MRI for Technologists

4712-401 Breast MRI

PROGRAM INFORMATION

MRI for Technologists is a training program designed to meet the needs of radiologic technologists entering or working in the field of magnetic resonance imaging (MRI). These units are designed to augment classroom instruction and on-site training for radiologic technology students and professionals planning to take the review board examinations, as well as to provide a review for those looking to refresh their knowledge base in MR imaging.

Original Release Date: **March 2014**
Expiration Date: **April 1, 2021**

This material will be reviewed for continued accuracy and relevance. Please go to icpme.us for up-to-date information regarding current expiration dates.

Note: Terms in **bold** throughout this material can be found in the glossary. Sample protocols can be found at the end of this material.

OVERVIEW

The skill of the technologist is the single most important factor in obtaining good quality diagnostic images. A successful MRI examination is the culmination of many factors under the direct control of the technologist.

Breast MRI introduces the learner to the role of MRI in the screening and detection of breast cancer. While mammography remains the gold standard for screening and diagnostic exams, the high sensitivity of BMRI often provides the ability to detect cancers not seen on other breast imaging modalities. BMRI also serves an important role in pre- and postoperative evaluation and planning.

After a review of the anatomy of the breast, the role of gadolinium-based contrast agents will be explained, as well as patient screening in light of the safety concerns of contrast-enhanced MRI. Benign and malignant conditions will be covered, followed by an explanation of patient preparation and performance of MRI-guided biopsy. Finally, sample protocols for routine BMRI, silicone implant, and biopsy are provided.

EDUCATIONAL Objectives

After completing this educational material, the reader should be able to:

- Describe the anatomy of the breast
- List the clinical indications for breast MRI
- Discuss benign and malignant findings on breast MRI
- Describe the benefit of using intravenous contrast agents and associated patient risk factors
- Properly position the patient for MR imaging and MRI-guided breast biopsy
- Implement a breast MRI-guided biopsy protocol

EDUCATIONAL CREDIT

This program has been approved by the American Society of Radiologic Technologists (ASRT) for 1.5 hours ARRT Category A continuing education credit.

HOW TO RECEIVE CREDIT

Estimated time to complete this activity is 1.5 hours. The posttest and evaluation are required to receive credit and must be completed online.

- Read the entire activity.
- Log in to your account at icpme.us to complete the posttest and evaluation, accessible through the course link in your account.
- A passing grade of at least 75% is required to be eligible to receive credit.
- You may take the test up to three times.
- Upon receipt of a passing grade, you will be able to print a certificate of credit from your online account.
- Your credit certificate will remain in your account as a permanent record of credits earned at *icpme.us.*

FACULTY

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Fairfax, VA

Mary Perrine has been an MRI technologist since 1988. She joined Fairfax Radiological Consultants in Fairfax, Virginia, in 1994 and was promoted to senior technologist in 1998. Ms. Perrine helped develop and establish the breast MRI program at FRC with Dr. Elise Berman and has worked in the role of Chief Technologist since the program was founded in 2005, providing oversight of the breast imaging program.

ACKNOWLEDGMENTS

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4712-401

Breast MRI

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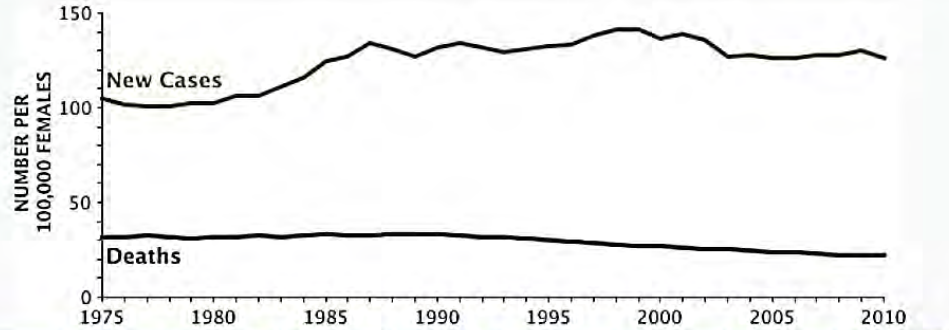
INTRODUCTION

Continuing improvements in diagnostic imaging have increased the ability for early detection of breast cancer. Breast cancer is the most frequently occurring cancer and the second leading cause of death in US women behind lung cancer. With advancements in early detection, the five-year breast cancer survival rate has risen from 75% in 1975-1977 to 89.2% in 2003-2009 (**Table 1**).[1]

Approximately 12% of women in the US will develop breast cancer in their lifetimes. In 2013, it was estimated that breast cancer comprised 14.1% of all new cancer diagnoses – 232,340 new cases of invasive breast cancer and another 64,640 cases of ***in situ*** breast cancer. Breast cancer mortality was estimated at 6.9% of all cancer deaths for 2013, or about 39,620 deaths.[2]

Unless otherwise noted, all images are courtesy of Fairfax Radiological Consultants.



Year	1975	1980	1985	1989	1993	1997	2001	2005
5-Year Relative Survival	75.2%	74.9%	78.4%	84.3%	85.7%	88.4%	89.5%	90.5%

Table 1. New Cases, Deaths, and 5-year Relative Survival. SEER 9 Incidence & U.S. Mortality 1975-2010, all races, females; rates are age-adjusted.

THE ROLE OF BREAST MRI

Breast MRI (BMRI) plays a major role in the early diagnosis of breast cancer as well as in defining the extent of tumor spread. BMRI often provides the ability to detect cancers not seen by mammography or ultrasound. The sensitivity for breast MRI in detecting breast cancer ranges from 77 to 100%.[3] This high rate of sensitivity allows visualization of *everything* within the breast, including cancerous lesions. This exquisite sensitivity can lead to the reporting of **false negatives**, which are actually positive findings but that may be obscured by benign tissue. Ductal carcinoma *in situ*, infiltrating lobular carcinoma, and rarely invasive ductal carcinoma are examples of positive findings that can be hidden behind normal tissue.

The drawback of this exemplar **sensitivity** is the varying range of **specificity**. As with any diagnostic study, there is the potential for **false positives**, such as fibroadenomas, fibrocystic changes, hyperplasia, adenosis, inflammatory changes, post-surgical changes, high-risk lesions, lobular carcinoma *in situ*, and atypia. By their nature, false positive findings require further evaluation, including biopsy, which is why MRI is not recommended as a screening exam for women who have an average risk of breast cancer.

MRI vs Mammography

It is important to note that while BMRI is extremely valuable for the early detection of breast cancer, it is not a replacement for mammography. Mammography remains the imaging modality of choice for breast cancer screening because mammography can detect findings that BMRI cannot, like architectural changes and calcifications, and the cost of a mammographic exam is significantly less than for MRI.

INDICATIONS FOR BMRI

High-risk Screening

One of the earliest indications for MR breast imaging was for evaluation of silicone implant integrity. However, high-risk screening has become one of the primary reasons for BMRI. The American Cancer Society (ACS) recommends BMRI for women:[4]

- known to have the ***BRCA1*** or ***BRCA2*** mutation
- who have a first-degree relative (parent, sister, brother, child) with a *BRCA1* or *BRCA2* gene mutation and have not had genetic testing themselves
- with a lifetime breast cancer risk of >20-25%
- who have a history of radiation therapy to the chest between ages 10-30
- who have **Li-Fraumeni syndrome**, **Cowden syndrome**, or **Bannayan-Riley-Ruvalcaba syndrome** or have first-degree relatives with one of these syndromes

The ACS does not recommend breast MRI for women:[5]

- whose lifetime risk of breast cancer is <15%
- with a personal history of breast cancer, ductal carcinoma *in situ* (DCIS), lobular carcinoma *in situ* (LCIS), atypical ductal hyperplasia (ADH), atypical lobular hyperplasia (ALH)
- with dense breast tissue as seen on mammography

Pre-operative Planning: Extent of Tumor

Pre-operative planning is an essential tool in the treatment of breast cancer. The extent of biopsy-proven cancers shown by BMRI greatly assists surgeons and oncologists in determining a treatment plan for cancer patients.

Patients with **multifocal** cancers (cancers with multiple lesions in the same quadrant) can still be candidates for breast conservation surgery. Patients with **multicentric** tumors (tumors in multiple quadrants) can sometimes only be treated with a more extensive surgery (**Figure 1**). Preoperative evaluation is also a useful tool in determining the extent of axillary lymph node involvement as well as chest wall invasion.

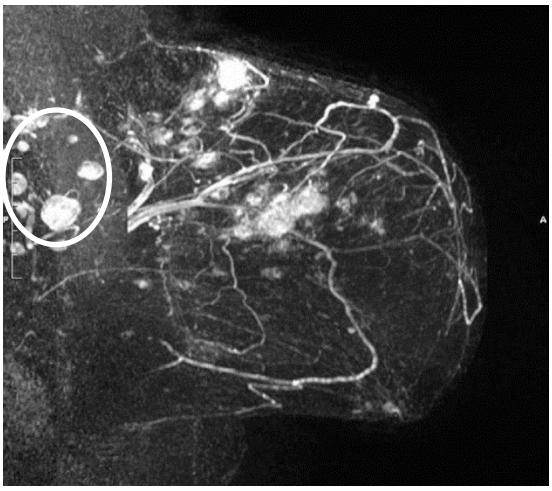


Figure 1. Multicentric breast cancer. MRI shows extent of tumor involvement within the entire breast, as well as the axillary lymph nodes (circle).

It is believed that about 5-10% of all breast cancer cases are hereditary. The gene mutation can be inherited from either the maternal or paternal side of the family with about a 50% chance of inheriting the mutation from the parent who carries the mutated gene. Approximately 55-65% of women with the *BRCA*1 mutation and 45% of women with the *BRCA*2 mutation will develop breast cancer in their lifetimes. *BRCA*1 and *BRCA2* genetic mutations increase the risk of developing both breast and ovarian cancers.[6] **Figure 2** shows images of a BRCA-positive patient, demonstrating why regular follow-up for this patient cohort is essential.

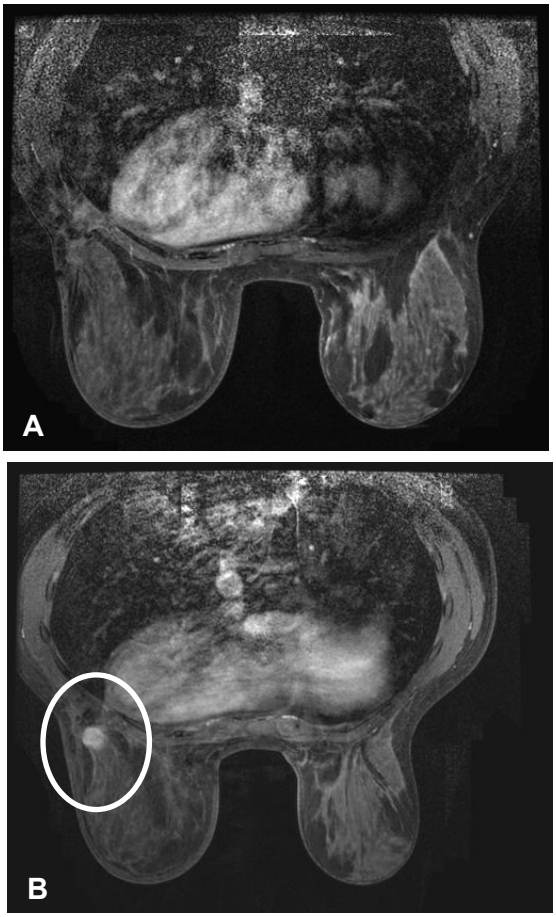


Figure 2. *BRCA*-positive patient. (A) Negative annual MRI. (B) Annual MRI one year later shows a new cancerous lesion (circle).

Contralateral Breast

Bilateral disease is somewhat more common in patients with infiltrating lobular carcinoma. Studies have shown that 3-10% of women with breast cancer will develop **contralateral** breast cancer in their lifetime.[7] This percentage increases to nearly 50% in women with who are *BRCA1* or *BRCA2* mutation carriers.[8,9]

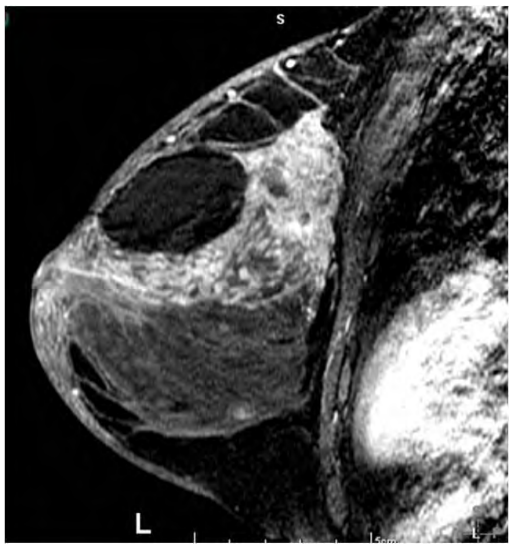


Figure 3. Postsurgical seroma with residual cancer.

Breast MRI is a very useful tool for evaluating the contralateral breast and patients with breast cancer should have bilateral MRI at the time of diagnosis to rule out synchronous disease.

Post-operative Evaluation

Post-operative evaluation is another indication for breast MRI. Patients with positive surgical margins and suspected residual cancer can greatly benefit from BMRI. Post-operative evaluation allows visualization of any residual cancer, the extent of the residual cancer, and any satellite lesions that may have been missed during the initial surgery (**Figure 3**).

Neoadjuvant Chemotherapy

BMRI can be used to evaluate the effectiveness of **neoadjuvant** chemotherapy administered to shrink the size of the tumor before surgery. The patient is scanned at intervals to evaluate the effect of the chemotherapy on the tumor. Often a complete pathologic response is seen (**Figure 4**). If the tumor does not respond to the treatment or if the tumor has grown, the appropriate treatment, including surgery, can then be prescribed or the type of chemotherapy changed **(Figure 5).** In some cases, a large cancer requiring mastectomy can be sufficiently reduced in size for the patient to undergo breast conservation surgery after neoadjuvant chemotherapy.

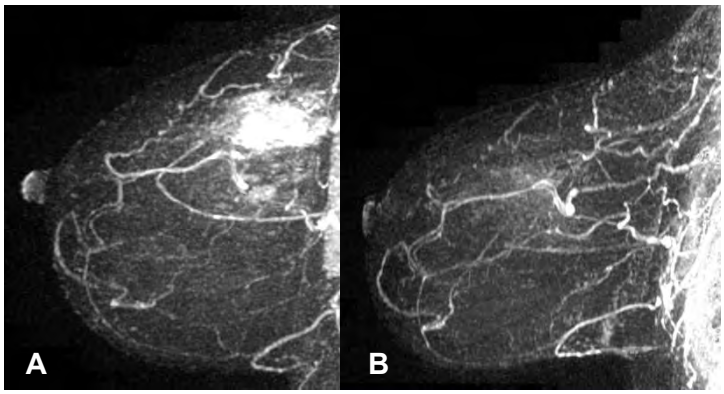


Figure 4. Results of neoadjuvant chemotherapy. (A) Pre-therapy. (B) Post-therapy, showing a complete response.

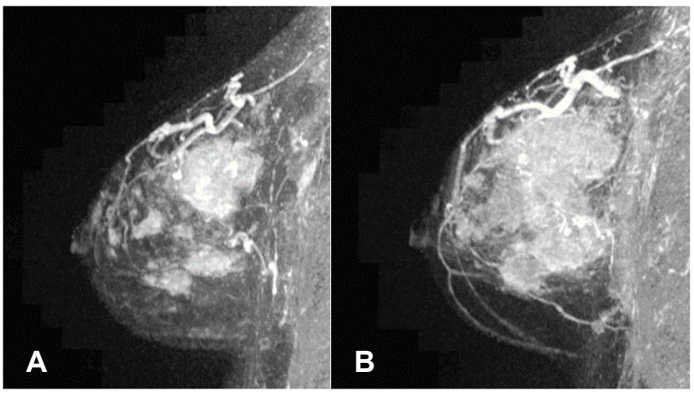


Figure 5. Results of neoadjuvant chemotherapy. (A) Pre-therapy. (B) Post-therapy, showing no response to treatment.

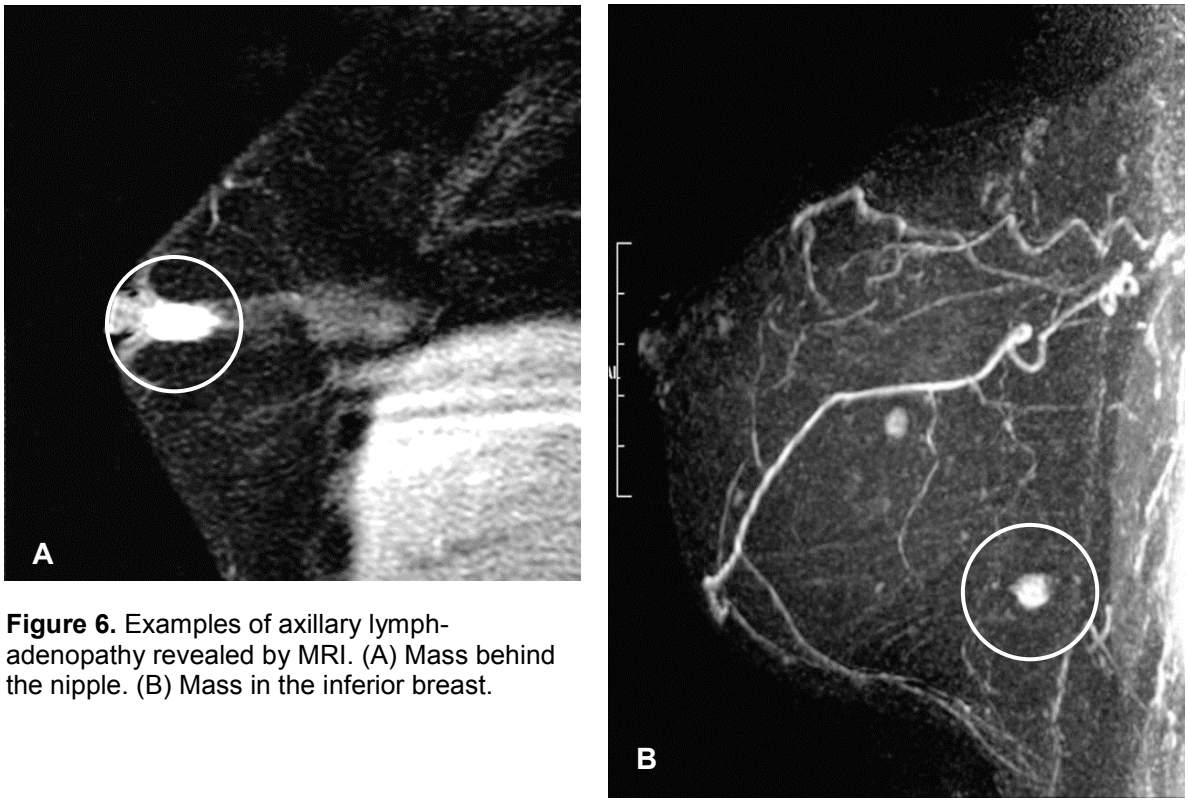


Figure 6. Examples of axillary lymph-adenopathy revealed by MRI. (A) Mass behind the nipple. (B) Mass in the inferior breast.

