# Breast MR

BY TERESA G. ODLE, B.A.

*Use of magnetic resonance (MR) imaging to evaluate the breast has steadily progressed along with technological advancements and the discovery of the procedure's high sensitivity. As innovations continue in MR protocols, standardized terminology and applications of breast MR, the use of the technology to diagnose and treat breast disease will increase.*

*This article is a Directed Reading.*

**After completing this article, readers should be able to:**

- *Understand the use of breast magnetic resonance (MR) in diagnosing and treating breast cancer.*
- *Know MR imaging principles and components.*
- *Know the basics of breast MR technique.*
- *Discuss the role of radiologic technologists in breast MR.*
- *Define basic safety terms related to the MR environment.*
- *Recognize the presentation of breast cancer lesions and benign findings on breast MR images.*

Conventional mammography and sonography have been used to detect and localize breast disease.[1] In the past decade, increased use of magnetic resonance (MR) imaging and introduction of contrast-enhanced MR have established breast MR as a useful tool in the screening and diagnosis of breast disease.[2-4]

Early detection of malignancy and differentiation from other breast diseases are characteristics of imaging's role in breast cancer. Though mammography is well established as the most effective imaging method for breast cancer screening, reports have been published of mammograms missing 10% to 30% of all breast cancers.[5,6] Although MR sensitivity is high for detecting breast cancer, the technique's specificity varies.[6] The use of MR in breast imaging has increased over time. Originally used to image breast implant ruptures, breast MR is now used as a breast cancer screening tool to verify characteristics of lesions detected by mammography or ultrasound, to assess treatment effectiveness and to guide breast biopsies.[3,7-9]

Breast MR plays a critical role – one that likely will continue to evolve – in breast cancer diagnosis and treatment. Combined use of mammography, clinical breast examination and breast MR generally represent the most accurate diagnostic approach to breast cancer.[10]

## History of Breast MR

MR imaging was first introduced for clinical use in the early 1980s; the breast was one of the first anatomic regions imaged by MR.[7,11] Its noninvasive nature and high-contrast imaging of soft tissues sparked a great deal of interest in the imaging community for its ability to diagnose tumor malignancy, as well as other applications.[5,6] When contrast enhancement was introduced, MR's sensitivity for breast cancer increased. MR also can create 3-D images and better image dense breasts.

The early advantages of breast MR touched off a wave of clinical studies in the 1990s that demonstrated expanded value for the technique. As of December 2005, use of breast MR has been studied in more than 20 000 patients in Europe and the United States.[6] MR is believed to be the most sensitive method for detecting breast cancer,[6,12] though reported

specificity for the technique is lower, varying from 37% to 97%.[12] Studies also reported detection of lesions – particularly invasive cancer – through breast MR that were not identified by clinical examination, mammography or ultrasound.[4]

The increased use of breast MR also has led to MR guidance for breast biopsy, with manufacturers and researchers working to improve guidance techniques and equipment.[3,13] Though some debate continues on the effectiveness of breast MR for screening purposes – and positive indications for its use continue to occur – further advances in MR technology may lead to widespread acceptance of its role in diagnosing and managing breast disease.[9,14-16]

## Benefits of Breast MR

Mammography has improved breast cancer screening and detection and improved treatment options and survival rates.[17] Together, mammography and sonography are the most widely used techniques for detecting and diagnosing breast cancer.[18]

But mammography is not perfect. It is estimated that 10% to 15% of all tumors are not visible on mammography. The procedure carries a false-negative rate of up to 20%, and the limitations of mammography in women with dense breasts are well documented.[17,19,20]

Diagnosing and treating breast cancer can require repeat imaging. Drawbacks to repeated mammography include discomfort, radiation exposure, the inability to distinguish tumor from dense glandular and fibrous tissue, poor tumor border demarcation, and geometric distortion from compression and magnification that can affect accuracy of tumor volume measurements. Though sonographic measurement is better than mammographic measurement, it is not effective if the mass is larger than the field of view or complex in shape.[19,21]

MR imaging of the breast – also called MR mammography – is noninvasive and uses no ionizing radiation.[18,22] Its primary benefit is high sensitivity. Studies conducted the past 20 years have reported sensitivity for breast MR ranging from 95% to 99%, the highest of any imaging technique for breast lesions.[8] MR offers high soft-tissue contrast, multiplanar sectional imaging and 3-D rendering of 1 or both breasts, the ability to detect small volume residual tumor and measurement of lesion size that corresponds with pathological measurement.[18,21]

Use of dynamic contrast-enhanced MR helps to noninvasively image the microvascular network of tumors to determine if they are benign or malignant and to map functional parameters of breast lesions. Vascular or metabolic parameters provide information on a tumor's early response to treatment so that treatment can be adjusted.[21,22]

As breast MR protocols are refined, the benefits and indications of the technique will increasingly aid in the diagnosis and management of breast cancer. The use of dynamic MR imaging, along with conventional mammography and ultrasound, is improving the timely diagnosis of breast cancer.[18,23,24]

## Challenges of Breast MR

Widespread acceptance of breast MR has been delayed by challenges and drawbacks to the technique. Of primary concern is a lack of specificity shown in many studies. This low specificity can result in high false-positive rates, leading to unnecessary biopsies.[25] Current efforts aim to increase specificity with standardized reporting (lexicons) and feature recognition, as well as the development of techniques to improve differential diagnosis.[23,26] Specificity is higher in select breast care centers.[20]

Cost also has been cited as a drawback of breast MR, at least when compared with mammography and ultrasound.[6] Beyond improving positive predictive values for biopsies, improving specificity also would improve breast MR's cost effectiveness.[27] The widespread growth of breast MR also has been constrained by limited commercial availability of MR-guided needle biopsy systems, which are now more widely available.[3,6]

## MR Basics

Originally termed nuclear magnetic resonance, or NMR, MR became the common term due to concerns that the term "nuclear" meant radioactivity or fission. On the contrary, MR involves no ionizing radiation. Further, no known adverse effects result from the technique's strong magnetic fields or radiofrequency (RF) pulses.

