagnosis: invasive ductal cancer

- Segmental enhancement refers to enhancement that conforms to a segment drained by a single duct system and may be triangular or cone shaped and pointing toward the nipple. This type of enhancement is highly predictive of malignancy and with linear type represents the most commonly encountered enhancement pattern in DCIS [32].
- Regional enhancement occupies a larger area of enhancement, not confined to a segment and less distinct from surrounding tissue, and may be patchy or geographic. Such enhancements are frequently associated with benign fibrocystic changes.
- Multiple regional enhancements are multiple areas of enhancement in a pattern described previously.
- Diffuse enhancement refers to evenly distributed enhancement throughout the fibroglandular tissue.

Multiple regional and diffuse patterns are nearly always related to benign or hormone-related changes particularly when bilateral. Occasionally when unilateral these patterns may be seen in invasive ductal and lobular cancers.

Internal Characteristics of NMLE

- Homogeneous is confluent and uniform enhancement.
- Heterogeneous is nonuniform NMLE that is separated by areas of nonenhancing normal breast parenchyma.
- Stippled/punctate are multiple dot-like scattered 1–2 mm enhancing foci and not conforming to a duct, and these are strongly associated with a benign process or normal breast tissue.
- Clumped enhancement appears as aggregate of enhancing masses or foci that may appear confluent; such a pattern is strongly associated with DCIS (Fig. 8.7).

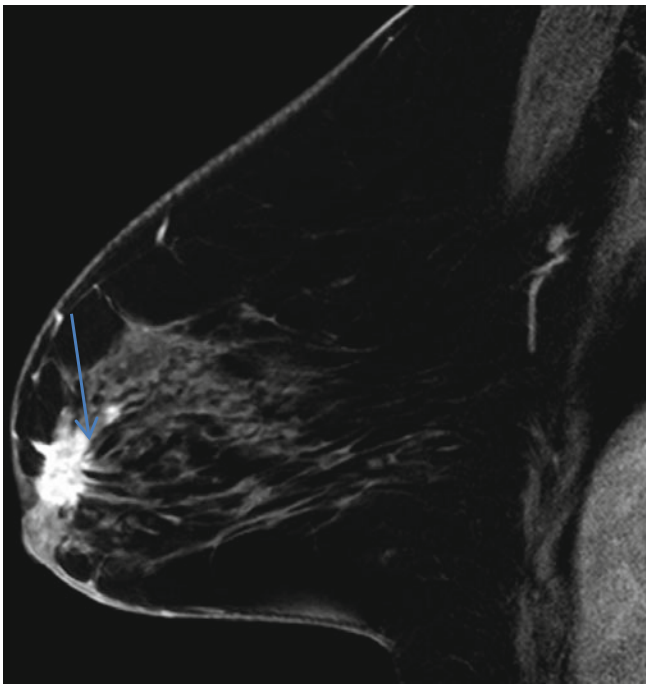

Fig. 8.5 Sagittal postcontrast fat-suppressed T1-weighted image shows an enhancing lesion with spiculated borders suspicious for malignancy in the retroareolar right breast. Histological diagnosis: invasive ductal cancer

- Dendritic/reticular pattern of enhancement appears as strands of enhancement and may represent involuting glandular tissue that leaves behind enhancing tissue between fat.
- Symmetry: When an enhancement pattern has a mirror image in the other breast, it is referred to as a symmetric pattern, and when enhancement is less pronounced in one breast, it is referred to as being asymmetric in distribution. Symmetric enhancement is strongly associated with benign findings.

Associated Findings

These include skin and areolar changes, lymph nodes, chest wall involvement in posterior carcinomas, ductal hyperintensity on precontrast images, cysts, hematoma, and signal void artifact arising from a clip. Enhancement of the nipple areolar complex is seen in the affected breast in Paget's disease of the nipple. Enhancement within the pectoral muscle when contiguous with a posterior carcinoma is suggestive of muscle invasion. Abnormal lymph nodes cannot be discriminated based on enhancement kinetics since they exhibit intense enhancement with washout kinetics similar to cancer. Correlation with T1-weighted images helps in making an accurate diagnosis of a benign lymph node. A short axis dimension of greater than 10 mm, absence of fatty hilum, rounded shape, and cortical abnormalities are predictors of abnormal lymph nodes. Dynamic contrast-enhanced MRI has been found to be useful in evaluating lymph node involvement in patients with known breast cancer [33, 34]. Using specific MRI lymph node findings such as presence of irregular margins, cortical nodularity or thickening, replaced fatty hilum, perinodal edema, rim enhancement, and lymph node asymmetry and with multivariate analysis, it has been reported that axillary lymph node metastasis can be diagnosed with a high diagnostic accuracy [34].