Biopsy-proven Axillary Carcinoma or Axillary Carcinoma with Unknown Primary Site

BMRI is considered one of the best tools for evaluating biopsy-proven axillary carcinoma (cancer of the lymph nodes in the underarm) with a primary cancer of unknown origin. These patients present with a palpable mass but a negative mammogram and ultrasound and are referred for further evaluation to identify the primary cancer site (**Figure 6**).

Positive nodes found in the right axilla indicate cancer of the right breast and in the left axilla, cancer of the left breast.

Inconclusive Imaging and Asymmetry

Patients with inconclusive imaging, distortion on one view on mammogram not reproducible by ultrasound, or who have asymmetry on diagnostic imaging**,** are good candidates for breast MRI.

Breast density can obscure malignancies on mammography or ultrasound but does not affect the ability of BMRI to visualize suspicious lesions (**Figure 7**). However, dense breast tissue in and of itself is not an indication for breast MRI evaluation.

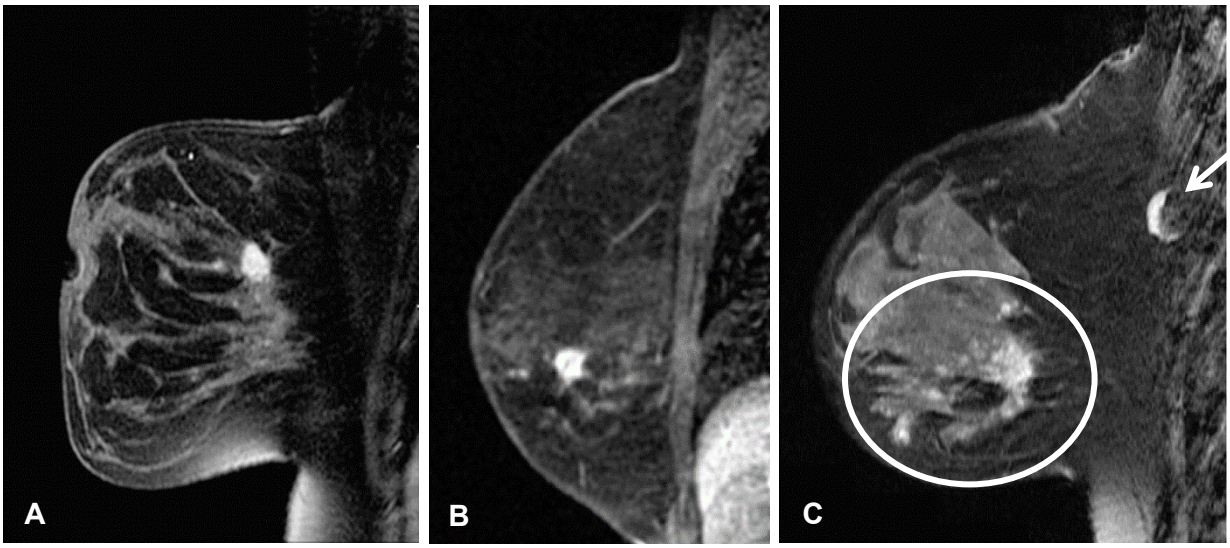


Figure 7. Examples of inconclusive breast imaging with positive MRI findings. (A) Distortion one-view only on mammography, normal ultrasound; MRI shows invasive lobular carcinoma. (B) Asymmetry on mammography with a normal US; MRI shows invasive ductal carcinoma. (C) Diffuse calcifications on mammography; MRI reveals DCIS (circle). Note enhancing incidental normal lymph node (arrow).

Silicone Implant Evaluation

Breast MRI still plays an important role in the evaluation of silicone implant integrity, visualizing implant rupture and differentiating between free silicone outside of the capsule and other anatomical structures **(Figure 8**).

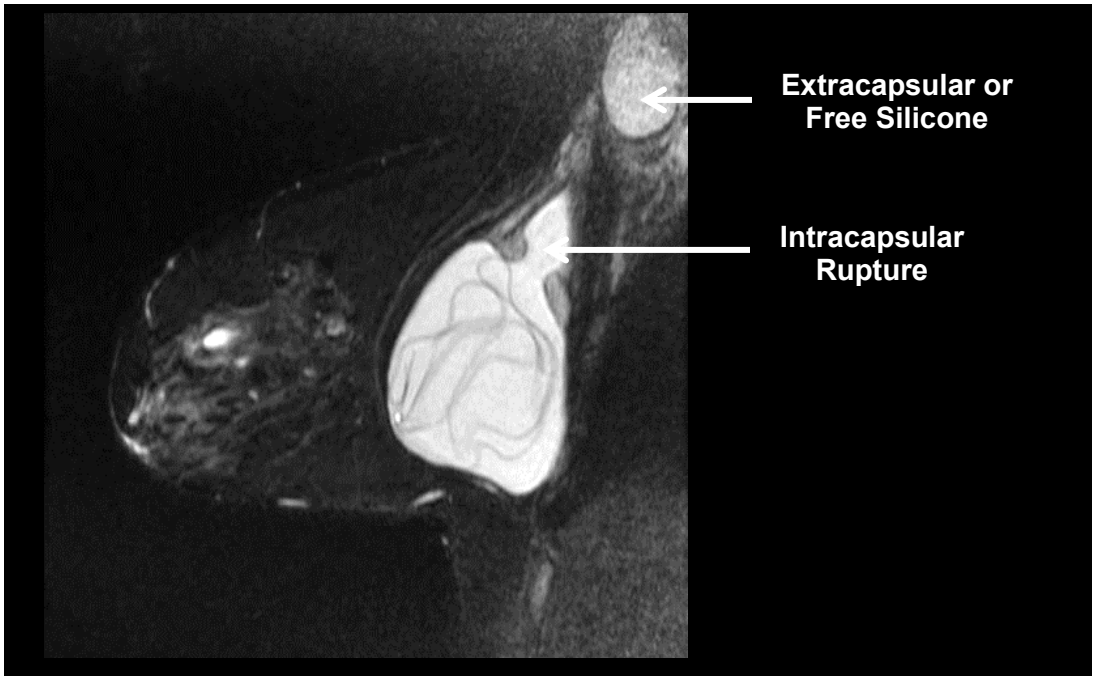


Figure 8. Silicone implant with intra-and extracapsular ruptures.

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BREAST ANATOMY

A thorough understanding of the anatomical structures within the breast and surrounding structures is essential for obtaining quality images (**Figure 9**).

The breast consists of skin, which contains hair follicles, glands, and the **parenchyma** (breast tissue). The breast is supported on the chest wall by bands of tissue called **Cooper's ligaments**.

The skin can reveal important information related to a variety of breast diseases. Skin thickening can be an indicator of a benign process including mastitis, post-radiation changes, or edema from heart failure or lymphatic obstruction. Skin thickening is also an indicator for inflammatory breast cancers, extensive primary invasive breast cancers, **Paget's disease** of the nipple, and lymphomas (**Figure 10**).

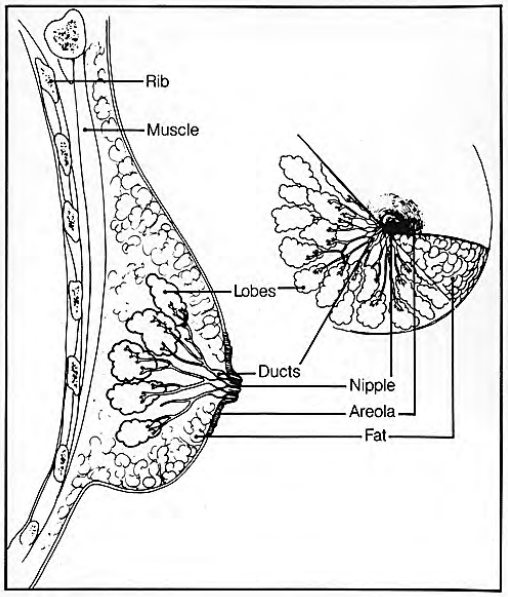


Figure 9. Breast anatomy.

Courtesy of the National Cancer Institute. Available at: Wikimedia Commons.

The breast parenchyma consists of milk-producing glands called **lobules** or **alveoli**. The parenchyma can be seen extending into the **axillary tail** and, in some patients, within the **axilla** itself. The inferior aspect of the breast is located at the **inframammary fold**, just underneath the breasts.

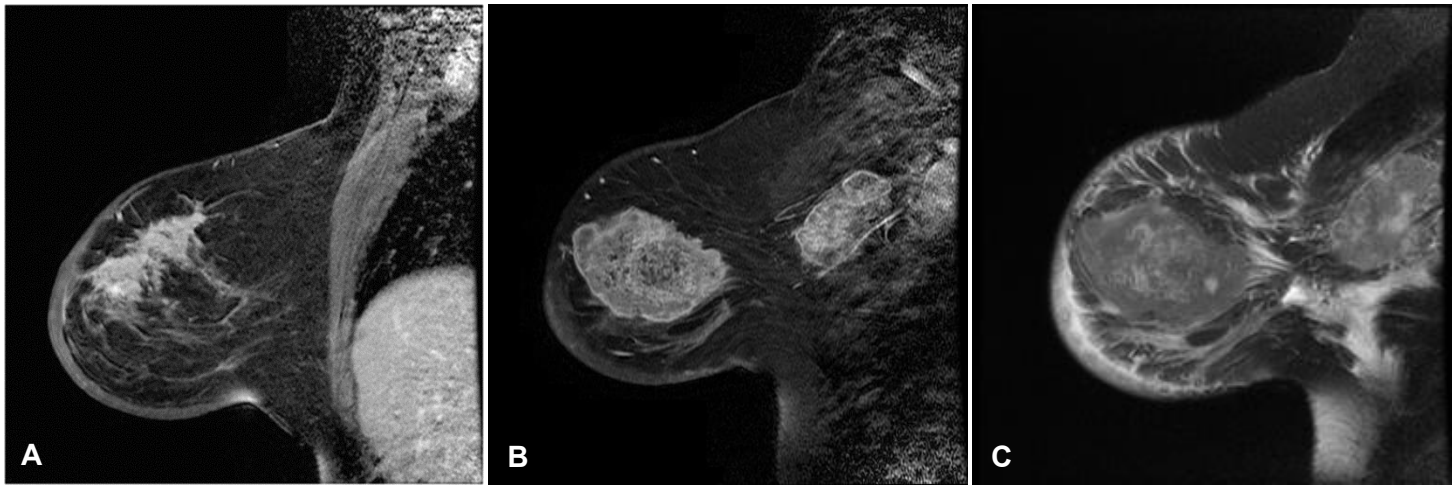


Figure 10. Skin thickening due to an inflammatory cancer. (A) Contrast-enhanced T1W FAT SAT. (B) Precontrast and (C) Postcontrast FAT SAT fast spin echo shows edema in the breast.

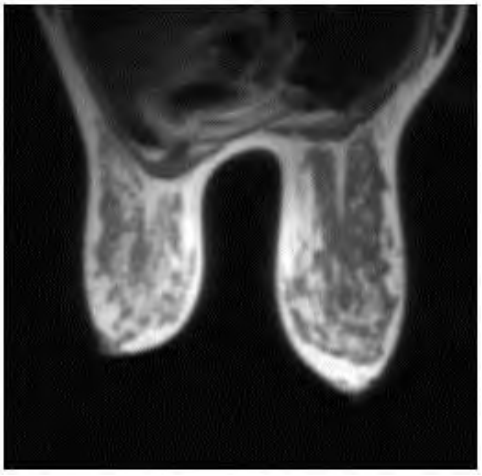


Figure 11. Example of normal asymmetrical breasts.

Milk ducts lead to the nipple from the glands. The breast has 20-40 lobules that drain into each duct, and fat surrounds the lobules and ducts.

At the tip of the breast is the nipple, which is surrounded by pigmented tissue known as the **areola**. Approximately 20 milk ducts empty into the nipple.

Difference in size between each breast is not uncommon; however, the nipples and areola are generally symmetric. While breast size and shape can vary with hormonal changes, the nipples should remain symmetric (**Figure 11**).

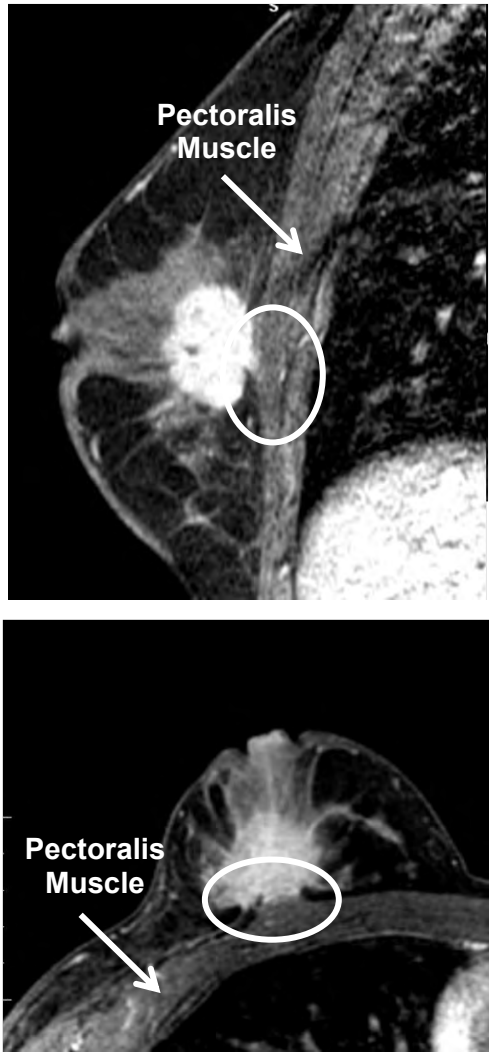


Figure 12. Invasive ductal carcinoma (circle) with pectoralis muscle involvement.

"Outside" the breast lie the pectoralis minor, pectoralis major, and sternalis muscles. Even though these muscles are not considered part of the chest wall, a BMRI should include them as extensive cancers can infiltrate into the pectoralis major muscle (**Figure 12**).

The chest wall includes the intercostal muscle, serratus anterior, and the ribs. Just like the muscles "outside" the breast, the chest wall is included in a BMRI evaluation.

Lymph nodes are commonly seen on breast MRI. These nodes are highly vascular, usually present on BMRI with a fatty hilum, and are generally associated with a vessel. Lymph nodes should enhance homogeneously. Refer to **Figure 7** to view a normally enhancing lymph node.

There are 15-40 axillary nodes responsible for most of the lymphatic drainage within the breast. On sagittal breast MRI images, lymph nodes located in the axillary tail give the appearance of grapes hanging on a vine (**Figure 13**).

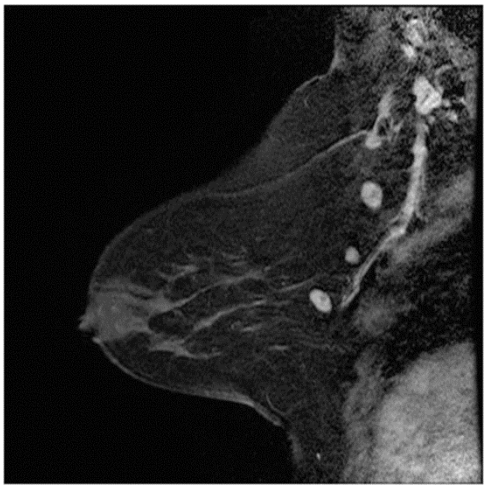


Figure 13. Normal-appearing lymph nodes.

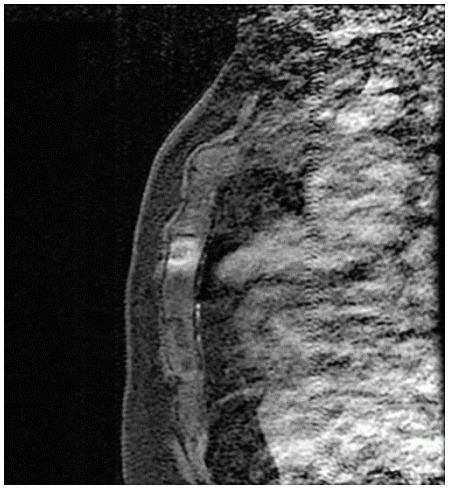


Figure 14. Enhancing metastatic lesion in the sternum seen on postcontrast imaging.

Intramammary lymph nodes are found within the breast parenchyma. They are most commonly seen in the upper outer quadrant of the breast. Lymph nodes can also be seen along the internal mammary chain or within the supraclavicular location, another route of drainage for the breast. These lymph nodes should always be assessed in known malignancy.

The sternum and ribs are also seen on BMRI. Post-radiation changes in the sternum generally appear as fatty replacement. Metastatic disease can be seen as high signal on T2W and as an increase in signal on fat-saturated, postcontrast images (**Figure 14**).

Enhancing Tissues of the Breast

The amount of breast parenchyma present determines the "density" of the breasts. On mammography, a breast with predominate parenchymal tissue and little fat is considered heterogeneously dense. A breast composed mainly of fat is considered to be "fatty replaced." On MRI, the breast can be easily assessed regardless of the amount of density or fat. (**Figure 15**).