### *Physical Basis of MR*

MR relies on the principle that certain nuclei possess minute magnetic properties. The nuclei rotate when a magnetic field is applied. This motion and alignment is referred to as precession. Spin is a fundamental property of certain nuclei, particularly hydrogen nuclei. Nuclear precession results from a complex relationship between the "magnetic moment" of the nucleus and its intrinsic spin.

The magnetic moment of a nucleus derives from its spin. The proton has a charge and spins on its axis. This induces nuclear magnetism and is referred to as the magnetic moment, or μ, so the moment orients to the spin

axis. Any change in direction requires reorienting the spin axis. When a patient is placed in the main magnetic field of the MR scanner, most of the nuclei (magnetic moments) line up parallel to the direction of the main magnetic field, producing a net magnetization vector.

The protons begin to precess, or wobble. Picturing a spinning top that continues to spin in the face of gravity provides an example. The top also has a slow wobble about its vertical. Like the spinning top, a nucleus will not simply swing into alignment when subjected to a magnetic field, but precess about the direction of the field. The precession is due to the main magnetic field acting on the spinning momentum of the nuclei.

The Larmor frequency refers to the frequency at which the nucleus precesses about the magnetic field. Its value is proportional to the magnetic field's strength, or tesla (T), and the gyromagnetic ratio of the nucleus. Hydrogen is the most important element in MR because it is abundant throughout the body in water and fat. Some elements, such as oxygen 16, do not exhibit magnetic resonance because their nuclei have no net spin.

Radiofrequency excitation occurs when a transverse oscillating magnetic field is applied to the tissue at exactly the same Larmor frequency. The nuclei precess at the same time and emit a detectable signal. To reach a higher energy or excited state, nuclei must absorb radiofrequency photons equal to the Larmor frequency. When the nuclei decay back to their initial states, or relax, they emit photons of the same frequency.

An MR signal is called free induction decay (FID). The decay is rapid after magnetization, though different tissues have different relaxation times, which result in signal contrast on the images. In MR imaging, the transverse relaxation time constant is referred to as T2. The time constant for nuclei to align themselves with the external or main magnetic field is T1, or longitudinal relaxation time.

As spins continue to process, they gradually come back into phase and produce a brief signal recovery. This is known as a spin echo; the time taken for the spins to rephase is equal to the time taken for them to dephase. When these times are added, the total is called echo time or TE. Spin echo and FID techniques are used to acquire images. A longer delay allows more time for T2; tissues with short T2 will appear darker, while those with long T2 will appear brighter. The brighter images are referred to as T2-weighted images.[28-30]

*MR Components*

The MR scanner's central component is a primary magnet that produces the stationary magnetic field ($B_0$). The magnetic field strength is measured in gauss (G) or T; 1 T = 10 000 G. The earth's magnetic field is about 0.5 G.[28] MR magnet field strengths vary, but most breast MR exams today are conducted on units ranging from 1.0 T to 3.0 T.[28,31,35]

Gradients are weaker, changing magnetic fields that can be used to adjust for linear variation to localize voxels within the slice. Gradient coils are positioned in the main magnet. RF coils are positioned within the magnet close to the patient and may be used to transmit and/or receive pulses. Surface RF coils detect signals from the region of interest and are designed to match the size and shape of anatomy under study.

The final major component of MR imaging is a computer system. The system interfaces with other equipment to acquire images, automate and digitize data/signal reconstruction and assist in image storage, retrieval, display and analysis. The computer connects to the operating console and also allows image transmittal to an image display/interpretation workstation.[28,30] An MR system also may interface with other hospital or radiology information systems for image and report transmittal to referring physicians.

## Indications for Breast MR

Breast MR has been used primarily as a diagnostic tool following clinical breast examination and mammography, not as a breast cancer screening tool.[32] For many years, the technique has been surrounded by controversy concerning its accuracy, necessity and cost effectiveness as a screening tool.[32,33] MR is one of the most expensive imaging examinations in terms of both technology and resources, such as examination time, contrast and postprocessing. Though its superior sensitivity over mammography or ultrasound in imaging dense breast tissue would help detect lesions early in younger women, the incidence of breast cancer in this age group is low – less than 1 in 10 000. MR is not considered practical as an approach to widespread screening of asymptomatic patients.[6,9]

On the other hand, breast MR, once considered useful only for imaging breast implants, has come a long way in recent years. In 2003, the American Cancer Society (ACS) updated its screening guidelines, adding that emerging data suggest that additional screening with ultrasound or MR may benefit certain patient populations, namely high-risk patients.[17] The role of MR as a screening tool for younger women with dense breasts may evolve in the future.[11]

At the 2006 American Society of Breast Disease annual

meeting, Alan Hollingsworth, M.D., medical director of Mercy Women's Center in Cedar Rapids, Iowa, reported on the success of a strategy that uses breast MR to screen women at high risk for breast cancer and those with dense breasts.[34]