Kinetic Enhancement Curve

The kinetic curve assessment is described from the most suspicious curve pattern selected from the fastest enhancing part of a lesion. The kinetic curve is assessed in two phases, the initial phase and the delayed phase. The initial phase is during the first two minutes after initiation of contrast injection. This phase is described as being slow, medium, or fast. The second or the delayed phase is after the first two minutes or after the kinetic curve begins to change. The delayed phase has three possible patterns: rapid washout, plateau, or persistent. A rapid initial phase is also a feature suspicious for malignancy. Rapid enhancement in the initial phase and washout or plateau delayed phase is commonly associated with invasive cancer, and persistence in the delayed phase is observed in benign lesions. Invasive lobular cancer may demonstrate low magnitude and persistent enhancement kinetics due to weak angiogenesis; therefore, in NMLE, kinetics have to be interpreted with caution never excluding malignancy based purely on kinetics. It is important to bear in mind that morphology always trumps kinetics. DCIS may also demonstrate slow initial phase and variable delayed phase enhancement patterns [31, 32]. Three types of enhancement patterns have been described. Type I refers to progressive enhancement, and this pattern is commonly associated with a benign lesion [83 %] and uncommonly with malignancy [9 %]. Type II curve is a plateau pattern where after initial enhancement there is flattening of the curve. Type III is a washout curve demonstrating an initial increase and a progressive washout. This pattern is characteristic of malignancy with 76 % of such patterns being reportedly associated with cancer; however, sensitivity is low and reported to be about 20 %. The reported range of association of the three types of enhancement with malignancy is as follows: Type I curve has a 5–9 % malignancy rate (Fig. 8.6d); the type II curve has an association of 6–64 % with malignancy; and the type III curve where there is a rapid washout has a 33–85 % association with malignancy. For optimal accuracy morphology has to be combined with enhancement kinetics [35].