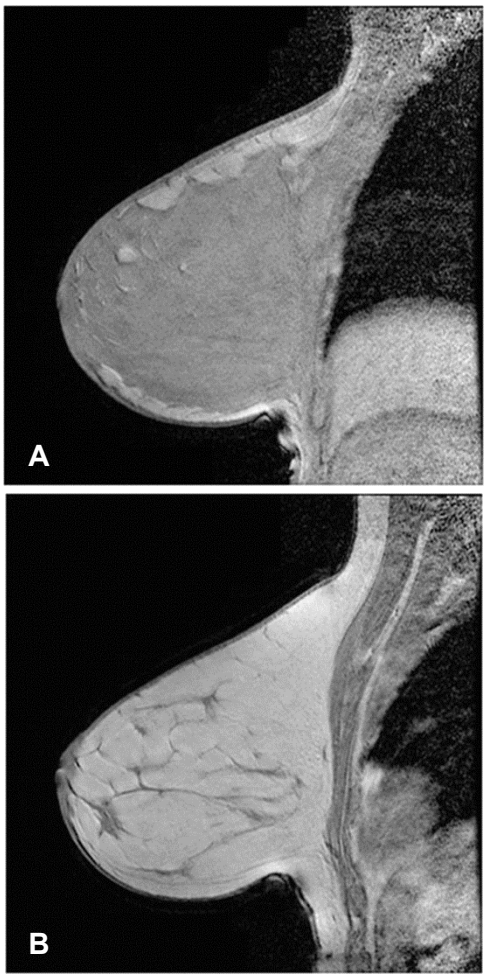


Figure 15. Non-FAT SAT T1W. (A) Dense breast. (B) Fatty breast.

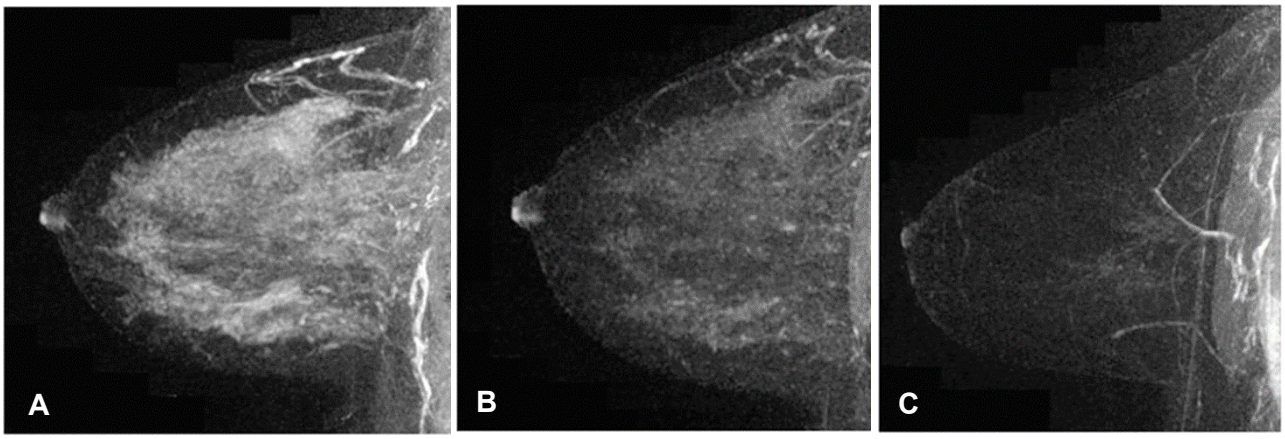


Figure 16. Background enhancement. (A) Marked. (B) Moderate. (C) Minimal.

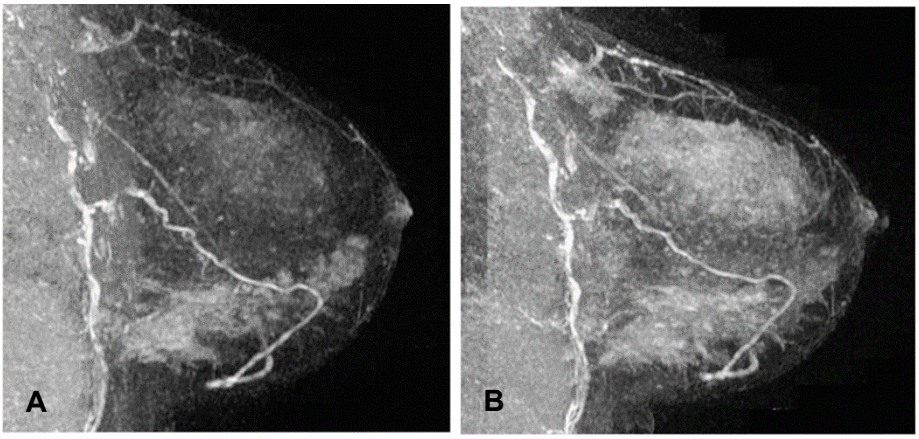


Figure 17. (A) Day 10 of the menstrual cycle. (B) Day 28.

Background enhancement is the normal enhancement within the breast parenchyma and not directly related to breast density. Background enhancement varies by patient and is affected by fibrocystic and hormonal changes (menstrual cycle, hormone replacement therapy, and hormonal chemotherapy). Background enhancement can be classified as minimal, moderate, and marked (**Figure 16**).

Fibrocystic change refers to the change in cell characteristics of glandular tissue due to normal hormonal fluctuations during the menstrual cycle that can result in breast tenderness, pain, and lumpiness. Although this is a benign finding, it can be difficult to differentiate between fibrocystic change and malignant findings because both morphologies enhance significantly.

Dramatic changes can be seen when scanning women during different times of the menstrual cycle. The time in the patient's cycle should be noted to assist the radiologist in differentiating normal fibrocystic change from malignancy (**Figure 17**). Ideally, pre-menopausal women should be scanned within 7-14 days from the first day of their last menstrual cycle. Of course, no delay should be made in scanning patients with suspected breast cancer.

IMAGING PROTOCOLS

Imaging can be done on either a 1.5 or 3.0T magnet. Injection of MRI contrast media as well as a dedicated breast coil is required to perform quality imaging. The breast coil should provide both imaging and biopsy capabilities as imaging sites offering BMRI should have the capacity to perform MR-guided breast biopsy. A sample protocol is included at the end of this material.

Positioning the Breast

Patient comfort is the foremost priority for achieving high-quality breast MR images. Patients are understandably anxious, and a sympathetic approach usually results in a technically better study.

It is extremely important to properly position the patient in the coil. Each breast should be centered and the tissue manually pulled into the coil, ensuring that no tissue remains outside of the coil (**Figure 18**).

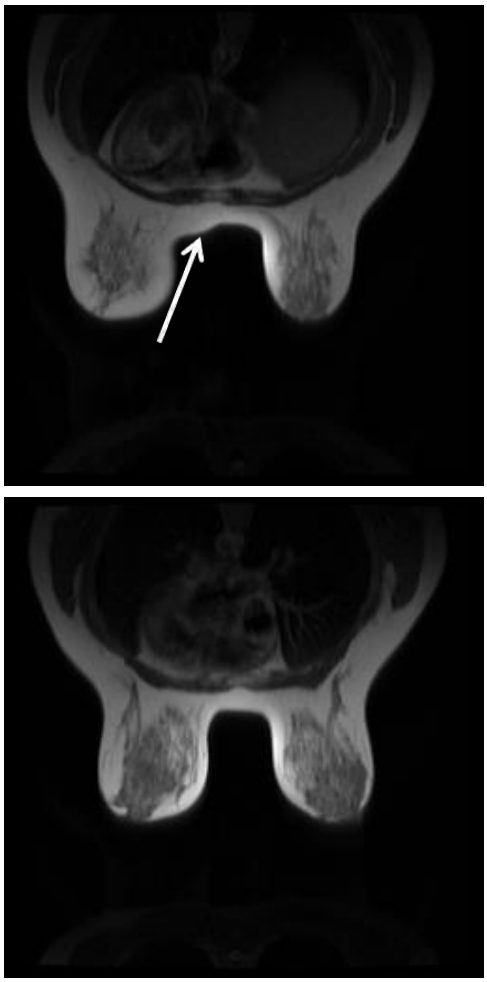


Figure 18. Three-plane localizer scan. (A) The breast is not adequately positioned in the coil (arrow). (B) Repositioning the patient before continuation of the exam ensures a thorough evaluation.

Routine Imaging Protocol

A routine breast imaging protocol should consist of the following series:

- 3-plane T2W localizer
- Sagittal T2W fat-saturated (FAT SAT) fast spin-echo
- Precontrast sagittal T1W non-FAT SAT with parallel imaging
- Pre and postcontrast sagittal T1W FAT SAT with parallel imaging
- Postcontrast axial T1W FAT SAT with parallel imaging

See **Figure 19** for sample protocol images.

THREE-PLANE LOCALIZER

A localizer series is used to verify appropriate positioning of the patient in the coil and check for incidental findings outside of the breast, including liver, lung, bone, and chest wall abnormalities. The 3-plane localizer series is required to prescribe future series and is performed non-fat-saturated using relatively thin slices with T2 weighting.

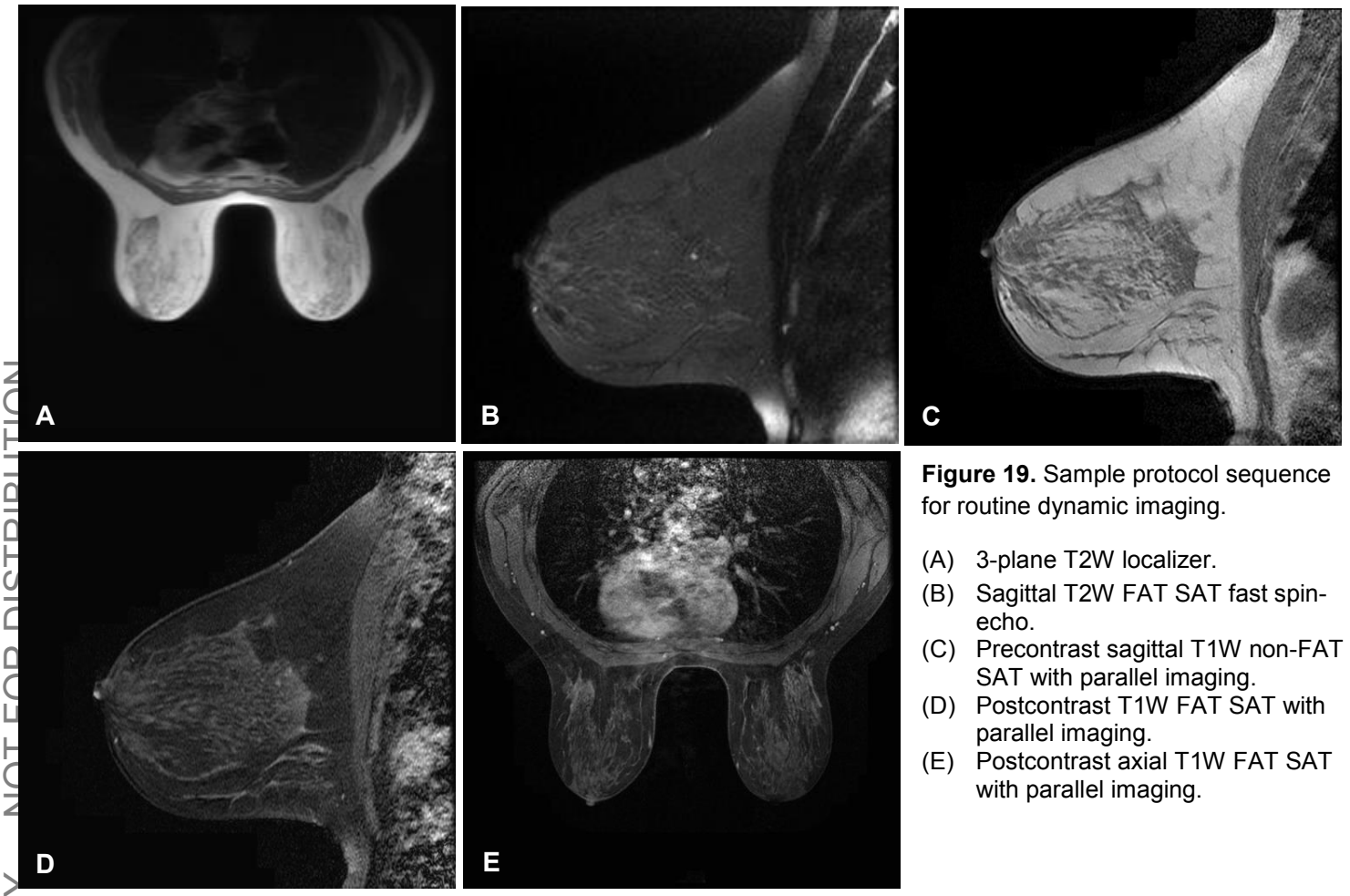


Figure 19. Sample protocol sequence for routine dynamic imaging.

(A) 3-plane T2W localizer.
(B) Sagittal T2W FAT SAT fast spin-echo.
(C) Precontrast sagittal T1W non-FAT SAT with parallel imaging.
(D) Postcontrast T1W FAT SAT with parallel imaging.
(E) Postcontrast axial T1W FAT SAT with parallel imaging.

T2-WEIGHTED FAT SATURATION

Sagittal T2-weighted **fat-saturated** or **inversion recovery** (IR) imaging is performed separately on each breast. Fluid and fluid-saturated tissues will show brighter signal on T2-weighted images. By suppressing fat in this series, even tiny cysts or areas of edema can be visualized. These images should be done at no more than a 4mm thickness. Care should be taken to include the axilla and sternum to evaluate lymph adenopathy and bony structures.

T2W fat-saturated images can be susceptible to artifacts caused by the position of the patient in the coil, or the presence of metallic foreign bodies such as biopsy markers and mediports, jewelry, and clothing. It is recommended that the patient remove earrings, necklaces, and clothing from the waist up and any other clothing containing metal. Care should be taken to screen for metallic implants and breast tissue expanders in patients preparing for breast reconstruction.

T1-WEIGHTED FAT SATURATION 3D PARALLEL IMAGING

A T1-weighted 3D **parallel imaging** sequence of both breasts should be performed simultaneously without fat saturation to visualize the breast structures in detail. Parallel imaging simply allows scanning of both breasts simultaneously.

A corresponding T1W 3D with fat saturation is used before and after administration of a gadolinium-based contrast agent. Postcontrast imaging requires very thin slices, T1W weighting, fat saturation, and high temporal resolution that captures rapid wash-in/wash-out of the contrast agent in the lesion. This series is done dynamically with one series precontrast and four series postcontrast in less than two minutes per series. From these data a time intensity enhancement kinetic curve can be generated to determine the enhancement patterns of a specific lesion. Kinetic curves and the benefits of the use of contrast-enhanced MRI will be discussed later in this material.

Breast MR imaging can be done in the sagittal plane to keep the field-of-view small, from 20 - 24cm, and to maintain high resolution, although some centers prefer to scan in the axial plane.

A T1W 3D fat-saturated series in the axial plane should be done after the dynamic postcontrast series. This series is an excellent tool for evaluating the axillary lymph nodes. Be aware of the direction of the **phase artifact** so that it does not obscure the axilla. Artifact thrown across the axilla from cardiac vessels may give the appearance of abnormal pathology (**Figure 20**).

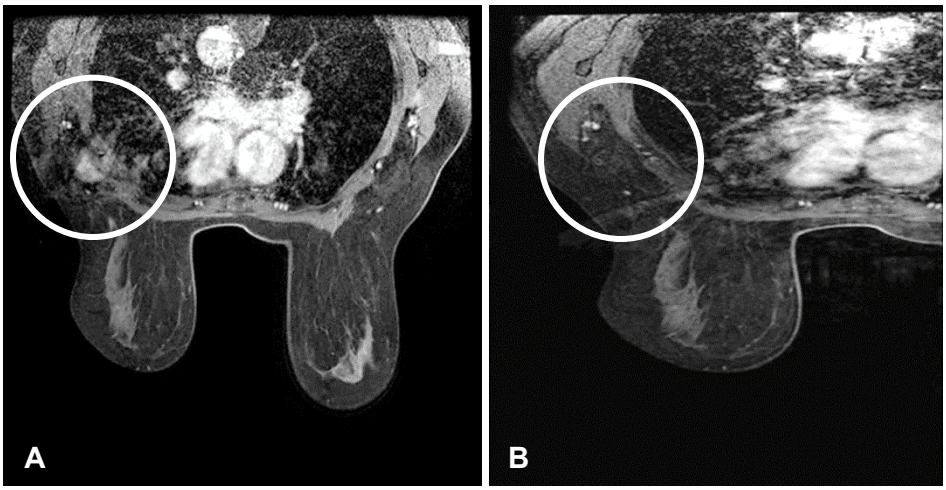


Figure 20. Example of phase artifact. (A) Phase artifact running right-to-left shows motion artifact from a cardiac vessel in the axilla giving the impression of a large abnormal axillary node. (B) Phase artifact running anterior-to-posterior provides an unobstructed view of the axillary region with no abnormality.

Silicone Implant MRI Protocol

BMRI is an excellent tool for the evaluation of silicone implants. An inversion recovery pulse sequence is used as well as a corresponding **water-saturated** IR pulse sequence to suppress tissue. The water-saturated IR series will suppress all tissue, leaving only the silicone visible (**Figure 21**). These sequences are done in both the sagittal and axial planes, allowing visualization of any silicone outside of a ruptured capsule while suppressing any non-silicone fluid that might surround the implant.

A T1W sagittal non-fat-saturated sequence will determine the location of the implant, either subpectoral or subglandular. This protocol should also be used when evaluating a double lumen implant, which consists of both silicone and saline components (**Figure 22**).