Until further research and debate resolve breast MR's screening use, the examination remains a valuable adjunct to conventional mammography. The American College of Radiology (ACR) developed a practice guideline in 2004 for the performance of MR imaging of the breast.[35] The guideline states that breast MR is "a useful tool for the detection and characterization of breast disease, assessment of local extent of disease, evaluation of treatment response and guidance for biopsy and localization." The guideline lists 12 indications for breast MR, adding that they are not limiting; the decision is at the discretion of the medical provider based on correlation with clinical history, physical examination and other imaging examination results.[35] The 12 ACR indications are:

- Lesion characterization.
- Neoadjuvant chemotherapy (before, during and after).
- Infiltrating lobular carcinoma.
- Infiltrating ductal carcinoma.
- Axillary adenopathy, primary unknown.
- Postoperative tissue reconstruction.
- Silicone and nonsilicone breast augmentation.
- Invasion deep to fascia.
- Contralateral breast examination in patients with breast malignancy.
- Postlumpectomy for residual disease.
- Surveillance of high-risk patients.
- Recurrence of breast cancer.

The recommendations are based largely on clinical trials and the proven sensitivity of MR imaging.[35] Standard practice generally follows the policies and guidelines of organizations such as the ACR and the American Society of Breast Disease, though debate and advances continue to shape the everyday use of breast MR in breast cancer diagnosis and management.[9,20,32]

### *High-risk Patients*

Although the ACR guideline does not support use of breast MR for widespread cancer screening in the general population, the guideline recommends MR for patients with a genetic predisposition to breast cancer. The ACR clarifies that patients should be referred for breast MR surveillance after genetic counseling by experts in hereditary breast cancer.[35]

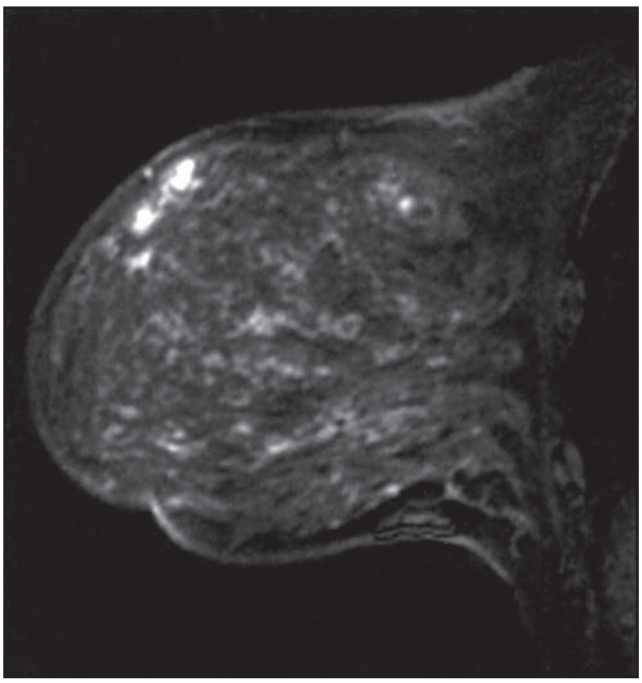


**Fig. 1.** *Screening breast magnetic resonance (MR) image of a 49-year-old woman at high-risk for breast cancer. Sagittal T1-weighted contrast-enhanced MR of right breast shows focal-clumped enhancement superiorly. MR-guided needle localization and surgical excision yielded invasive lobular cancer (0.7 cm). (Reprinted with permission from: Bartella L, Liberman L, Morris EA, Dershaw DD. Nonpalpable mamographically occult invasive breast cancers detected by MRI.* AJR Am J Roentgenol. *2006;186:866.)*

Women with a strong family history of breast cancer or who have a high probability of a BRCA1, BRCA2 or TP53 mutation are more likely to have breast cancer at a younger age than women in the general population.[33] (See Fig. 1.) Women with a BRCA mutation have a lifetime risk for breast cancer as high as 80%; those already diagnosed with breast cancer have a 60% chance of developing a second primary breast cancer.[36] Only a laboratory test can verify that a woman carries the genetic mutations, but epidemiologic studies confirm traits associated with carriers of the genes, including having 2 or more relatives with breast or ovarian cancer, having a relative younger than 50 with breast cancer, having relatives with both breast and ovarian cancer, having 1 or more relatives with 2 cancers (eg, both relatives had cancers of the breast or breast and ovarian cancer), having a male relative with breast cancer, having a family history of breast or ovarian cancer and being of Ashkenazi Jewish heritage.

Table 1
**Diagnostic Sensitivities for Imaging Modalities in Various Risk Categories**[36]

| | Mammography | | Ultrasound | | Mammography And Ultrasound | | Magnetic Resonance (MR) | | Mammography And MR | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sensitivity (%) | TP/TP +FN | Sensitivity (%) | TP/TP +FN | Sensitivity (%) | TP/TP +FN | Sensitivity (%) | TP/TP +FN | Sensitivity (%) | TP/TP +FN |
| All women | 32.6 | 14/43 | 39.5 | 17/43 | 48.8 | 21/43 | 90.7 | 39/43 | 93.0 | 40/43 |
| With personal history of breast cancer | 33.3 | 4/12 | 41.7 | 5/12 | 41.7 | 5/12 | 66.6 | 8/12 | 75.0 | 9/12 |
| Without personal history of breast cancer | 32.3 | 10/31 | 38.7 | 12/31 | 51.6 | 16/31 | 100.0 | 31/31 | 100.0 | 31/31 |
| Risk 20% | 50.0 | 3/6 | 67.7 | 4/6 | 83.3 | 5/6 | 100.0 | 6/6 | 100.0 | 6/6 |
| Risk 21% to 40% | 25.0 | 5/20 | 30.0 | 6/20 | 45.0 | 9/20 | 100.0 | 20/20 | 100.0 | 20/20 |
| Mutation carriers | 25.0 | 2/8 | 25.0 | 2/8 | 37.5 | 3/8 | 100.0 | 8/8 | 100.0 | 8/8 |