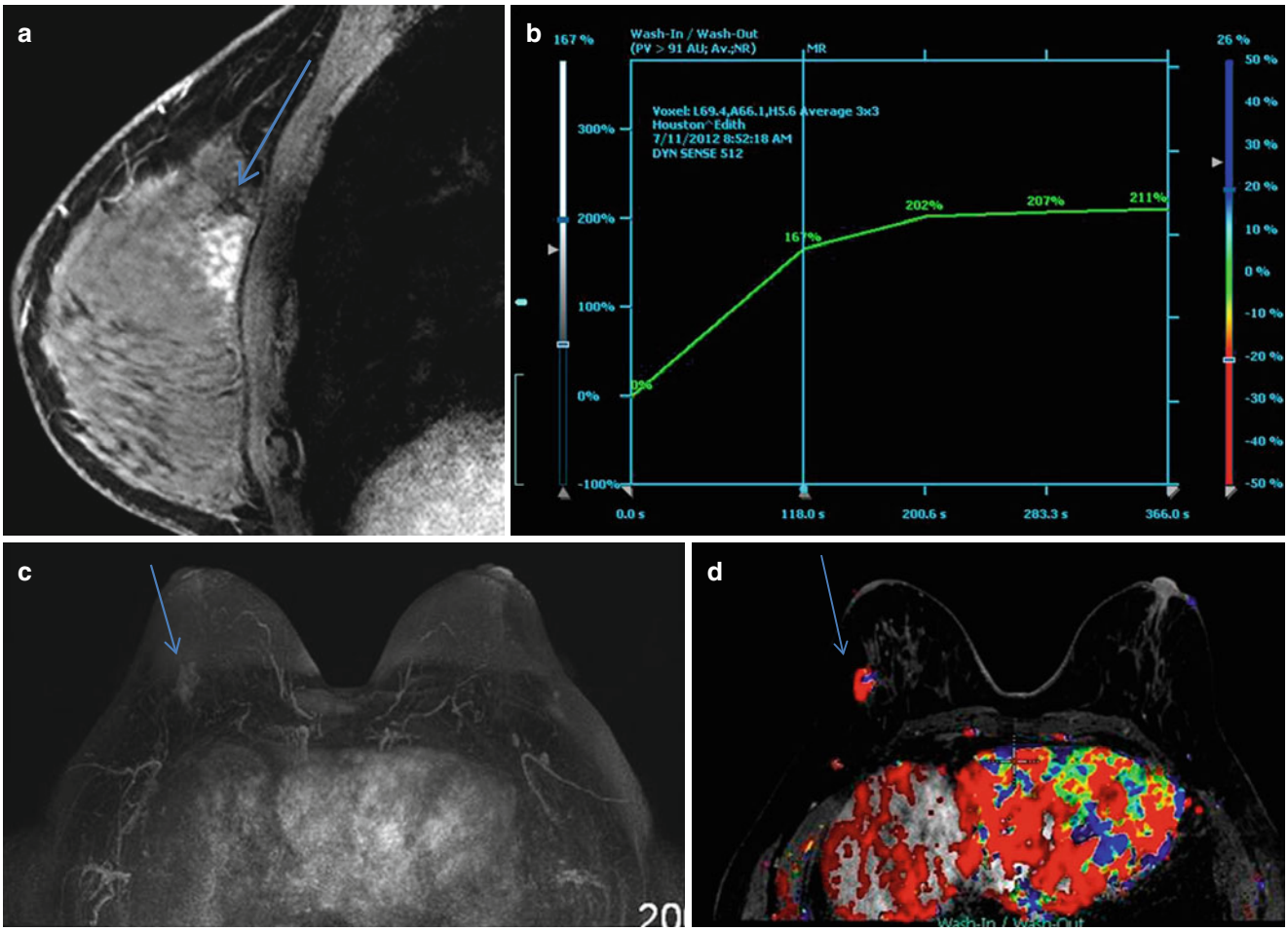

Fig. 8.6 (**a**–**d**) Non-mass-like enhancement [NMLE]. (**a**) Sagittal postcontrast T1-weighted image shows a segmental area of non-mass-like enhancement in the posterior upper right breast. (**b**) Kinetic curve demonstrates slow uptake and progressive enhancement characteristic of a benign abnormality. (**c**) 3D MIP image demonstrates a NMLE in the posterior outer right breast. (**d**) Color overlay demonstrates washout kinetics. Histological diagnosis: invasive ductal cancer

Updated MRI BI-RADS Lexicon

There are several important descriptors in dynamic contrast-enhanced [DCE] breast MR imaging that do not appear in the BI-RADS™ lexicon [36]. "Blooming sign" refers to well-demarcated margins exhibited by malignant lesions that on subsequent delayed scans appear less distinct [36]. Hook sign refers to a hooklike dendrite leading from the center of a malignant lesion and extending to the pectoral muscle on T2-weighted images. Edema appearing as bright T2 signal around a lesion and prominent vessels in relation to a lesion are signs associated with malignancy.

The soon to be released version of the American College of Radiology MRI BI-RADS recommends the use of precontrast T2-weighted sequence. Combined reporting of findings on mammograms, ultrasound, and breast MRI is recommended. A section on breast implants has been added describing findings in normal and ruptured implants. A description of background breast parenchymal enhancement is added since this can affect sensitivity of breast MRI in cancer detection. This can be none, minimal, mild, moderate, or marked. Central and septal enhancements and enhancing septations have been deleted. Clustered ring enhancement has been added. The term non-mass-like enhancement will be replaced with non-mass enhancement. The term irregular margin is to be replaced by uneven margin in masses with an irregular shape. There are no changes in the kinetic terminology in the upcoming BI-RADS™ atlas [36].