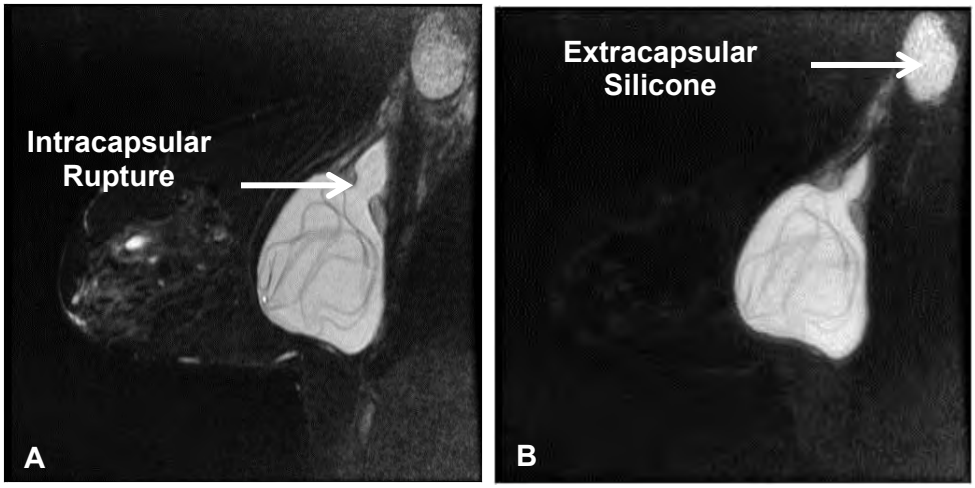


Figure 21. (A) Silicone implant rupture using inversion recovery. (B) Inversion recovery with water saturation. By doing a water-saturated IR, the area in the superior breast can be confirmed as extracapsular silicone.

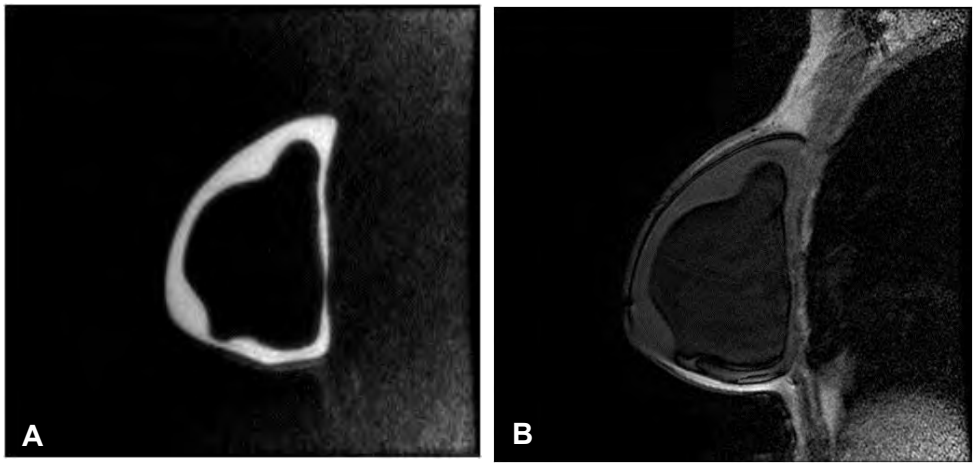


Figure 22. Double lumen implant showing a saline inner lumen and silicone outer lumen. (A) IR using water saturation. (B) Postcontrast T1W non-FAT SAT.

Saline vs Silicone Implant Protocol

Rupture of a saline implant can be evaluated using the routine breast MR imaging protocol. A noticeable difference in the ruptured saline implant is usually seen on all series. At 1.5T, the saline implant will be hyperintense on T2W fat-saturated images. A silicone implant, however, will be hypointense because the frequency of fat and silicone are very close; when fat suppresses, silicone also suppresses. On an inversion recovery, the silicone implant is visible and the characteristics within the implant can be evaluated (**Figure 23**).

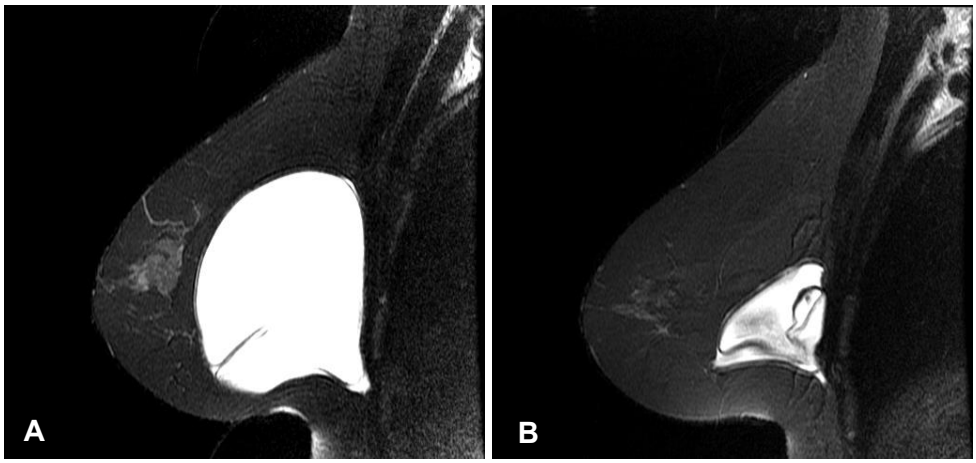


Figure 23. (A) Intact saline implant. (B) Ruptured saline implant.

If the patient presents with a mass or pain, it is important to perform a dynamic contrast-enhanced series to determine if a pathological process is the cause of the patient's symptoms.

NOTES

The Role of Gadolinium-based Contrast Agents in Breast MRI

With the exception of evaluation of silicone implant integrity, *all* breast MR images require the use of a gadolinium-based contrast agent. GBCA dose is based on patient weight and can vary depending on the product manufacturer.

As with any MRI study performed using GBCA administration, a completed screening form should be obtained and reviewed with the patient.

Allergic reactions to GBCAs are rare and can range from a mild rash, hypotension, and shortness of breath to the extremely rare severe **anaphylactoid** reaction. Incidence of allergic reactions range from 0.0004-0.7% for mild to moderate reaction to 0.001-0.01% for anaphylactoid reactions[10].

Patients should be carefully screened for the following risk factors to determine if they are at risk for a GBCA-related adverse event:

- Patient over 60
- History of renal disease
- Dialysis
- Kidney transplant
- Single kidney
- History of lupus
- History of chemotherapy within 2 years
- Diabetes

Nephrogenic Systemic Fibrosis

While gadolinium-based contrast agents have proven to be extremely safe, patients with a chronic or acute renal insufficiency should not receive contrast administration due to the increased risk of developing **nephrogenic systemic fibrosis** (NSF), a rare but potentially fatal condition. A serum creatinine level should be performed before the MRI is scheduled to assess the patient's **glomerular filtration rate** (GFR), a measurement of renal function. GBCAs are contraindicated in patients with a GFR of <30.

Gadolinium Deposition

Researchers now recognize that gadolinium-based contrast agents can leave deposits of gadolinium in the brain, bone, skin, and other organs. As of February 2017, it is unknown whether these deposits have any clinical significance or will result in adverse health effects.

In June 2016, The American College of Radiology and American Society of Neuroradiology issued a joint statement which in part reads, "If the decision is made to use a gadolinium-based contrast agent for an MRI study for an individual patient, multiple factors need to be considered … including diagnostic efficacy, relaxivity, rate of adverse reactions, dosing/concentration and propensity to deposit in more sensitive organs, such as the brain."

For additional information about GBCA safety, go to:

American College of Radiology Manual on Contrast Media, Version 10.2, 2016:
http://www.acr.org/~/media/ACR/Documents/PDF/QualitySafety/Resources/Contrast%20Manual/2016_Contrast_Media.pdf

American College of Radiology
MR Safety guidelines.

American Society of Neuroradiology:
http://www.asnr.org/index.php/resources/asnr-advocacy-activities/acr-manual-contrast-media-contains-asnracr-statement-addressing-gadolinium-concerns/

FDA Drug Safety Announcement:
http://www.fda.gov/Drugs/DrugSafety/ucm455386.htm

International Society for Magnetic Resonance in Medicine:
http://www.ismrm.org/mr-safety-links/gadolinium-retention-updates-and-resources/

Notes

BREAST MRI BI-RADS® ASSESSMENT CATEGORIES

Breast Imaging Reporting and Database System (BI-RADS®) is a quality assurance guide created by the American College of Radiology and designed to both standardize breast imaging reporting and facilitate outcome monitoring. The BI-RADS assessment tool is used for mammography, ultrasound, and MRI breast imaging.

While the FDA does not require that BI-RADS categories be assigned to MRI findings as it does for mammographic findings, the ACR recommends using the BI-RADS assessment codes when reporting MRI findings **(Table 2)**[11]**.**

Assessment Category	Description
Category 0 – Incomplete: Need additional imaging evaluation	Finding for which additional evaluation is needed
Final Assessment	
Category 1 – Negative	No abnormal enhancement, no lesion found (routine follow-up)
Category 2 – Benign finding	Benign, no malignant features, eg, cyst (routine follow-up)
Category 3 – Probably benign finding	Probably benign finding (short interval follow-up)
Category 4 – Suspicious abnormality	Low to moderate suspicion for malignancy (biopsy should be considered)
Category 5 – Highly suggestive of malignancy	High probability of malignancy (appropriate action should be taken)
Category 6 – Known cancer	Biopsy-proven malignancy diagnosis on the imaged finding prior to definitive therapy (appropriate action should be taken)

Table 2. Breast MRI BI-RADS® Assessment Categories.

KINETIC ANALYSIS (CURVE)

Signal intensity vs time, or kinetic curves, can be generated from the wash-in and wash-out patterns of GBCA uptake (**Figure 24**). The type of curve generated for an area of interest is a predictor for the likelihood of malignancy.

There are three types of contrast enhancement patterns:[12]

- A Type I (persistent) curve shows a slow initial rise with a continued rise in the delayed phase. This is a benign type of enhancement kinetic curve. A lesion with a Type I curve has a 6% chance of being malignant. (**Figure 25A**).
- A Type II (plateau) curve also shows a slow initial rise but then plateaus over time. Type II lesions have a 64% likelihood of being malignant.
- Type III (washout) curve shows a rapid initial rise, followed by a drop-off with time (washout) in the delayed phase. This is a malignant type of kinetic curve. The likelihood of malignancy with this type of kinetic curve is approximately 87% (**Figure 25B**).

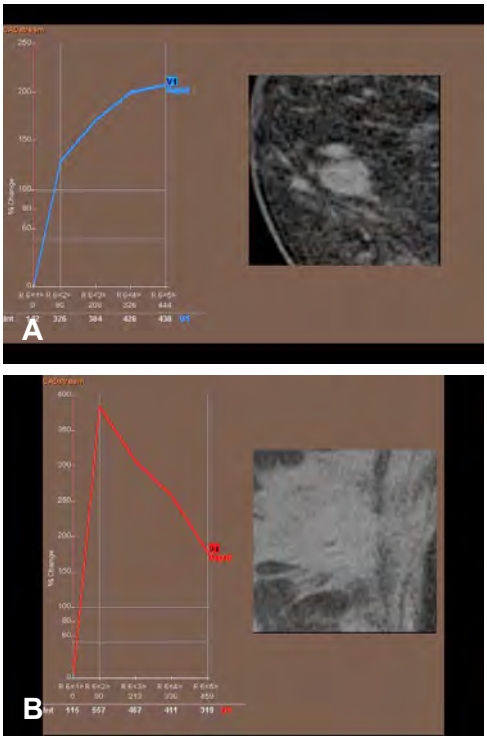


Figure 25. MOVIES. (A) Type I curve indicating a benign lesion. (B) Type III curve representing a malignant lesion.

Click on the links below to view the movies:
Youtube/ICPMEducation.com Benign Curve
Youtube/ICPMEducation.com Malignant Curve

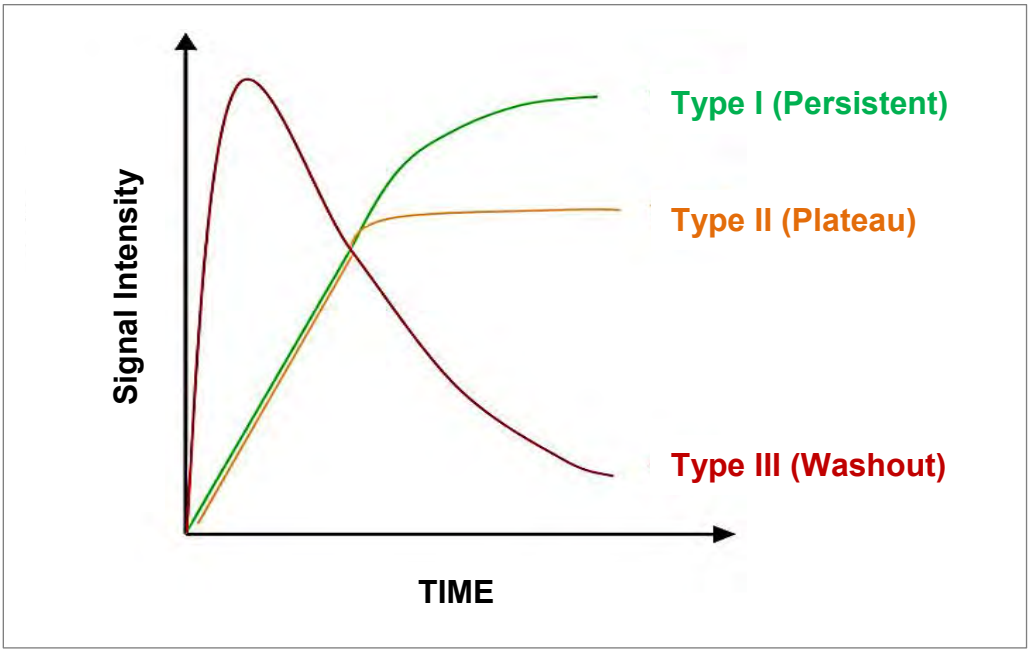


Figure 24. Time intensity enhancement curves[13].

Neoangiogenesis

The growth of malignant lesions is dependent on **neoangiogenesis**, the formation of a new blood supply to feed tumor growth (**Figure 26**). The blood vessels that form to feed a malignant lesion are abnormal and leaky. It is this process that allows for kinetic assessment of cancerous lesions.

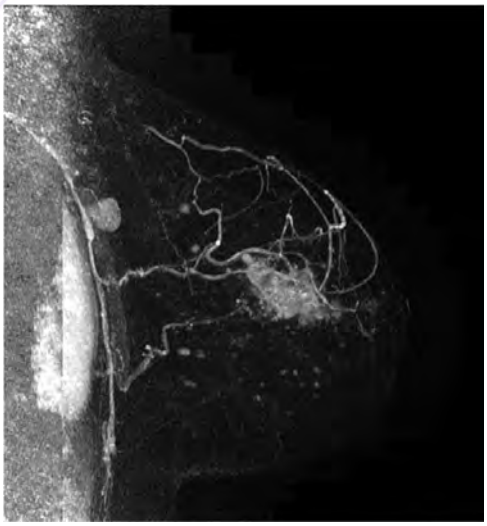


Figure 26. Example of neoangiogenesis. Note new blood vessels that supply the mass.

Typically in MR imaging, normal tissue will progressively enhance, showing a continuous increase in signal intensity. Malignant lesions will rapidly take up contrast media and the abnormal, leaky vessels will allow the contrast agent to rapidly wash out, showing a reduction in enhancement in the delayed phase.

BENIGN FINDINGS ON MRI

Cysts

Cysts are commonly seen on BMRI, and one or several cysts may be present. Simple cysts are hyperintense on T2-weighted images. If cysts are complex and filled with **proteinaceous** material, they will appear hyperintense on T1-weighted images. Inflamed cysts will show rim enhancement on postcontrast images (**Figure 27**).

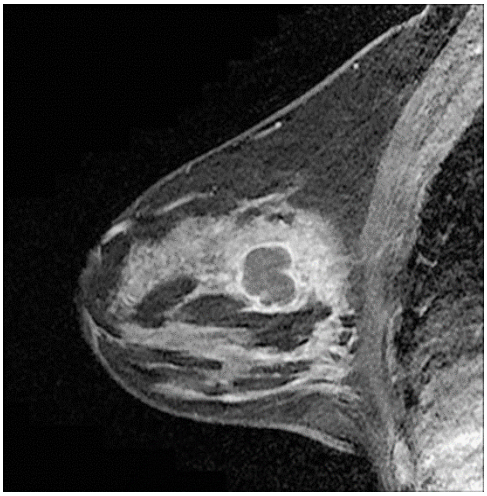


Figure 27. Inflamed cyst. Postcontrast T1W FAT SAT.

Cysts will often resolve on their own. However, larger cysts can be aspirated to reduce pain and patient concern.

Fibroadenomas

Fibroadenomas are common benign masses often seen on BMRI. They have smooth margins and are round or oval in shape. They can vary in size, and a patient may have one or many.

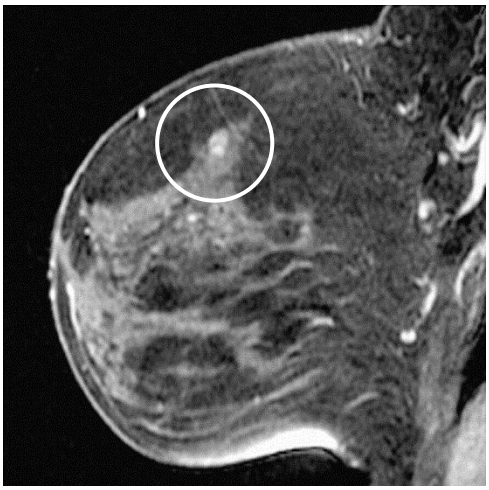


Figure 28. Fibroadenoma. Postcontrast T1W FAT SAT. Note the dark internal septations.

Fibroadenomas have varying contrast enhancement patterns depending on the cellularity of the lesion. Dark internal **septations** on T2-weighted and postcontrast images are a common characteristic of a fibroadenomas (**Figure 28**). Generally, fibroadenomas are proven by biopsy.

Hamartoma

Hamartoma or "breast within a breast," is a rare benign lesion consisting of fat, connective tissue, and glandular tissue. The parenchymal elements of a hamartoma will enhance more avidly than surrounding breast parenchyma.