*Abbreviations: MR - magnetic resonance imaging, TP - true positive diagnoses (no. of cancers detected); FN - true positive and false-negative diagnoses (total no. of cancers).*

ACS screening guidelines suggest clinical breast examination and screening mammography beginning at age 30 or younger for carriers of BRCA mutations, along with the options of shorter screening intervals and the addition of MR or ultrasound screening.[37] These women have denser breasts, which are better imaged with MR than with conventional mammography.[33]

Several clinical studies have been conducted to assess the effectiveness of MR screening in high-risk populations. Kuhl et al[36] performed annual surveillance on 529 asymptomatic women considered at high risk based on family history and/or mutational analysis. The protocol for annual surveillance included clinical breast examination, ultrasound, conventional mammography and breast MR. Participants were followed for an average of 5.3 years.

A total of 43 breast cancers were identified in the cohort. Breast MR demonstrated significantly higher sensitivity than mammography, ultrasound or the combination of both, leading the authors to conclude that MR use in surveillance of women at high risk for breast cancer achieves diagnosis of intraductal and invasive cancer with higher sensitivity at a more favorable stage.[36] (See Table 1.)

The multicenter Magnetic Resonance Imaging for Breast Screening (MARIBS) trial in the United Kingdom recruited participants at high risk for breast cancer from 22 centers in the United Kingdom and offered annual screening with contrast-enhanced MR for 2 to 7 years. They found the technique more sensitive than mammography for cancer detection and concluded that specificity for both procedures was acceptable. By combining their results with similar studies, the authors concluded that a combination of contrast-enhanced MR and mammography provides the most effective screening examination for high-risk patients.[33]

*Patients With Dense Breasts*

About 25% of breast cancers occur in women aged 50 years and younger. Cancers occurring in premenopausal women with dense breasts are associated with poorer prognoses, as their cancers usually are detected at

advanced clinical stages.[11,38] Although conventional mammography sensitivity has been reported to range from 63% to 98%, sensitivity of the procedure in dense breasts has been reported as low as 30% to 48%. In 2004, Berg et al[10] reported that mammography sensitivity was inversely related to breast density in demonstrating invasive ductal carcinoma (IDC). Yet the extent of breast density does not appear to limit breast MR sensitivity.[15]

The ACR guideline for breast MR includes radiographically dense breasts as an indication for breast MR when other imaging examinations and physical examination are inconclusive for the presence of breast cancer.[35] At some women's clinics, the weight of the patient also is listed as an indication for imaging breast density.[34] The superior sensitivity of MR imaging in dense breasts makes it a useful tool not only in detecting lesions, but also in presurgical staging of detected cancer.[38]

*Breast Implant Evaluation*

The ACR guideline states that breast MR may be used to evaluate patients with breast implants and silicone injections if mammography will be difficult. The guideline also indicates use of MR for nonsilicone implants. Implants can limit evaluation of the breast by palpation and reduce mammography sensitivity, which may indicate the need for contrast-enhanced MR.[5,20]

MR is widely accepted as the diagnostic imaging technique of choice for breast implant rupture evaluation. (See Fig. 2.) MR has shown higher sensitivity than and similar specificity to ultrasound for detecting silicone implant rupture.[6,39] Silicone implant ruptures occur at a rate of about 2 per 100 implant years. For example, among a group of 25 women each having had silicone breast implants for 4 years, 2 of those implants are expected to rupture. A small percentage of implant ruptures can be detected by clinical examination, though breast pain at examination is a strong indication of rupture.[39]

Breast MR not only is useful for evaluating implant integrity and rupture, but also for diagnosing breast cancer in women with augmentation.[35] Liquid paraffin was used by physicians throughout the first half of the 20th century and largely abandoned by the 1970s. Patients can experience serious short- and long-term complications from paraffin injections. Although complications can occur within 2 years of the procedure, they may not present until decades later.[40]

*Occult Lesions*

Some local and invasive cancers are clinically and mammographically occult, but can be detected by more sensitive breast MR imaging.[6,12] Past studies have observed patients with unknown primary cancer and have demonstrated metastatic patterns that indicate a primary breast cancer is present, such as axillary node metastasis or distant metastasis consistent with breast cancer.[6,15] MR has diagnosed the primary malignancy in 80% to 100% of these studies, often when conventional mammography, ultrasound or clinical examination failed.[6]

Those primary cancers that have not been detectable by imaging or pathology have been treated by whole breast irradiation or mastectomy. Some primary tumors are so small that they are not detectable at serial sectioning after mastectomy. The ability to detect occult lesions with breast MR may potentially make breast conservation an option and improve biopsy capability.[15]

The ACR guideline for breast MR includes "axillary adenopathy primary unknown," noting that when no mammographic or physical signs of primary breast cancer are evident, MR can locate the primary tumor and define disease extent. Likewise, negative MR findings may exclude the breast as the primary site of cancer, helping to prevent unnecessary mastectomy.[35]