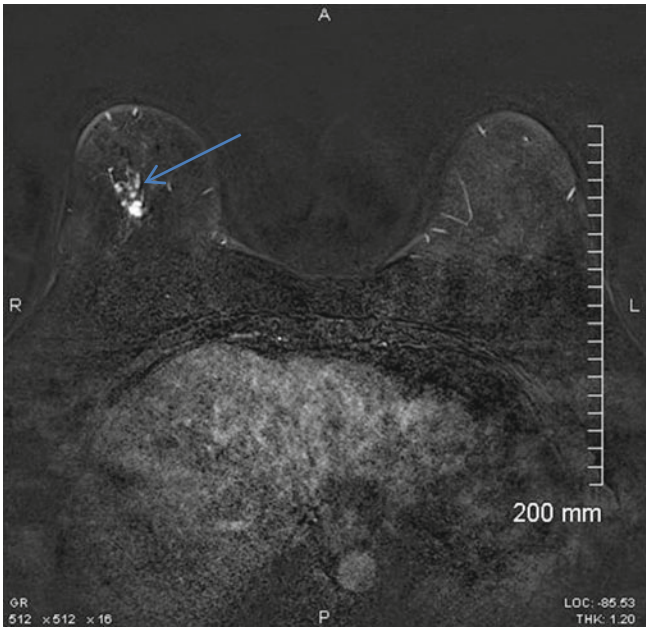

Fig. 8.7 Axial postcontrast subtraction image demonstrates linear clumped enhancement in the posterior central right breast. Histological diagnosis: DCIS

Lesions with Bright T2 Signal

Bright T2 signal lesions may occur in solid tumors that have extensive necrosis, a cystic or microcystic component, an adipose or sebaceous component, mucinous stroma, loose myxoid stroma, stromal edema, and hemorrhagic changes [37]. Mucinous carcinoma may have a lobulated or circumscribed border and bright T2 signal and hence may simulate a benign lesion; however, rim or heterogeneous enhancement may point correctly to a malignant diagnosis. Necrotic invasive ductal carcinoma can also display bright signal on T2-weighted images. Metaplastic carcinoma is rare but also commonly demonstrates bright signal on T2-weighted imaging sequence.

Positive Predictive Value of BI-RADS MRI Assessment

Criteria for Benignity

The absence of a visible lesion on contrast-enhanced MRI corresponding to a palpable or a mammographic lesion is predictive of a benign abnormality. A mass with a smooth margin or internal nonenhancing septa is highly predictive of benignity [NPV = 98 %]. A lobulated mass with minimal enhancement has a nearly 100 % likelihood of benignity. Mild regional non-mass-like enhancement has a 92 % NPV for a benign abnormality. T2 hyperintensity within enhancing portions of a tumor is suggestive of a benign abnormality in a lobulated or a mass with smooth margins. Fibroadenomas particularly in younger women tend to be T2 hyperintense. Most cancers tend to appear hypo- or isointense compared to surrounding breast tissue on T2-weighted images [35].

Predictors of Malignancy

In a large prospective multicenter trial of screening breast MR imaging, mass lesions with an irregular shape had a positive predictive value of 30.6 %, spiculated margins had a PPV of 33.3 %, and marked internal enhancement had a PPV of 23 %. Ductal enhancement type of NMLE had a PPV of 50 % [38]. The likelihood of cancer was high with initial rapid enhancement and for both plateau and washout kinetic curve. The PPV for cancer with BI-RADS 4 and 5 was 28 % [38]. A study of enhancement curves in 125 lesions, 42 malignant and 83 benign; there were no significant differences in initial peak enhancement between benign and malignant lesions. Washout was the most suspicious with 45.7 % being malignant compared to 20 % with plateau and 13.3 % with entirely persistent enhancement [39]. It is clear from these data that kinetic curves are useful adjunctive tools but cannot be relied on solely to confirm or exclude malignancy. In a study of 666 nonpalpable mammographically occult MR-detected lesions undergoing MR-guided localization, mean lesion size was 1 cm [40]. Malignancy was present in 22 % of lesions. Frequency of malignancy increased with lesion size, with only one out of 37 lesions under 5 mm being malignant (3 %).