No treatment is required, although patient preference may be to have the lesion biopsied and removed (**Figure 29**).

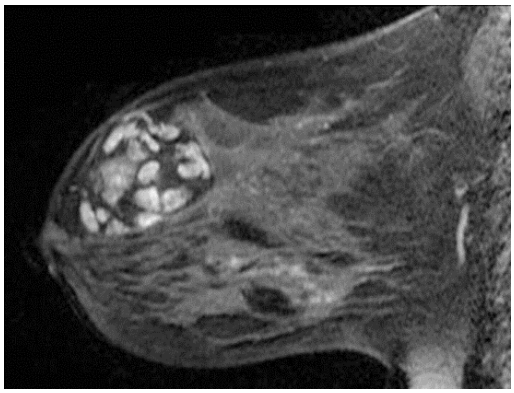


Figure 29. Hamartoma. Contrast-enhanced T1W FAT SAT.

LCIS

Lobular cancer *in situ* is not considered a cancer and usually does not spread outside the milk ducts so is considered atypical. LCIS is also referred to as lobular neoplasia.

Phyllodes

Phyllodes tumors occur in the connective tissue of the breast. They are generally benign and may look like a fibroadenoma. However, there are malignant phyllodes that demonstrate malignant features, including irregular shape, heterogeneous enhancement, and contrast wash-out. Phyllodes tumors are biopsy-proven. Benign tumors require no treatment; the rare malignant phyllodes tumor requires further work-up.

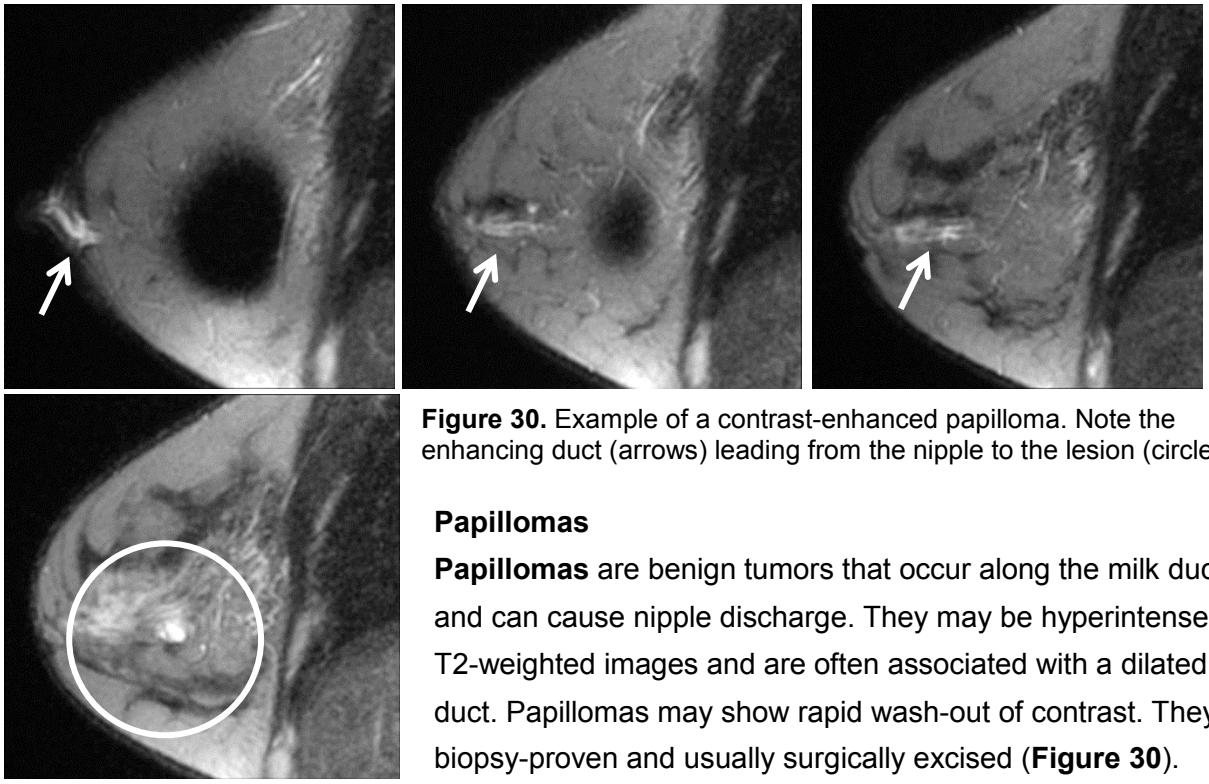


Figure 30. Example of a contrast-enhanced papilloma. Note the enhancing duct (arrows) leading from the nipple to the lesion (circle).

Papillomas

Papillomas are benign tumors that occur along the milk ducts and can cause nipple discharge. They may be hyperintense on T2-weighted images and are often associated with a dilated duct. Papillomas may show rapid wash-out of contrast. They are biopsy-proven and usually surgically excised (**Figure 30**).

Lactation

Lactating breasts can be challenging to image on BMRI because of an overall marked increase in background enhancement and diffuse increase in T2 signal. It is best not to scan women who are lactating unless there is a cause for concern (**Figure 31**).

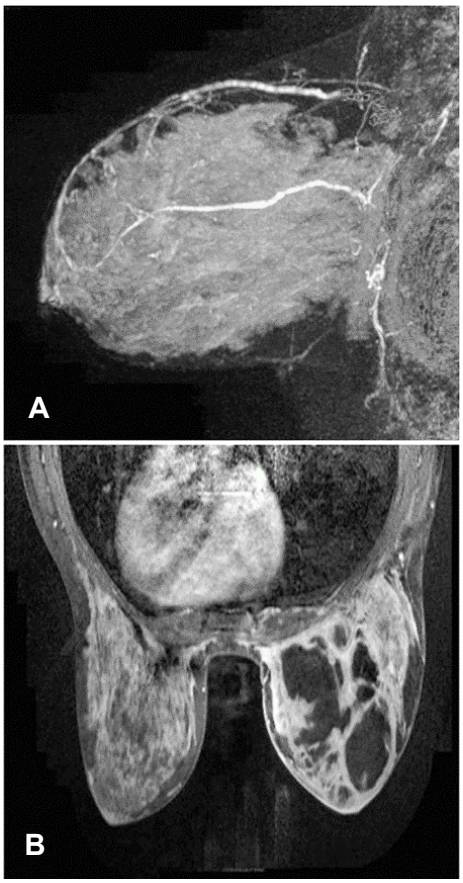


Figure 31. Lactating breast.
(A) Normal postcontrast T1W.
(B) Postcontrast T1W of MRSA in the right breast.

Mastitis

Mastitis is a result of a clogged milk duct and presents on BMRI as an overall increase in enhancement in T2 signal in the affected breast. The skin may be thickened and lymph nodes enlarged. When the skin enhances in mastitis, the enhancement is homogeneous and progressive. An abscess appears as a T2W hyperintense or heterogeneous mass. It can be challenging to differentiate mastitis from inflammatory carcinoma because the symptoms are similar with pain, redness, and swelling. Mastitis is usually treated with antibiotics.

Post-operative Changes

Post-operative changes seen with BMRI include seroma, hematoma, abscess, scar tissue, and fat necrosis.

A **hematoma** is a collection of blood that usually results from biopsy and resolves on its own. Hematoma is heterogeneous on all pulse sequences with peripheral enhancement. An **abscess** may be difficult to differentiate from hematoma due to the similarity in enhancement characteristics (**Figure 32**).

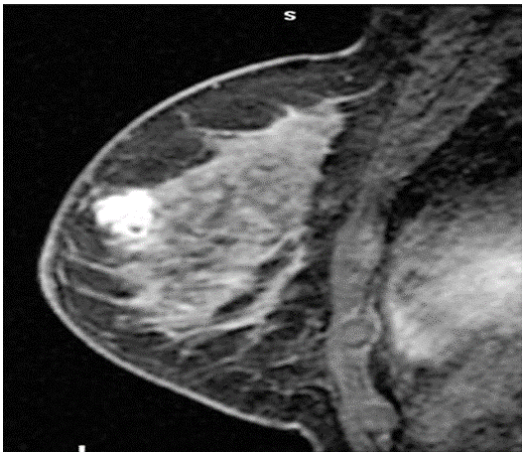


Figure 32. Hematoma on T1W postcontrast.

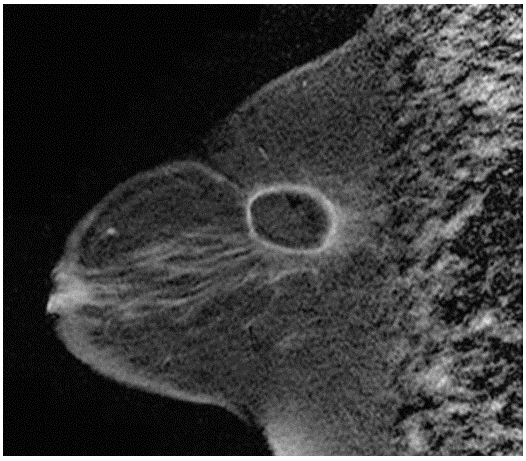


Figure 33. Seroma on T1W postcontrast.

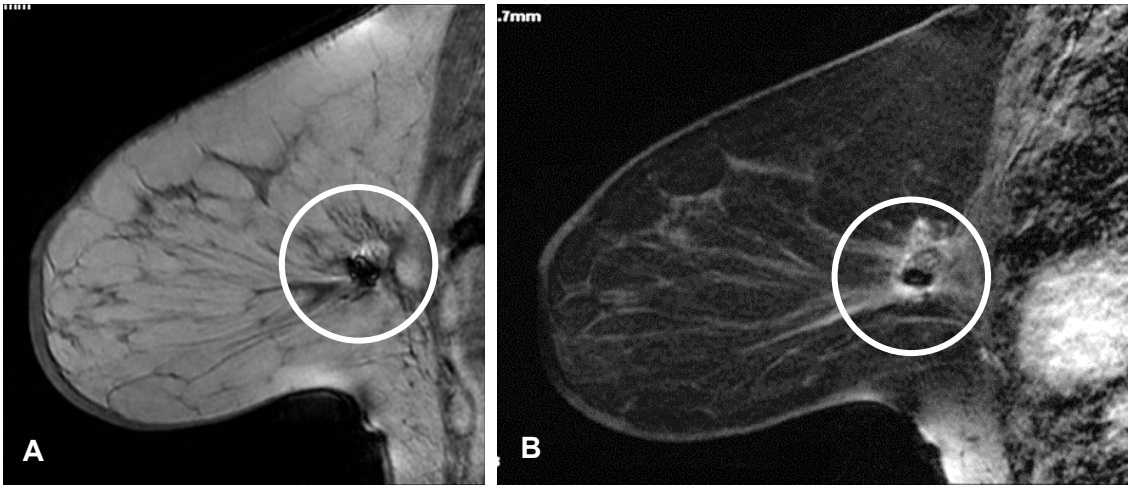


Figure 34. Post-operative scar tissue surrounding the surgical site (circles). (A) Non-contrast-enhanced, T1W non-FAT SAT. (B) Postcontrast T1W FAT SAT.

A **seroma** is a fluid-filled, surgical cavity and may present for years after surgery. On postcontrast images, seromas may demonstrate rim enhancement (**Figure 33**). Post-operative scar tissue may show progressive homogeneous enhancement (**Figure 34**). Fat necrosis can be diagnosed by fat signal intensity on fat-saturated and non-fat-saturated images but in the initial stages when fat is not present, the necrosis may appear as a malignancy. Fat necrosis is often seen at the excisional biopsy or lumpectomy sites **(Figure 35).**

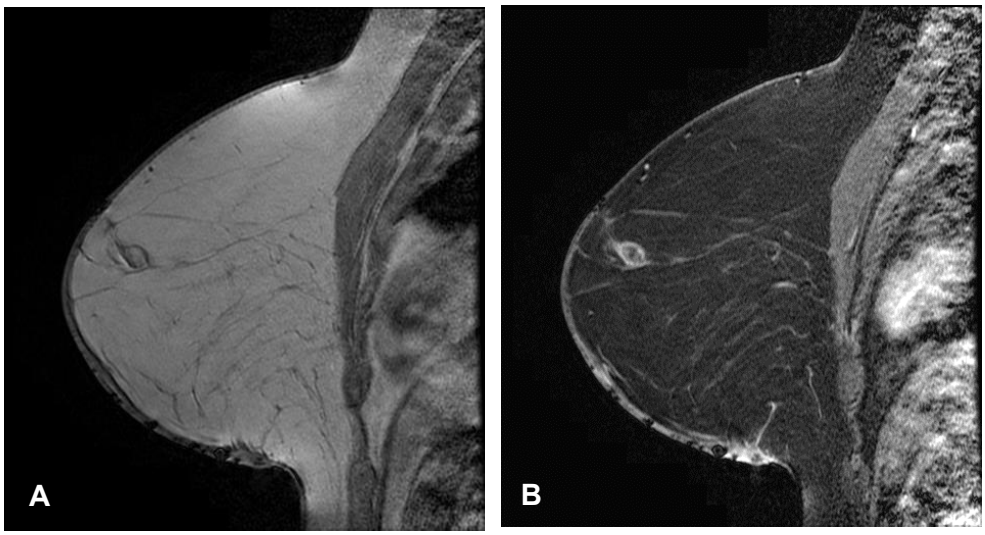


Figure 35. Examples of fat necrosis after TRAM reconstructive surgery.
(A) Postcontrast T1W non-FAT SAT. (B) Postcontrast T1W FAT SAT.

Post-radiation Changes

Post-radiation changes may be seen for many years after treatment and consist of breast edema and skin thickening. Typically overall background parenchymal enhancement decreases after radiation treatment, most notable when the patient has moderate or marked background enhancement in the untreated breast (**Figure 36**).

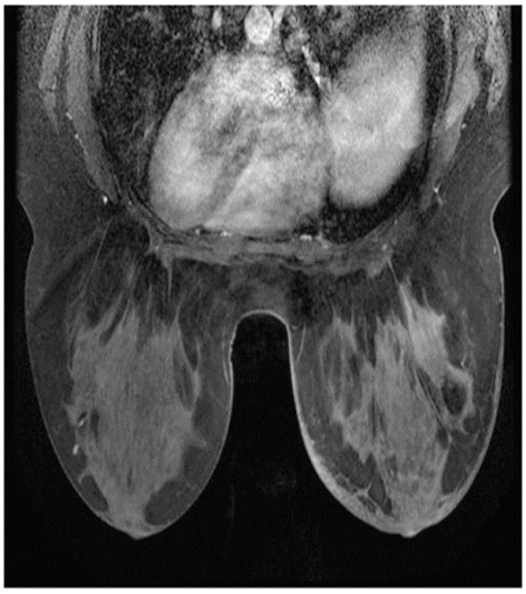


Figure 36. Post-radiation changes. Left breast background parenchymal enhancement is decreased.

ENHANCING LESIONS

Enhancing lesions are divided into three main categories: **focus**/**foci**, **masses**, and areas of **non-mass enhancement**.

- *Focus* (or when multiple, *foci*) is an area of enhancement measuring less than 5mm in diameter and is too small to characterize.
- *A mass* is a three-dimensional lesion that occupies a space within the breast. Just as in mammography and ultrasound, shape, margins, and internal characteristics including its T1W and T2W characteristics as well its enhancement pattern are examined.
- *Non-mass enhancement* are areas of enhancement without a detectable three-dimensional mass. Features of non-mass enhancement include distribution characteristics, internal enhancement pattern, and whether the enhancement is symmetric or asymmetric.

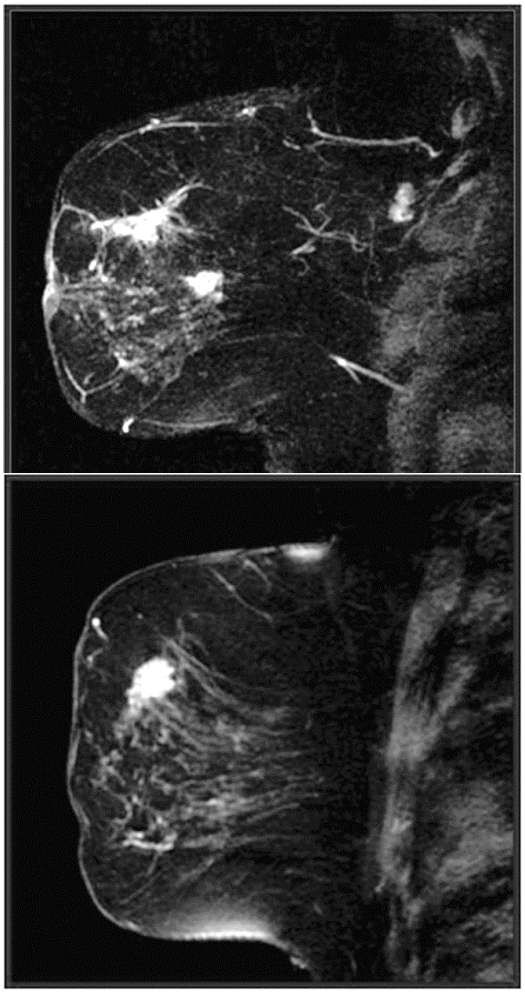


Figure 37. Multicentric non-mass enhancement seen in more than one quadrant of the breast in the same patient.

Foci vs Mass

The size of the abnormality has been associated with the likelihood of malignancy. A foci ≤ 5mm has a likelihood of malignancy of approximately 3%, whereas a mass ≥10 mm has a 25% to 31% likelihood of malignancy[14].

Unless otherwise noted, all images are courtesy of Fairfax Radiological Consultants.

Non-mass Enhancement

Malignant tumors tend to have irregular shapes and irregular margins, heterogeneous enhancement, and wash-out kinetics. When not a discrete mass, the abnormal findings associated with malignancy are termed non-mass enhancement (NME).

Malignant NME may have a segmental, linear, or ductal distribution as well as clumped or heterogeneous morphology. NME can be regional, multifocal, with more than one cancer in the same quadrant, or multicentric, with lesions seen in more than one quadrant of the breast (**Figure 37**).