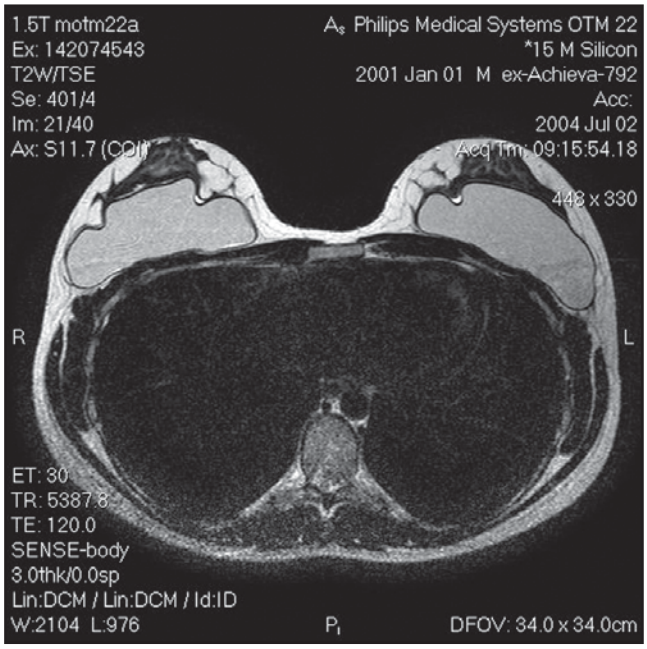



**Fig. 2.** *T2-weighted magnetic resonance bilateral study of silicon breast implants with sensitivity encoding (SENSE) imaging at 1.5 T field strength. This is image 22 of 40. (Image courtesy of Philips Medical Systems, Bothell, Wash.)*

*Contralateral and Ipsilateral Breast Evaluation*

Patients who have a history of breast cancer may develop a second cancer in the ipsilateral or contralateral breast simultaneously with the primary cancer or at a later date.[41] MR may detect an unsuspected second cancer in the ipsilateral breast in as many as 10% of women with recently diagnosed breast cancer and in the contralateral breast in 4% to 5% of patients.[35,42] (See Fig. 3.)

Certain types of breast cancer, such as invasive lobular carcinoma (ILC), have higher incidence of multicentric and contralateral presentation than other types.[25] Patients younger than age 55 also have an increased risk of contralateral breast cancer.[10] MR can be useful in identifying multifocal and multicentric disease of the ipsilateral or contralateral breast.[25,43] Though false-positive rates for MR in identifying multicentric disease are higher than for mammography, its sensitivity ranges from 89% to 100% for bilateral imaging to 95% to 100% for unilateral imaging.[6]

Several studies have shown the benefits of imaging the contralateral breast of patients with breast cancer. The ACR guideline includes contralateral breast evaluation of patients with breast malignancy among its indications, even when there are negative findings on mammography and physical examination.[35]

*Assessing Disease Extent and Staging Disease*

MR imaging can better correlate with pathology in determining the extent of breast cancer disease than other imaging methods.[10] Clinical assessment of a breast tumor often relies on mammography and ultrasound, which can underestimate tumor size or extent. Ultrasound assessment can be compromised by architectural distortion and ductal dilation, and mammography sensitivity can be particularly low for dense breasts. By comparison, MR imaging has been shown as the most accurate method to assess tumor size and to identify tumor foci in multifocal or multicentric disease.[38] For approximately 20% of women recently diagnosed with breast cancer, MR imaging has revealed more extensive disease than was originally detected.[42]

The accuracy of MR to depict size and extent of lesions and to detect multicentric disease has led to studies about MR's use in staging breast cancer. MR may have an impact on therapy decisions.[6] The ability of MR to define tumor borders can help spare healthy tissue, particularly as MR-guided wire localizations have become increasingly common.[9] The ACR guideline for breast MR states that the procedure may be used before chemotherapy to evaluate the extent of disease. The guideline indicates breast MR for evaluating extent, multifocality and multicentricity of ILC.