BI-RADS™ 3 Probably Benign Findings Category Lesions on MRI

There are no established criteria in the BI-RADS atlas to categorize lesions on DCE breast MRI as probably benign. In a large series of 106 patients with a BI-RADS 3 assessment, the most common underlying lesion was NMLE [40.7 %], followed by foci [32.4 %] and masses [25.5 %]. In this study there was no malignancy detected at 2 years of follow-up in 78 % of women, and the remainder of the patients had a tissue diagnosis due to either patient preference or interval change. There was one case of DCIS in this group leading to a malignancy rate of 0.9 % in the BI-RADS 3 category [41]. In a series that evaluated MRI BI-RADS 3 lesions, such an assessment was given in 20 % of 809 exams, and in them there was only one cancer with a malignancy rate of 1 in 160 [0.6 %] [42]. In another series, 260 [10.1 %] of 2,569 consecutive examinations had an assignment of BI-RADS 3; cancer yield was 0.85 % with both cases being DCIS.

There were no cancers in 69 foci with persistent enhancement [43]. In a series of 44 patients comprising of 6.3 % of consecutive breast examination, one malignancy was identified which was a malignant phyllodes tumor [44]. The overall malignancy rate in several studies of MR BI-RADS 3 lesions varies from 0.7 to 10 % [43]. The criteria for BI-RADS 3 categorization on a breast MRI examination have not been established or validated. These studies were retrospective studies and none provide an explanation for including lesions with suspicious morphology or kinetics in the study group. The low malignancy yield has to be considered with caution because of lack of uniformity in selection criteria to categorize lesions as BI-RADS 3. Based on data available it seems prudent to categorize foci with persistent kinetics as BI-RADS 2. Regional NMLE when unilateral seems to be a type of lesion that can be categorized as BI-RADS 3. There is need for more robust data from well-designed prospective studies for establishing criteria to categorize lesions on DCE breast MRI with adequate follow-up as has been done for mammographic BI-RADS 3 lesions.

Breast MRI: Methodology and Protocol

Breast MRI protocol has to be optimized to capitalize on the high sensitivity of mammography to detect breast cancer. There are certain basic prerequisites to optimize the quality of the morphology and kinetics of abnormalities seen on breast MR examination [45]:

- Bilateral dedicated breast coil has to be used and patient scanned in the prone position. Bilateral imaging is now the accepted standard of care. This allows for accurate identification of bilateral symmetric physiologic changes and also detection of occult contralateral cancers.
- MR imaging system with a high field strength and with a magnetic field that is homogeneous across the whole field of view covering both breasts to allow for uniform fat suppression.
- Mild compression of the breast is helpful to decrease motion that prevents misregistration artifacts and decreases the image acquisition times in axial and sagittal plane.
- Dedicated multichannel breast coils provide high signal to noise ratios and uniform image resolution. Vendors currently offer 7, 12, and 16 channel dedicated breast coils. Multichannel coil imaging also allows a reduction in image acquisition times.
- Protocol typically includes the following sequences:
  1. A T1-weighted sequence to assess masses and lymph nodes, a T2-weighted sequence to identify cysts, and a 3-D imaging using spoiled gradient-echo T1-weighted imaging with fat suppression prior to and following intravenous contrast administration. Frequency-selective fat suppression is needed for homogeneous fat suppression.
  2. The imaging thickness should be less than 3 mm and pixel size less than 1 mm in each plane.
  3. Intravenous administration of gadolinium chelate at a dose of 0.1–0.2 mmol/kg is injected at 1–2 cc/s.
  4. Four to five postcontrast acquisition are obtained following one prior to contrast. Imaging continues to about 7 min after injection, each acquisition lasting 1–2 min.
  5. Peak contrast enhancement in a malignant lesion typically occurs between 90 and 180 s after injection of the contrast agent requiring an optimal temporal resolution of less than 2 min to assess the kinetic curve of enhancement. Since data from postcontrast images are subtracted from the precontrast image, it is critical to keep imaging parameters identical on both these sets of images. To evaluate the shape of the enhancement curve scanning is continued for 6–7 min with multiple acquisitions.
  6. Time enhancement curves assess the pattern of enhancement of lesions by displaying signal intensity over time. The signal intensity is color coded. The region of interest [ROI] is placed on the part of the lesion showing maximum enhancement on the non-subtracted image. The threshold level is typically set around 60 % increase in signal intensity from precontrast images. It is critical to document and take into account the most suspicious of the kinetic curve [45].