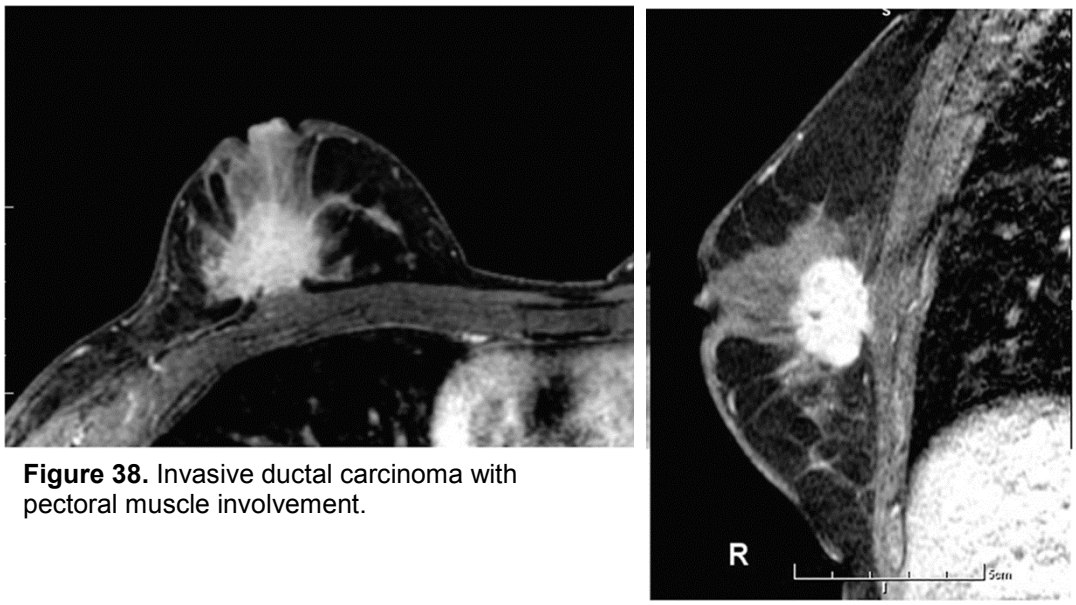


Figure 38. Invasive ductal carcinoma with pectoral muscle involvement.

MALIGNANT FINDINGS ON MRI

Invasive Ductal Carcinoma

Invasive ductal carcinoma (IDC) is the most frequently encountered cancer seen on breast MRI. IDC develops in the milk ducts and if left untreated, IDC infiltrates through the membranes of the ducts into the surrounding tissue. MRI sensitivity is 95-98% for invasive ductal carcinomas[15] (**Figure 38**).

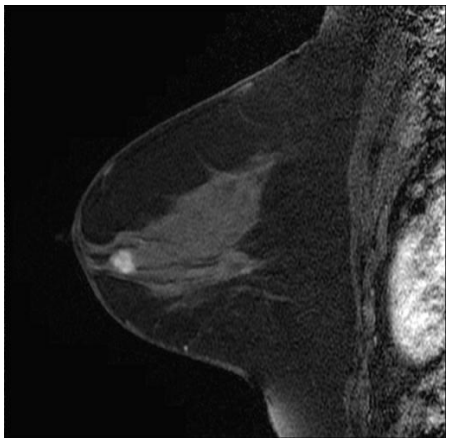


Figure 39. Biopsy-proven mucinous carcinoma.

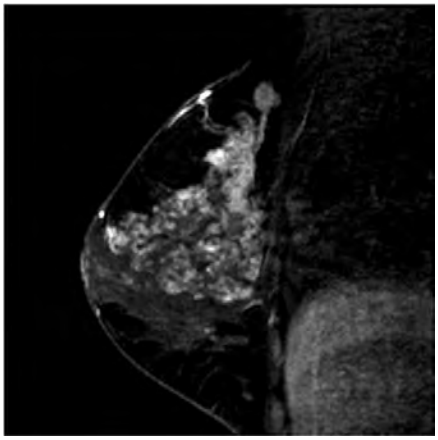


Figure 40. DCIS segmental clumped enhancement.

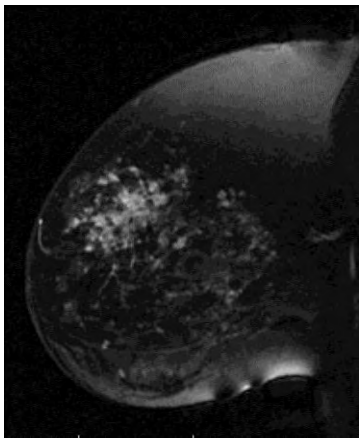


Figure 41. Biopsy-proven invasive lobular carcinoma.

Medullary and Mucinous Cancers

Medullary and **mucinous** cancers are rare subtypes of ductal carcinoma. On MRI, they appear similar to fibroadenomas with distinct borders and require careful pathological determination (**Figure 39**).

Ductal Carcinoma *in situ*

Ductal carcinoma *in situ* (DCIS) stays within the lining of the ducts with no invasion into the breast tissue. While DCIS is considered precancerous, it is typically treated as a malignancy and managed with surgery and/or radiation therapy (**Figure 40**).

Infiltrating Lobular Cancer

Infiltrating or invasive lobular cancer begins in the cells of the milk-producing glands. Infiltrating lobular cancer invades nearby tissue, spreading in a web-like pattern, making it difficult to diagnose. Lobular cancer is difficult to detect with all imaging modalities but best visualized on MRI (**Figure 41**).

Inflammatory Cancer

Inflammatory cancer is an aggressive breast cancer that typically presents with redness, swelling, and pain. This cancer often involves over half of the breast, commonly infiltrating the skin and mammary tissues. The inflammation is due to tumor invading the lymphatic system and blocking drainage, and the skin can develop an orange peel or **peau d'orange** appearance. On MRI, the skin is thickened with heterogeneous enhancement, subcutaneous edema, and edema through the breast (**Figure 42**).

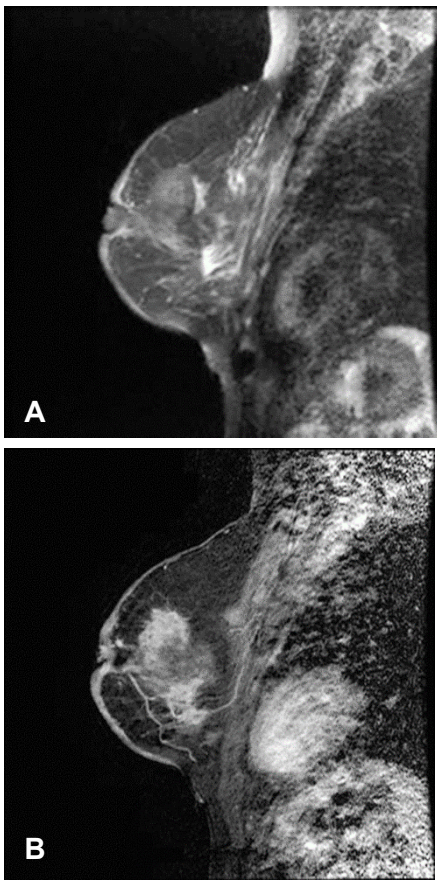


Figure 42. Inflammatory cancer. Note enhancing skin thickening.
(A) T2W FAT SAT showing edema within the tissues.
(B) Postcontrast T1W.

IMAGING THE AUGMENTED AND RECONSTRUCTED BREAST

The following are the most common types of augmentation and reconstruction:

- Implants
- Transrectus abdominis myocutaneous flap
- Deep inferior epigastric perforator
- Silicone injections

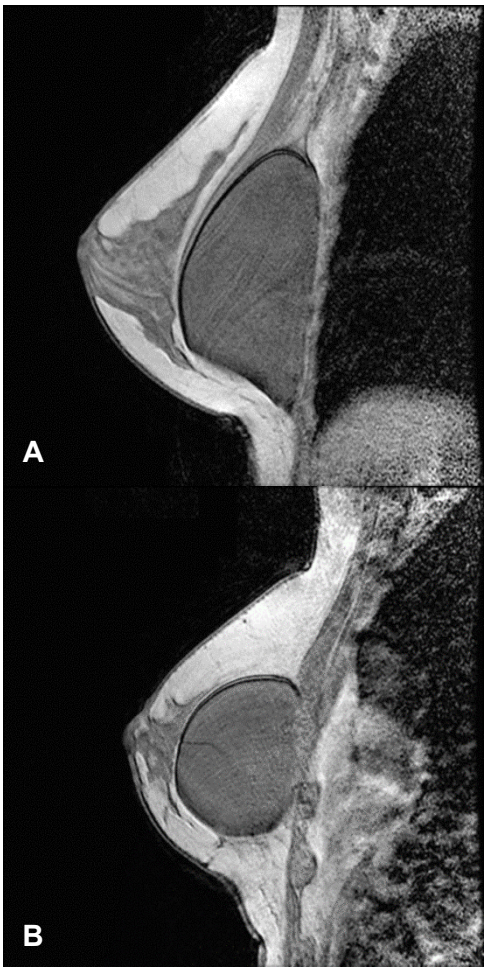


Figure 43. Implants. (A) Subpectoral. (B) Subglandular.

Implants

In post-mastectomy patients, silicone or saline implants can be used for reconstruction. The decision to use silicone or saline is made by the patient and her surgeon. Implants are usually placed subpectorally but can be inserted subglandularly (**Figure 43**).

Before subpectoral implant insertion, a tissue expander is used to "stretch" the tissue to accommodate the implant. Caution should be taken when interviewing patients undergoing reconstruction as there are several tissue expanders that are NOT MR compatible. After the tissue is stretched adequately, the expander is replaced with a permanent implant.

Transrectus Abdominis Myocutaneous Flap

Transrectus abdominis myocutaneous flap (TRAM) reconstruction uses the rectus abdominis muscle to supply blood to the fat and tissue of the abdominal skin used to form a new breast. Often areas of fat necrosis are associated with a TRAM reconstruction. On MRI there is an area of triangular tissue known as the **pedicle** that often shows magnetic susceptibility artifacts due to the surgical procedure. The pedicle is formed from part of the rectus muscle that has been moved from the abdominal wall (**Figure 44**).

Deep Inferior Epigastric Perforator

Unlike for TRAM reconstructions, the **deep inferior epigastric perforator** (DIEP) procedure takes tissue and fat from the abdomen leaving the abdominal muscles intact.

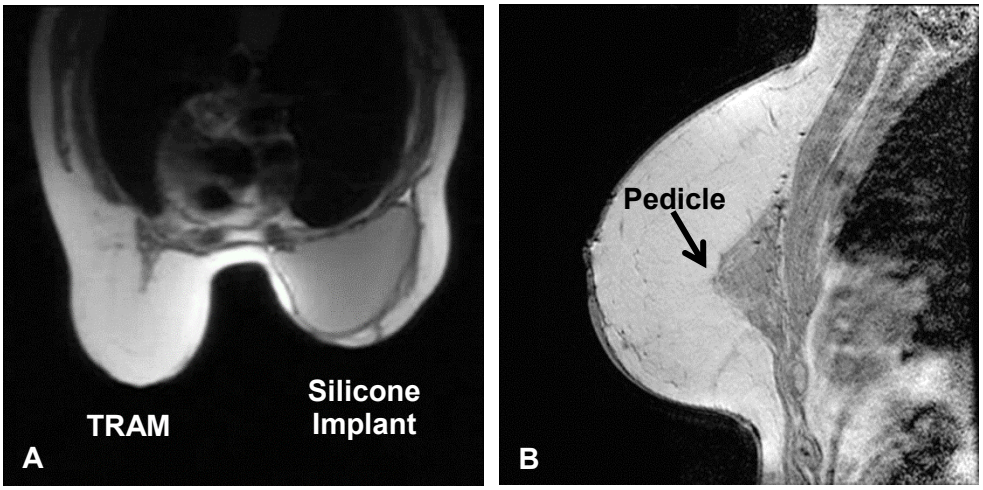


Figure 44. Patient with bilateral breast cancer diagnosed several years apart. (A) TRAM reconstruction and implant. (B) Note section of abdominis rectus (pedicle) seen on TRAM reconstruction.

Silicone Injections

Silicone injections are a type of augmentation rarely used today. It is important to image using a water-saturated inversion recovery sequence to visualize residual silicone vs granulation tissue. **Figure 45** demonstrates how silicone appears on BMRI.

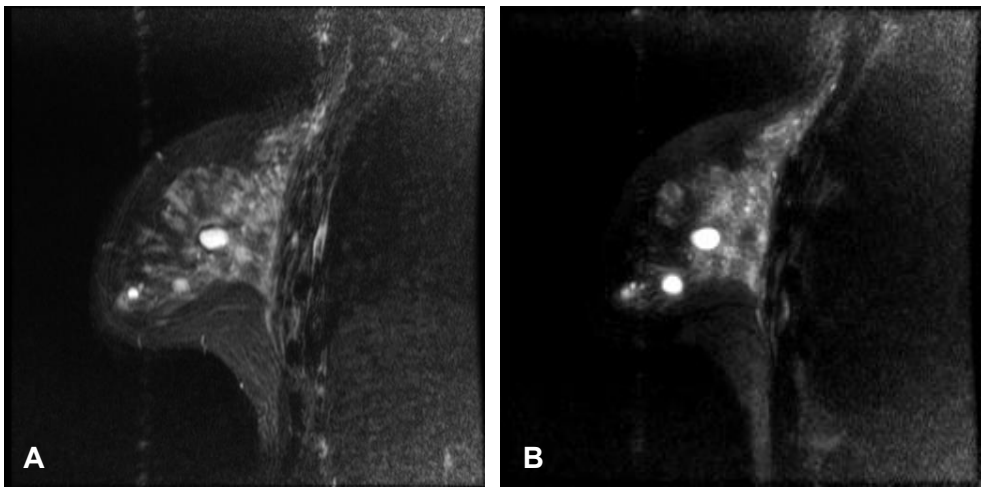
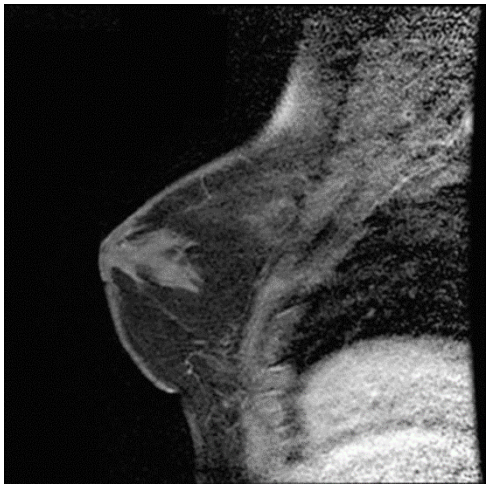


Figure 45. Augmentation using silicone injections. (A) Inversion recovery. (B) Inversion recovery with water saturation. Note multiple areas of injected silicone.



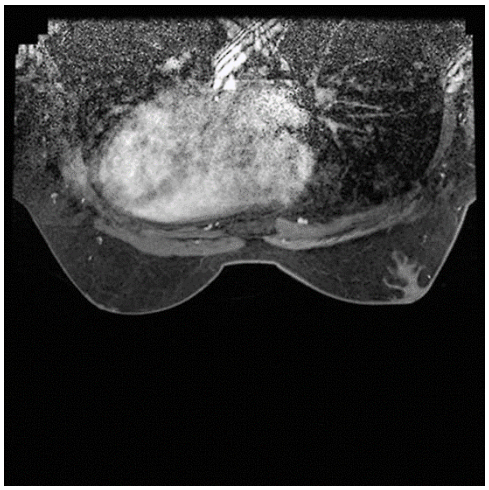


Figure 46. Gynecomastia seen on T1W postcontrast.

BREAST CONDITIONS IN MEN

Gynecomastia

Gynecomastia is tissue enlargement in the male breast, usually due to abnormal hormone levels, primarily increased estrogen (**Figure 46**). Hormone level fluctuations can be due to natural changes of puberty or aging, obesity, or diseases of the endocrine glands or liver. Some medications can also cause elevated estrogen levels.

Gynecomastia can occur in one or both breasts and is a benign condition.

Breast Cancer

Though uncommon, breast cancer can occur in men, accounting for less than 1% of all diagnosed breast cancers. The lifetime risk for breast cancer in men is about 1 in 1,000. In 2014, it is estimated that about 2,360 new cases of invasive breast cancer will be diagnosed and that about 430 men will die from breast cancer[16] (**Figure 47**).

Inherited genetic mutations such as *BRCA*1 and *BRCA*2 carry lifetime risks of about 6 in 100 and 1 in 100, respectively, and can be linked to male breast cancer. Radiation to the chest for reasons such as non-Hodgkin's lymphoma also accounts for in a very small number of male breast cancers[17].

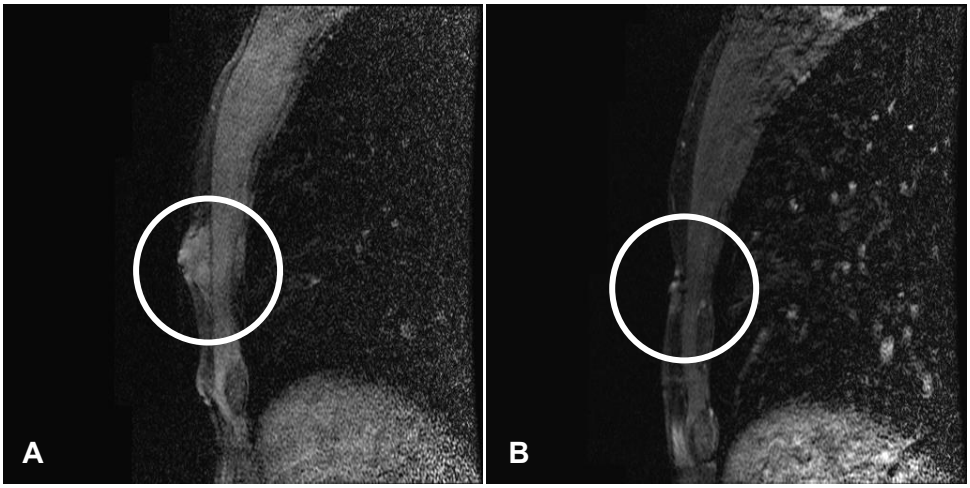


Figure 47. Breast cancer in a male. (A) Sagittal contrast-enhanced FAT SAT T1W. (B) Contrast-enhanced T1W fat-saturated, post-lumpectomy.