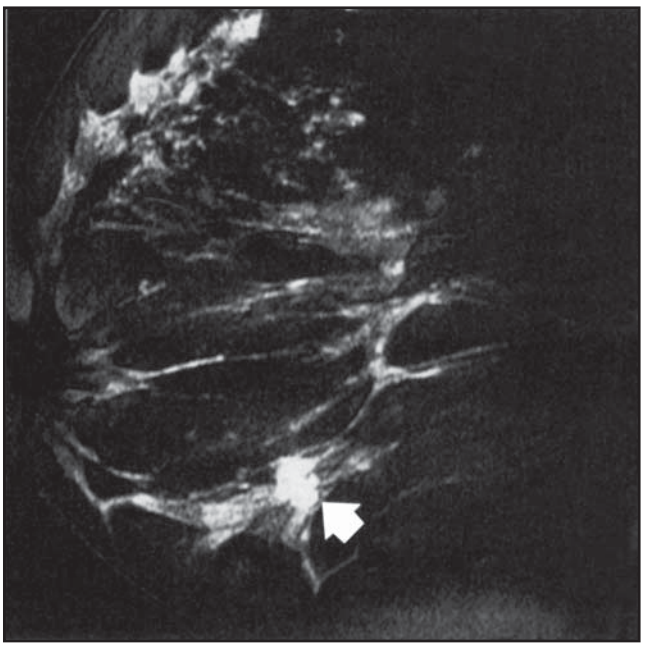


**Fig. 3.** *True-positive magnetic resonance (MR) finding. Fifty-three-year-old woman with newly diagnosed invasive cancer with ductal and lobular features in the left breast. Sagittal, gadolinium-enhanced fat-suppressed, spoiled 3-D gradient-echo MR image (18.2/2.1) of the right breast reveals an enhancing 1-cm mass (arrow) with irregular borders. Directed ultrasound (not shown) following MR imaging revealed a subtle ill-defined hypoechoic lesion best visualized at the 6-o'clock position. As the lesion was better visualized on MR imaging, an MR imaging-guided core biopsy was performed, which revealed well-differentiated invasive ductal cancer. The patient underwent a bilateral mastectomy procedure. (Reprinted with permission from: Lee SG, Orel SG, Woo IJ, et al. MR imaging of the contralateral breast in patients with newly diagnosed breast cancer: preliminary results.* Radiology. *2003;226(3):776.)*

The ACR guideline states that MR is more accurate than standard mammography and clinical examination at determining the extent of disease for infiltrating ductal carcinoma (IDC). The guideline says that MR may be necessary in evaluating IDC to determine disease extent, particularly in candidates for breast conservation surgery.[35]

When breast cancer involves the chest wall or pectoral muscle, it may not affect the staging, but may affect surgical therapy. MR imaging can detect invasion to muscles and tissues that might affect surgical therapy planning.[6,35] Nipple involvement also is important to surgical treatment plans and breast conservation surgery;

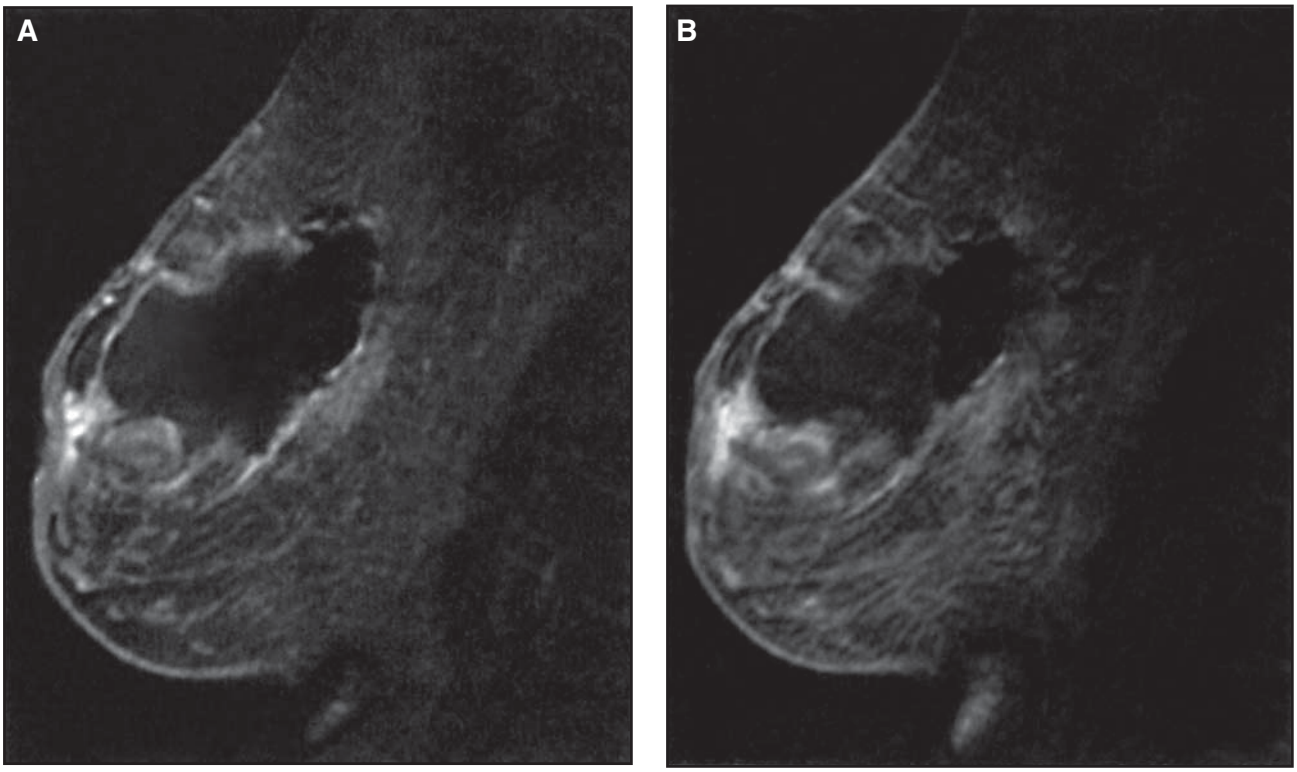



**Fig. 4.** *Sixty-four-year-old woman after left lumpectomy for invasive ductal carcinoma with positive surgical margins. A. Sagittal T1-weighted image from postoperative magnetic resonance (MR) of left breast immediately after contrast injection shows focal clumped enhancement in the anterior aspect of the seroma cavity. B. Delayed contrast-enhanced T1-weighted image from left breast MR shows clumped enhancement with persistent kinetics. Surgery revealed invasive ductal cancer at site. (Reprinted with permission from: Bartella L, Liberman L, Morris EA, Dershaw DD. Nonpalpable mammographically occult invasive breast cancers detected by MRI.* AJR Am J Roentgenol. *2006;186(3):869.)*

reports of up to 80% sensitivity on MR imaging for identification of nipple involvement have been published.[6]