Potential Pitfalls and Artifacts in MR Imaging [46, 47]

False Positive

- *False Enhancement*: This occurs due to movement of the breast between pre- and postcontrast images leading to an area of pseudoenhancement that appears at the edge of fat parenchyma interface. Movement most often is related to contraction of the pectoral muscle which may be apparent on inspection of the appearance of the muscle on the images. When movement occurs in the same plane as the slice, the artifact is more readily apparent since an area of bright signal corresponding to pseudoenhancement appears next to an area of dark signal. However, problem arises when the displacement occurs in a plane that is not the same as that of the MRI image acquisition. Pre- and postcontrast source images need to be carefully reviewed to identify motion artifacts causing pseudoenhancement.
- *Normally Enhancing Structures*: These include blood vessels, lymph nodes and the nipple, and hormone-related enhancement of breast parenchyma [48–50]. Blood vessels

Table 8.3 Differential diagnosis of abnormalities in the breast

	Benign	Probably benign	Suspicious
Mass	Cyst	Smooth borders, uniform enhancement, T2 hyperintensity, benign kinetics in a non-BRCA patient	Irregular margins, heterogeneous or rim enhancement
	Lymph node		Washout kinetic curve
	Fat necrosis		
Non-mass-like enhancement	Bilateral symmetric, benign kinetics	Diffuse unilateral or regional patchy or stippled	Regional clumped, ductal, heterogeneous
			Segmental
Focus	Multiple or bilateral, single without washout	Single, washout, in non-BRCA patient	Single, washout in a BRCA patient

are easily recognized due to their course and bright signal on T2 images. Lymph nodes are predominantly seen in the upper outer quadrant of the breast. They can demonstrate intense rapid enhancement with washout kinetics. T1-weighted images demonstrate the fatty hilum and allow for a confident diagnosis of a lymph node. The rich vascularity of the nipple areolar complex may produce enhancement in the nipple that can be confusing particularly when the nipple is displaced or flattened against the coil. Precontrast images, comparison with the opposite nipple and 3-D reformatting is helpful in making an accurate assessment [47]. Normal breast parenchyma may also show mild enhancement; however, especially in the second half of the cycle or during menstruation, multiple bilateral foci of enhancement may be seen predominantly in the outer breasts, and these may also be seen in post menopausal women on hormonal therapy. Cessation of hormonal therapy 4–6 weeks prior to MRI and scanning menstruating women during the first part of the menstrual cycle are advised whenever feasible.

False Negative

- *Nonenhancing Cancer*: Detection of cancer in breast MRI is based on the presence of neovascularity and tumor angiogenesis that causes cancers to enhance and be identified. The degree of angiogenesis is variable and is lower in DCIS and invasive cancers that are smaller than 5 mm [51, 52]. About 2/3 of nonenhancing cancers are DCIS [51]. Occasionally, cancers larger than 5 mm do not enhance, and this has been reported in inflammatory breast cancer [53]. A lesion that is considered suspicious based on mammographic or sonographic characteristics should not be downgraded based on lack of enhancement.
- *Missed Enhancement*: Careful analysis of the images is important to ensure that contrast has been injected by identifying normally enhancing structures such as the heart and blood vessels. Motion can lead to misregistration artifacts, and areas of true enhancement may be missed by being subtracted out. A strong background parenchymal enhancement can also be a cause of missing a small enhancing cancer. In one series 83 % of false-negative cases were attributed to a strong surrounding enhancement pattern [51].
- *Misinterpretation Enhancement*: This occurs due to morphological characteristics or kinetic curve pattern that may have benign features or in cases where a lesion was considered benign due to being stable.

To minimize the likelihood of missing breast cancer on an MRI examination, it is important to assess both morphology and the kinetic curve pattern, and, keeping in mind that the kinetic curve pattern may have significant overlap between benign and malignant lesions, it is important not to solely rely on the enhancement curve pattern to exclude cancer. Table 8.3 summarizes the common imaging features of benign, probably benign, and malignant lesions on a breast MRI.

MRI of the breast when appropriate is a useful breast imaging tool. Although controversies continue on its use in staging the extent of disease in a known breast cancer patient, it is useful in screening women at an elevated risk for breast cancer, for assessment of implants, and occasional use for problem-solving tool as a supplement to mammography and sonography.

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