MRI-GUIDED BREAST BIOPSY

If an area of abnormality is seen on breast MRI and cannot be reproduced by either mammography or ultrasound, an MRI-guided breast biopsy (MRBX) may be performed. MRBX is typically performed using vacuum-assisted core biopsy. All centers providing breast MRI should have the capability to provide MRI-guided breast biopsy.

Patient Care and Comfort

Patients arriving for an MRBX may be understandably anxious about the procedure and should be afforded additional attention by the breast center staff. As with any breast biopsy, check to be sure that the patient has discontinued aspirin, ibuprofen, vitamin E, or any other blood-thinning medications prior to the procedure.

It is important to keep this procedure simple as possible. The diagnostic breast MRI as well as prior mammographic and ultrasound images should be reviewed and the biopsy approach determined by the radiologist prior to the procedure to minimize the procedure time. The biopsy team should review the case, identify the target of the biopsy, and discuss the approach and best patient position before beginning. A set of images showing the location of the lesion to be targeted should be at the MR console for reference.

It is important for the patient to feel as comfortable as possible to alleviate stress as well as decrease or eliminate motion during the procedure. A head support, blankets, and the presence of a technologist or nurse at all times will help put the patient at ease.

Patient Positioning

Patient positioning is essential for obtaining an accurate biopsy. Determining the optimal approach prior to the procedure saves time, and with proper positioning the procedure will be more comfortable for the patient.

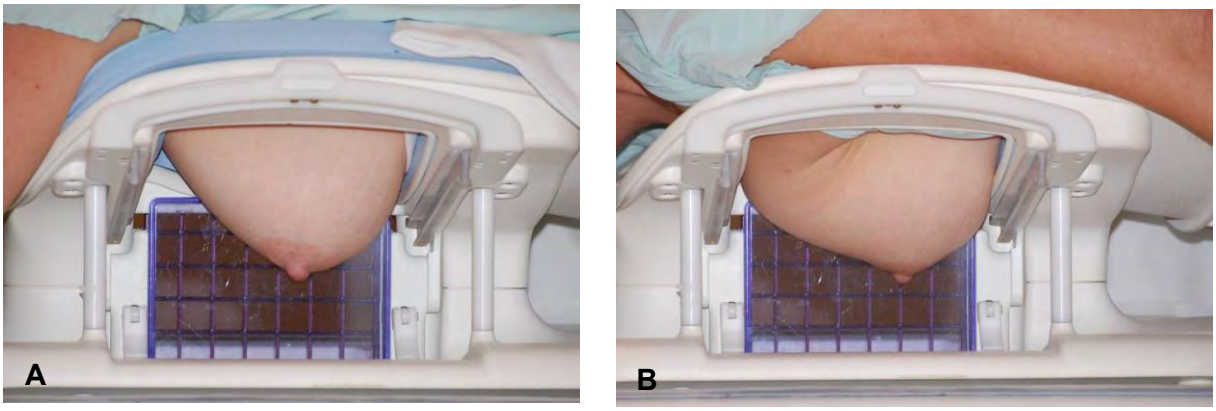


Figure 48. Patient positioning. (A) Arm up above head. (B) Arm down by patient's side.

It is helpful to ask the following questions:

- Is the lesion on the lateral or medial side of the breast?
- Is the lesion in the anterior or posterior portion of the breast?
- Will the patient need to be elevated in the coil to access a very anterior or retro-areolar lesion, or is the lesion so posterior that the patient will need to be lowered down into the coil by using a smaller pad on the coil, pulling the breast, and placing the patient's arm down by her side (**Figure 48**)?
- Is there anything to limit access to the lesion – post-surgical seroma or a large blood vessel?

It is important to know these answers before you begin.

Breast Placement

It is important to pull the breast into the coil to provide both better access and compression. Care should be taken not to pinch the skin or place the compression plate too tightly when immobilizing the breast (**Figure 49**).

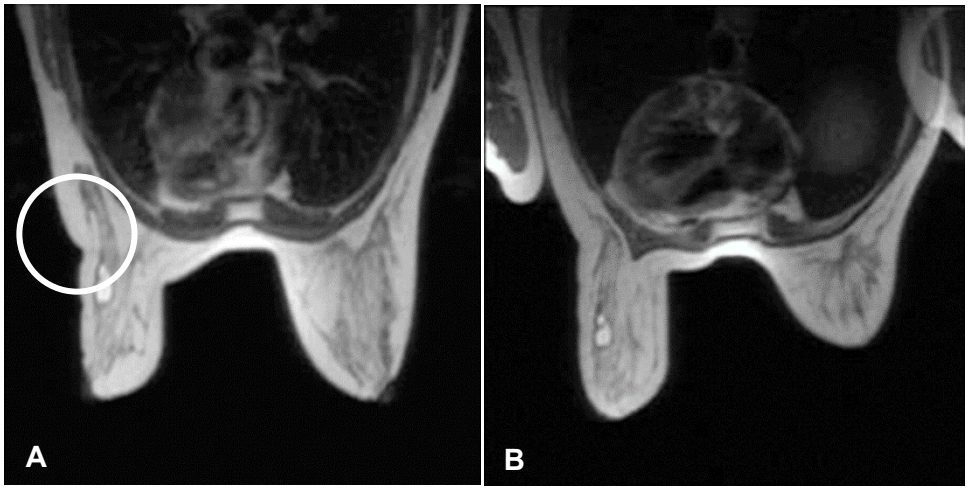


Figure 49. Biopsy positioning. (A) Poorly positioned breast with tissue outside the coil. (B) Pull the breast and place the arms by the patient's sides for better access to posterior lesions.

If compression is uneven, a wedge can be placed to provide more uniform compression (**Figure 50**).

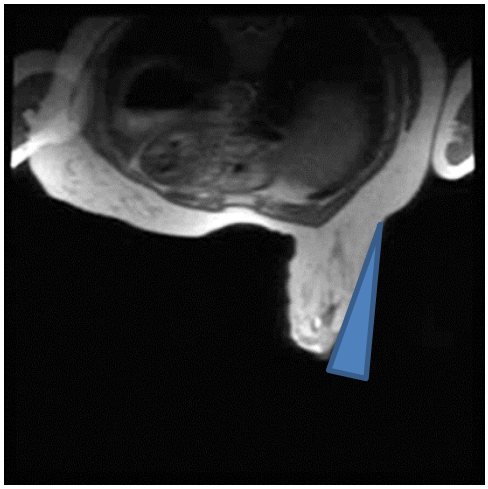


Figure 50. Medial approach with wedge on lateral side.

Once the patient is comfortable, properly positioned, and the breast is in compression, a **fiducial** marker is placed near the expected region of the abnormality.

Breast Biopsy Scan Protocol

A simple protocol is all that is needed for an MRI-guided biopsy. A 3-plane localizer is used to determine if the patient is adequately positioned. A 3D sagittal T1W-weighted fat-saturated sequence is used to visualize the breast and the lesion. Only the area of the abnormality needs to be scanned. Be sure to include the face of the compression grid in this scan. A precontrast scan is performed to ensure the area of interest is accessible and the fiducial can be seen.

Contrast Agent Administration

A gadolinium-based contrast agent is administered only after it is determined that the patient is properly positioned and the area of interest can be visualized and is accessible within the compression grid. The contrast agent is given manually, and postcontrast images are acquired immediately following GBCA injection. It is not necessary to use a power injector for this procedure; however, it is important to work quickly and efficiently to reduce lesion wash-out and to minimize background enhancement.

Once the area of interest is identified on the postcontrast images, the coordinates of the lesion are determined within the compression grid and the depth of the lesion is calculated.

If the area of interest is not visualized postcontrast, perform two or three additional postcontrast scans and reassess. Was the contrast adequately administered? Was the compression too tight, not allowing adequate blood flow to the breast? Is the lesion seen on the diagnostic study truly a suspicious lesion or could it be fibrocystic change that might not be seen at this point in the patient's menstrual cycle?

Biopsy Needle Placement

The location of the biopsy needle placement can be determined once the area of interest is identified on the postcontrast images.

For masses, it is important to choose a location that will not "skewer" the mass so as not to push away or obliterate the lesion. Instead the biopsy needle should be placed immediately adjacent to the targeted lesion. However, if the area of interest is linear or is an area of large clumped enhancement, it may be best to target the center of the area.

Prepping the Skin

While the location of the needle placement is being determined, the patient should be brought out of the magnet. It is important that a technologist or nurse stay with the patient to prevent patient movement. If the patient moves, the lesion may not be located in the calculated location.

At this point the biopsy device can be readied. The breast is cleaned with Chloraprep® or Betadine® and then anesthetized with a numbing agent both at the surface and to the depth of the lesion.

Introducer Placement

An introducer guide needle with an introducer sheath is placed to the appropriate depth of the area of interest. The guide needle is removed and replaced with a plastic **obturator**. The patient is then moved back into the magnet to assess the placement of the introducer. Did the lesion move with the insertion of the guide needle? Is the introducer properly placed? If yes, then the biopsy device can be placed and samples taken. If the lesion has moved with the insertion of the guide needle, the lesion depth must be recalculated based on the post-introducer images and appropriate adjustments made to the location of the introducer. Replace the obturator and rescan the patient.

Tissue Sampling

It is only necessary to biopsy in the direction of the lesion. The direction of tissue sampling is determined in relation to the guide needle: is the area of interest toward the patient's head, chest, feet, or nipple? Remember the position of the patient on the table will be different from the patient's position on the console monitor. Take great care to determine the correct direction of rotation of the biopsy device.

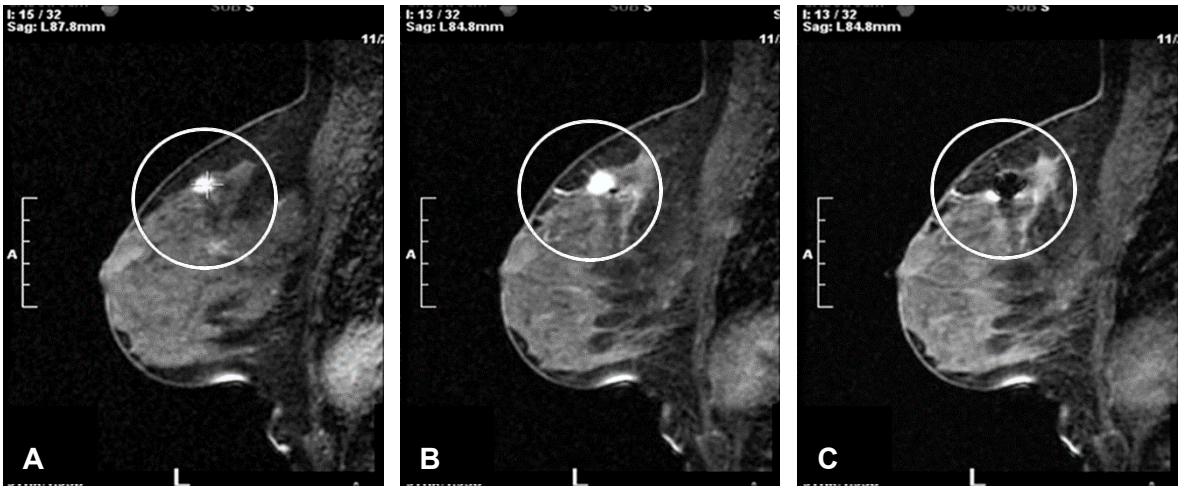


Figure 51. Biopsy site. (A) Lesion localization postcontrast. (B) Mass with obturator (small dark hole adjacent to the mass). (C) Post-biopsy.

It is important to determine if the lesion was adequately sampled. Care should be taken to compare the post-biopsy images with the post-introducer images as the lesion may have moved after the initial postcontrast images (**Figure 51**).

If a hematoma appears, one or two biopsy cores will help eliminate the blood accumulation for better visualization of the biopsy cavity. If the lesion washes out, use anatomical landmarks to help determine your position. Once it has been determined that the lesion was adequately sampled, an MR-compatible biopsy marker is deployed. Some radiologists prefer to perform one last scan to confirm marker placement, although this practice varies from facility to facility.

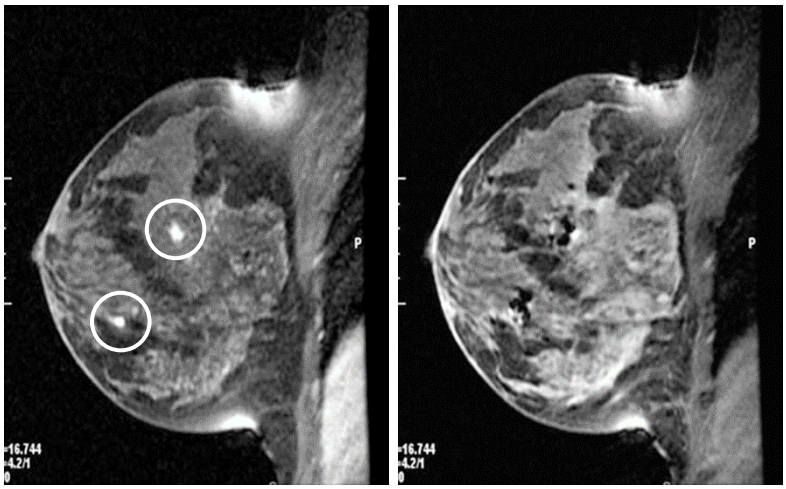


Figure 52. Multiple biopsy sites. (A) Post-contrast. (B) Post-biopsy.

Multiple Biopsies

If more than one biopsy or bilateral biopsy is needed, more than one area can be targeted during the biopsy procedure (**Figure 52**). Care must be taken to label samples correctly, remembering to be consistent in the approach taken to label tissue samples.

Patient Care after Biopsy

After completion of the biopsy, pressure is held at the biopsy site until bleeding has stopped. Steri-Strips™ should be applied, along with an ice pack and compression binder. A post-biopsy mammogram should always be performed to record placement of the biopsy marker. Post-biopsy care instructions should be given to the patient at discharge.

See **Appendix A** Sample Steps for a MRI-guided Breast Biopsy

See **Appendix B** Sample Post-Procedure Patient Instructions

Figure 53 is a video of a patient undergoing MRI-guided breast biopsy using computer-aided detection (CAD) and the grid method.

Figure 53. MOVIE. Patient undergoing breast biopsy.
Click here to view the movie: www.Youtube/ICPMEducation.com

Used with permission of Hologic, Inc.

SUMMARY

Breast MRI serves an important role in both the detection and diagnosis of breast cancer in select patient populations for screening, evaluation of extent of disease, assessment of tumor response to neoadjuvant chemotherapy, and preoperative planning. BMRI provides methods for obtaining images that have both high spatial and high temporal resolution without the use of ionizing radiation. With continued advances in breast imaging techniques, earlier cancer detection and treatment will continue to improve quality of life.

APPENDIX A

Sample Steps for an MRI-guided Breast Biopsy	
1	Position patient: a. Pull/immobilize breast b. Place breast in compression c. Use wedge if needed d. Place fiducial
2	Initial scanning – 3-plane localizer and 3D T1W fat-saturated sagittal image
3	Check location of breast in compression grid using diagnostic MRI and physical landmarks
4	Inject contrast agent
5	Scan immediately
6	When lesion is visualized, the technologist prepares biopsy device
7	Determine the physical location of lesion using grid coordinates
8	Prepare breast with topical cleaning and local numbing agent
9	Place introducer guide needle
10	Re-scan patient to determine that the needle is correctly placed a. If correct, proceed with biopsy b. If not correct, reposition guide needle and rescan
11	Scan to determine if the lesion in question has been adequately biopsied a. If yes, always deploy a biopsy marker b. If no, take more biopsy cores as needed
12	Hold manual compression, apply Steri-Strips™, ice pack, and compression binder
13	Obtain post-biopsy mammogram

Courtesy Fairfax Radiological Consultants, Fairfax, VA

APPENDIX B

MRI-Guided Breast Biopsy
Sample Post-Procedure Patient Instructions

What the Patient Should Know

- A small amount of bloody drainage at the biopsy site is possible. If bleeding occurs, hold pressure on the site for 10 minutes. Do not release pressure before 10 minutes is up. If bleeding continues, hold pressure for another 10 minutes. If bleeding has not stopped, call the office number provided. If after hours, proceed to the local Emergency Room.
- Bruising and swelling at the site of the biopsy are common. Mild to moderate bruising will resolve in one or two weeks. More severe bruising can take up to a month to resolve completely.
- A hematoma, which is a collection of blood, can develop and will feel like a mass at the site of the biopsy. A hematoma will may require several months to fully resolve.

Instructions:

- To decrease swelling and discomfort, apply an ice pack to the biopsy area the day and evening after the procedure. Use as needed the day following the procedure.
- For pain relief, take Tylenol® or Extra Strength Tylenol® every 4-6 hours as instructed on the bottle.
- Wear a tight-fitting bra or sports bra for 48 hours, including overnight.
- Do not participate in strenuous activities for at least 48 hours.
- Keep the breast and biopsy site dry for 24 hours.
- Remove the gauze and paper tape after 24 hours.
- Shower after 24 hours, but do not scrub or rub the biopsy site. Gently pat the site dry.
- Any medications that were discontinued for the biopsy may be resumed in 48 hours.
- Remove Steri-Strips™ on the 4th day after the biopsy.

For 3 Days:

- No heavy lifting with the arm on the side of the biopsy.
- No aspirin, vitamin E, or ibuprofen.
- No Band-Aids® covering the site of the biopsy.

For 7 Days:

- Do not soak the breast in a bath tub, swimming pool, or hot tub.
- Do not participate in vigorous activities that stretch and bounce the breast, such as jogging.

Test Results:

- The final results of the biopsy will be sent to the referring physician. You will be contacted by your physician to discuss biopsy results and follow-up recommendations.
- You should receive biopsy results within 4 working days. Feel free to call the office where the procedure was performed if you haven't received results within that timeframe.