The ACR guideline for breast MR recommends evaluation of deep invasion to fascia prior to surgical treatment in both mastectomy and breast conservation candidates. MR is used to define the relationship to the fascia, extension into pectoralis major or extension into serratus anterior and intercostal muscles.[35]

*Residual Disease*

If disease extent has not been fully determined prior to surgery, pathology specimens may demonstrate close or positive margins, indicating residual disease. MR also is useful for detecting residual disease after surgery or neoadjuvant therapy.[6,35]

The ACR guideline for breast MR states that the procedure may be indicated after lumpectomy for patients who did not have an MR examination prior to their surgery and whose pathology results indicated residual disease. (See Fig. 4.) MR can help determine which patients could be treated most effectively with re-excision and which patients might require mastectomy by evaluating multifocality and multicentricity.[35]

*Therapy Follow-up*

MR is useful for noninvasively assessing a tumor's response to chemotherapy and for monitoring local recurrence following therapy.[44] MR is sensitive for monitoring the disease before, during and after chemotherapy, radiation therapy and surgery and for evaluating the success of neoadjuvant therapy.[9] This is critical because local recurrences after breast-conserving therapy can cause distant metastases.[45]

Radiation-induced edema or fibrosis can mimic or obscure recurrence of breast cancer after radiation therapy. Breast MR has demonstrated high specificity in

differentiating tumor recurrence from fibrosis. In the past, breast MR was discouraged in the first few months after radiation therapy because of reports of contrast enhancement that was associated with radiation-induced inflammatory changes. However, studies later showed that these changes were less severe than expected and that they subsided sooner than reported. Refinement of diagnostic criteria to help distinguish benign from malignant features added to confidence in breast MR soon after radiation therapy.[45]

Just as contrast-enhanced MR imaging is the most accurate method for measuring tumor size and extent and depicting residual disease after therapy, several studies have shown MR excels at evaluating disease throughout chemotherapy treatment. Since neoadjuvant chemotherapy is used to reduce surgical requirements before surgery in patients with primary breast cancer, it is important to accurately measure its progress and the final pathologic response and volume of residual active disease.[46] Past trials have shown that proper use of MR may lead to alterations in treatment.[6,46]

The ACR guideline includes an indication for use of breast MR before, during and/or after a course of chemotherapy to evaluate chemotherapeutic response, as well as extent of residual disease before surgical treatment. The guideline states that MR-compatible localization tissue markers may be placed prior to the start of therapy in the event of complete response with no detectable tumor for resection.[35]

*Other Uses of Breast MR*

- MR ductography. Recently proposed as an alternative to conventional ductography, MR ductography uses a microscopic coil and is noninvasive. Conventional ductography does not provide enough information to distinguish benign and malignant lesions and requires insertion of a cannula and contrast material into the discharging duct. Breast MR can detect intraductal papilloma, but a conventional coil cannot detect small lesions; the use of a microscopic coil helps show distinguishable features of the disease.[47]
- Pregnancy and lactation. Pregnancy-associated breast cancer is diagnosed during pregnancy or up to 1 year after delivery; it is the most frequently diagnosed cancer during pregnancy. Mammographic sensitivity decreases during pregnancy and lactation because of an increase in parenchymal density, water content and glandularity of the lactating breast.[48] Espinosa et al[48] performed unilateral breast MR on 10 breasts in 7 lactating patients to describe their MR characteristics. They noted increased density in normal lactating glands; their findings suggested that MR imaging may be more reliable than conventional mammography in showing the extent of invasive cancers in lactating patients.[48]
- Male patients with breast cancer. Although rare – accounting for 1% of all breast cancers and less than 1% of cancers in men – male breast cancer has the same prognosis as breast cancer in women.[49,50] The most common cause of male breast cancer is gynecomastia. Most male breast cancer presents as IDC.[49] Mammographic and sonographic appearances of male breast cancers have been reported and are similar to those of female breast cancers. Little has been reported concerning male breast MR.[50] Use of MR imaging may or may not have an effect on the clinical management of male patients with breast cancer. A study by Shi et al[49] in 2005 reported that MR was the best imaging technique to help characterize the vascular nature of male breast cancer and to define the extent of involvement. MR's depiction of pectoral muscle involvement can aid in surgical planning.[49]

## Contraindications

Presence of ferromagnetic foreign bodies in critical areas of the body or ferromagnetic intracranial aneurysm clips, certain neurostimulators, certain cochlear implants and other ferromagnetic implants and devices may contraindicate breast MR. Cardiac pacemakers also may contraindicate the MR examination. The ACR guideline for breast MR states that contraindications or reference to published test results should be listed on a screening questionnaire. The ACR guideline also states that onsite testing of an identical device prior to the patient procedure may help determine if a patient can be safely scanned.