APPENDIX C

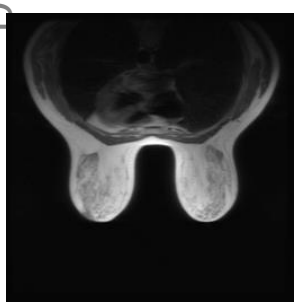
Below are examples of protocols utilizing dynamic sagittal imaging. As all protocols are site-dependent, other facilities may choose to perform dynamic imaging in another plane. Regardless of the imaging plane chosen, imaging protocols must meet the American College of Radiology imaging standards.

Protocols courtesy of Fairfax Radiological Consultants, Fairfax, VA.

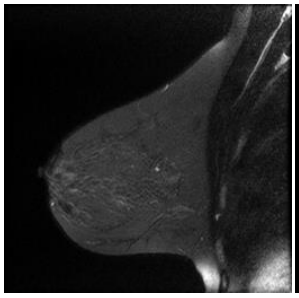
SAMPLE BREAST MR IMAGING PROTOCOL

	Localizer	Calibration	Right/Left T2W FAT SAT	Parallel Imaging T1W Non-FAT SAT	Parallel Imaging T1W Pre/Post	Parallel Imaging T1W Post-FAT SAT
Plane	3-Plane	Axial	Sagittal	Sagittal	Sagittal	Axial
FSP	SSFSE	Fast GRE	FSE-XL	Parallel Imaging	Parallel Imaging	Parallel Imaging
TR	MIN		~5000	SET	SET	SET
TE/TI	MIN		85	IN-PHASE	IN-PHASE	IN-PHASE
ETL/FLIP			14	10	10	10
RBW	83		21	32	42	42
FOV	38	48	~20	~20	~20	~32
Slice TK/ SKIP	7	8	4/1	3mm	3mm	3mm
Matrix	256x192		256x192	320x256	384x224	384x350
NEX	1		2	1	1	1
Slices	15/12/3	46	~26	100	500	100
Options			FAT SAT, PURE, NPW	NPW, ASSET, PURE	NPW, ASSET, FAT SAT	PURE, FAT SAT

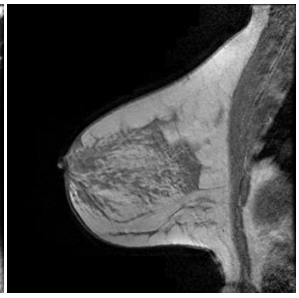
Right and left sagittal T2 FSE are done separately. Sagittal FAT SAT parallel imaging pre/postcontrast done with multiphase imaging. 5 phases total – 1 pre/4 postcontrast. Keep scan times on dynamic sagittal parallel imaging pre/postcontrast scans ≤ 2 minutes. To increase scanning area, increase slice thickness, not number of slices.



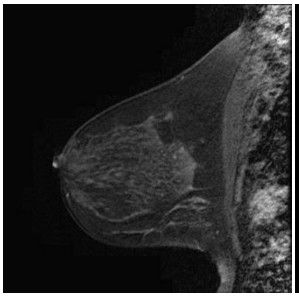
3-plane Localizer



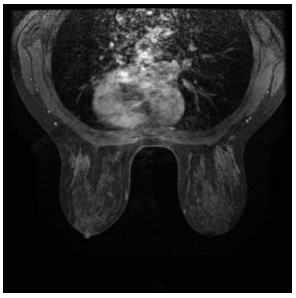
T2W FAT SAT
Fast Spin-Echo



Precontrast
TW1 Non-FAT SAT



Postcontrast
T1W FAT SAT



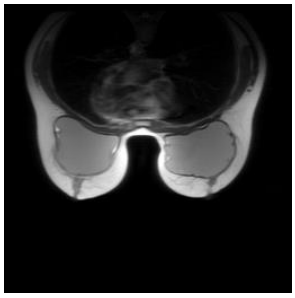
Postcontrast
T1W FAT SAT

Unless otherwise noted, all images are courtesy of Fairfax Radiological Consultants.

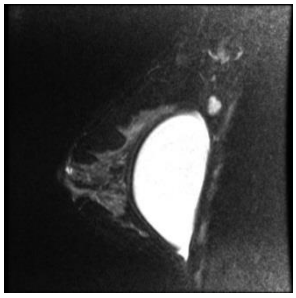
SAMPLE BREAST SILICONE IMPLANT PROTOCOL

	Localizer	Calibration	Right/Left STIR	Right/Left STIR WAT SAT	STIR WAT SAT	STIR	Parallel Imaging Non-FAT SAT
Plane	3-plane	Axial	Sagittal	Sagittal	Axial	Axial	Sagittal
PSD	SSFSE	Fast GRE	FSE-IR	FSE-IR	SE-IR	FSE-IR	Parallel Imaging
TR	MIN		~8000	~8000	~7500	~7500	SET
TE/TI	MIN		50/150	50/150	50/150	50/150	IN-PHASE
ETL/Flip Angle			12	12	12	12	
RBW	83		32	32	32	32	32
FOV	38	48	~20	~20	~32	~32	~20
Slice TK/SKIP	7	8	4/1	4/1	4/1	4/1	3mm
Matrix	256x192		320x160	256x192	256x192	320x224	320x256
NEX	1		2	1	1	1	1
Slices	15/12/3	46	~26	~26	~30	~30	100
Options			NPW, FC, PURE	NPW, FC, PURE, WAT SAT	NPW, FC, PURE, WAT SAT	NWP, FC, PURE	NPW, ASSET, FSE/TSE

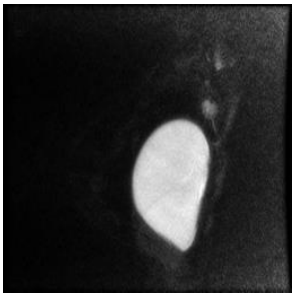
This protocol is done only if looking for a silicone implant rupture. If scanning for a breast mass with a questionable implant rupture, add sagittal parallel imaging FAT SAT pre/post-sequence and axial parallel imaging postcontrast sequence to this protocol. Left and right STIR series should be done separately.



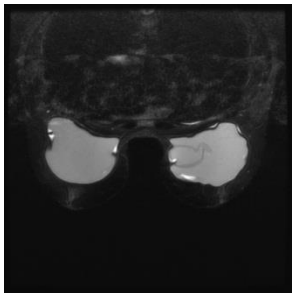
3-plane Localizer



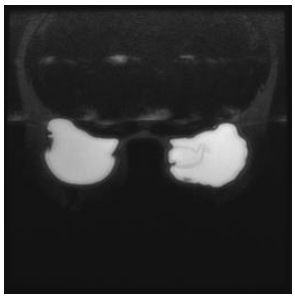
Sagittal IR



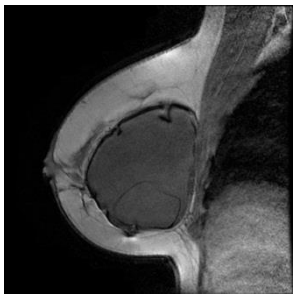
Sagittal WAT SAT IR



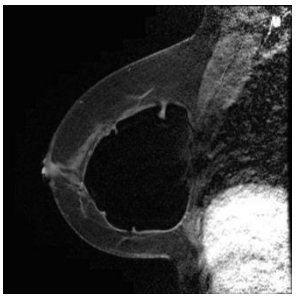
Axial IR



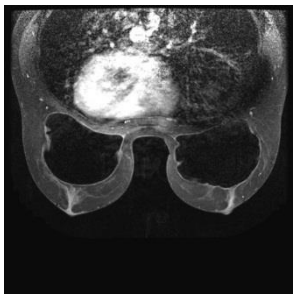
Axial WAT SAT IR



Non-FAT SAT 3D parallel T1W



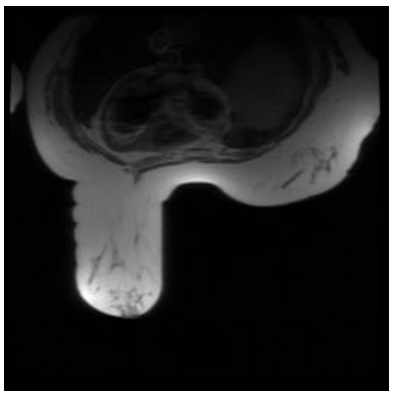
Sagittal FAT SAT 3D parallel T1W



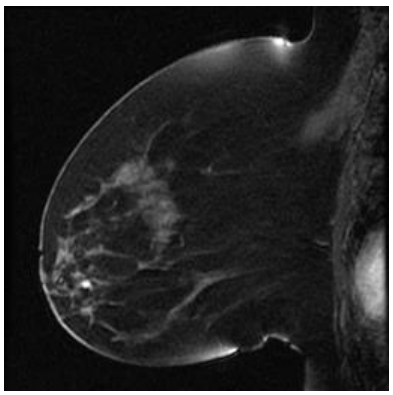
Postcontrast axial FAT SAT 3D parallel T1W

Unless otherwise noted, all images are courtesy of Fairfax Radiological Consultants.

SAMPLE BREAST MRI-GUIDED BIOPSY PROTOCOL				
	Localizer	**3D FAT SAT**	**Optional SPGR**	**Optional Non-FAT SAT**
Plane	3-plane	Sagittal	Axial	Sagittal
PSD	SSFSE	FSPGR	FSPGR	FSPGR
TR	MIN	--	--	--
TE/TI	MIN	IN-PHASE	IN-PHASE	IN-PHASE
ETL/Flip Angle		30	30	30
RBW	83	32	32	32
FOV	38	20	20	20
Slice TK/SKIP	5mm	3mm	3mm	3mm
Matrix	256x192	192x160	192x160	192x160
NEX		1	1	1
Options	12/12/3	NPW, FAT SAT	NPW, FAT SAT	NPW
# Slices		~18	~18	~18



3-plane Localizer



FAT SAT T1W

LEGEND

Asset	Array Spatial Sensitivity Encoding Technique
FC	Flow Compensation
NPW	No Phase Wrap
PURE:	Phased array Uniformity Enhancement
FSE/TSE	Fast or Turbo Spin echo

Unless otherwise noted, all images are courtesy of Fairfax Radiological Consultants.

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4. American Cancer Society website. American Cancer Society recommendations for early breast cancer detection in women without breast symptoms. Available at: http://www.cancer.org/cancer/breastcancer/moreinformation/breastcancerearlydetection/breast-cancer-early-detection-acs-recs. Accessed February 10, 2014.

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GLOSSARY OF ABBREVIATIONS

ACR	American College of Radiology
ACR	American Cancer Society
ADH	atypical ductal hyperplasia
ALH	atypical lobular hyperplasia
BI-RADS®	Breast Imaging Reporting and Database System
BMRI	breast magnetic resonance imaging
BRCA	breast cancer genetic mutation
DCIS	ductal carcinoma *in situ*
DIEP	deep inferior epigastric perforator
FOV	field-of-view
FSE	fast spin echo
GBCA	gadolinium-based contrast agent
GFR	glomerular filtration rate
HRT	hormone replacement therapy
IR	inversion recovery
IDC	invasive or infiltrating ductal carcinoma
LCIS	lobular carcinoma *in situ*
mm	millimeter
MRBX	MR-guided biopsy
NME	non-mass enhancement
NSF	nephrogenic systemic fibrosis
SSFSE	single-shot fast-spin echo
T	tesla
TSE	turbo spin echo
TRAM	transrectus abdominis myocutaneous flap

GLOSSARY OF TERMS

abscess
a collection of pus within a tissue that usually causes swelling and inflammation and often due to an infection

alveoli
milk-producing gland; also lobule

anaphylactoid reaction / anaphylactic / anaphylaxis
a systemic or generalized hypersensitivity reaction from exposure of a sensitized individual to a specific antigen, like shellfish, nuts, or penicillin, which otherwise are harmless to non-sensitized individuals. Unlike an allergic reaction, anaphylaxis can result in complete airway obstruction, shock, and even death. An *anaphylactoid* reaction resembles anaphylaxis but does not involve an immunological mechanism; sometimes called *pseudoanaphylactic*.

areola
the pigmented area around the breast nipple

axilla, axillary tail
the area under the arm; the axillary extension of the breast tissue that extends into the underarm

background enhancement
normal enhancement within the breast parenchyma; associated with hormonal changes such as menstrual cycle, hormone replacement therapy, and hormone chemotherapy

Bannayan-Riley-Ruvalcaba syndrome
a genetic condition characterized by a large head size (macrocephaly), multiple noncancerous tumors and tumor-like growths called hamartomas

BRCA (breast cancer) mutation/testing
BRCA1 is a tumor-suppression gene; BRCA 2 is a Type 2 susceptibility protein; carriers of either genetic mutation are predisposed to develop both breast and ovarian cancers

contralateral
relating to the opposite side

Cooper's ligaments
bands of ligaments on the chest wall that support the breasts

Cowden syndrome
A disorder characterized by multiple noncancerous, tumor-like growths called hamartomas and an increased risk of developing certain cancers

cyst
an abnormal sac that contains gas, fluid, or semi-solid material

deep inferior epigastric perforator (DIEP)
surgical reconstruction of the breast where tissue and fat are taken from the abdomen leaving the abdominal muscle intact, unlike in a TRAM procedure

ductal carcinoma *in situ* (DCIS)
the most common form of non-invasive breast cancer, which develops in the lining of the milk ducts; DCIS is considered precancerous and is generally treated surgically and with radiation therapy

false negative
an incorrect test result due to the test's not recognizing an existing condition or finding; a result that appears to be negative when in fact is it positive

false positive
the presence of a condition that does not exist

fat saturation
also known as fat-sat or fat suppression, a method to reduce or eliminate the effects of fat on MR images

fibroadenoma
a common benign finding on breast MRI characterized by a smooth margins and round or oval in shape

fibrocystic change
the change in cell characteristics of glandular tissue of the breast due to normal hormonal fluctuations during the menstrual cycle; can result in breast tenderness, pain, and lumpiness

fiducial
a fixed point of reference of comparison; in MRBX, a fiducial is place near the expected region of the abnormality

focus
in breast imaging, a dot-like area of enhancement <5mm in size; plural of focus is *foci*

glomerular filtration rate (GFR)
volume of blood that passes through the kidney's filters (glomeruli) each minute

gynecomastia
tissue enlargement of the male breast, usually hormone induced

hamartoma
"breast within a breast"; a rare, benign lesion that consists of fat, connective tissue, and glandular tissue

hematoma
a circumscribed collection of blood in a tissue or organ and usually clotted

in situ
literally, within position. When used in the context of cancer, *in situ* means that malignant cells are present within the tumor but have not spread or metastasized outside the tumor wall

inflammatory cancer
an aggressive breast cancer that often involves more than half the breast and infiltrates the skin and mammary tissues

inframammary fold
the natural boundary where the lower breast and chest meet

invasive ductal carcinoma (IDC)
the most frequently encountered cancer on BMRI; IDC develops in the ducts, infiltrating the duct membrane and surrounding tissue

inversion recovery (IR)
pulse sequence characterized by an initial 180° RF inversion pulse

lactation
production of milk

Li-Fraumeni syndrome
a rare disorder that greatly increases the risk of developing several types of cancer, particularly in children and young adults. The cancers most often associated with Li-Fraumeni syndrome include breast cancer, a form of bone cancer called osteosarcoma, and cancers of soft tissues (such as muscle) called soft tissue sarcomas.

lobular carcinoma
an invasive or infiltrating cancer that begins in the mild-producing glands and spreads in a web-like pattern; lobular cancer *in situ* is not considered cancerous and can be described as a neoplasia; also called lobular neoplasia

lobule
milk-producing gland; also called alveoli

mass
in breast imaging, a space-occupying lesion >5mm

mastitis
inflammation or infection of the breast that results in pain, swelling, warmth, and redness; most commonly occurs in women who are breast-feeding

medullary breast cancer
a subtype of ductal carcinoma that appears similar to a fibroadenoma and requires careful pathological consideration

mucinous cancer
a subtype of ductal cancer that appears similar to a fibroadenoma and requires careful pathological consideration

multicentric cancers
tumors located in multiple quadrants of the same breast

multifocal tumors
cancers with multiple lesions in the same quadrant of the breast

neoadjuvant therapy
therapy given prior to surgery, for example, radiation therapy or chemotherapy to help shrink the tumor before the procedure

neoangiogenesis
formation of a new blood supply that feeds tumor growth

nephrogenic systemic fibrosis (NSF)
a rare but potentially serious condition that has been associated with the use of gadolinium-based contrast agents in patients with kidney disease

non-mass enhancement (NME)
abnormal findings associated with malignant tissue that is not characterized by typical malignant features such as irregular shape, irregular margins, heterogeneous enhancement, and wash-out kinetics

obturator
plastic targeting device inserted through a biopsy sheath that is MRI compatible

Paget's disease of the breast
a condition that outwardly can present like eczema and is indicative of underlying breast disease

papilloma
a benign tumor that occurs along the milk ducts and can present as benign nipple discharge

parallel imaging
a reduced dataset in the phase-encoding direction(s) of *k*-space acquired to shorten acquisition time, combining the signal of several coil arrays. The spatial information related to the phased-array coil elements is used for reducing the amount of conventional Fourier encoding; allows for simultaneous imaging of both breasts

parenchyma
the specific tissue of an organ as opposed to connective or supporting tissue

peau d'orange
an orange peel appearance due to edematous, thickened skin overlying diseased tissue. The edema results from stromal (connective tissue) infiltration and lymphatic obstruction

pedicle
in breast reconstruction, an area of triangular tissue formed from part of the rectus abdominis muscle that is moved from the abdominal wall during transrectus abdominis myocutaneous flap breast reconstruction surgery

phyllodes
generally a benign breast mass, although phyllodes can be malignant; resembles a fibroadenoma

proteinaceous
resembling a protein

sensitivity
the ability of an imaging technique to determine whether there is pathology

septation
division into parts by a septum

seroma
fluid-filled surgical cavity

specificity
the ability of an imaging technique to determine the specific pathology of tissue

transrectus abdominis myocutaneous flap (TRAM)
surgical reconstruction that uses the rectus abdominis muscle to supply blood to the fat and tissue used to form a new breast

water saturation
also water-sat or water suppression, a method that eliminates or reduces the water signal on MR images