The decision to scan a pregnant woman must be made on an individual basis. There are no known effects of MR on the fetus, but gadolinium contrast has not been established as safe for pregnant women or nursing mothers.[35]

## Biopsy Guidance

The widespread adoption of MR has been held back to some extent by the limited commercial availability of MR-guided needle biopsy systems that allow practitioners to have matching correlates and tissue sampling for lesions detected only by MR.[3,6,12] As radiologists have worked to improve MR-specificity issues – and resulting

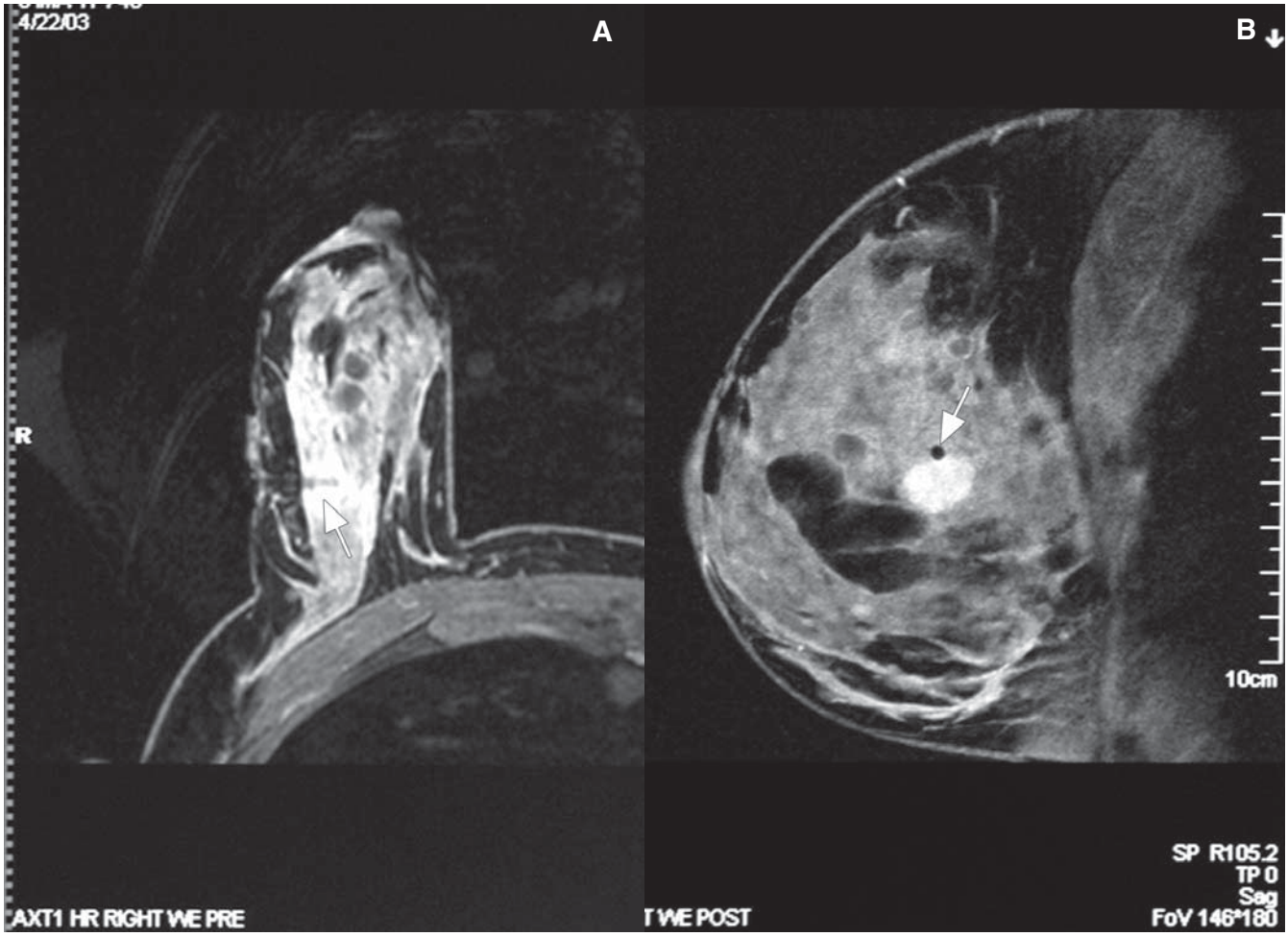



**Fig. 5.** *Vacuum-assisted breast biopsy. A. Prebiopsy image locates lesion (arrow). B. Contrast-enhanced image shows obturator tip (arrow) within mass. (Images courtesy of Suros Surgical Systems Inc., Indianapolis, Ind.)*

false-positive rates – they also have worked with manufacturers to develop MR-guided biopsy techniques.

Wire localization and surgical excision, or core biopsy, are biopsy techniques that have traditionally been used with MR. Dedicated breast coils also have been used.[3,13,26] Core-needle biopsy has not been as accurate as desired for the work-up of MR-detected lesions, largely because the patient cannot be examined while in a closed magnetic bore. The use of MR-compatible probes causes artifacts that can obscure the lesion.[13]

A new method of vacuum-assisted biopsy with MR-guidance is emerging as safe, effective and time-efficient.[3] Vacuum assistance helps acquire a larger tissue volume and reduces sampling error. Tissue shift from bleeding is avoided because blood is continuously suctioned.[13] The ATEC Breast Biopsy and Excision System (Suros Surgical Systems Inc., Indianapolis, Ind) includes a breast coil, a single-use introducer set, needle guide, a coaxial introducer sheath, a nonferrous inner stylet and a plastic localizing obturator. The localizing obturator will not produce an artifact, but appears as a black dot on the image in sagittal view to identify the sheath position. The tip of the obturator corresponds to the center of the sampling chamber.[3] (See Fig. 5.)

MR-guided vacuum-assisted biopsy is less time-consuming than open surgical biopsy combined with MR-guided needle localization. Results of a study by Perlet et al[13] conducted at 5 European centers using the Mammotome (Biopsys, Irvine, Calif) vacuum-assisted biopsy needle and MR guidance showed that successful biopsy was performed in 517 of 538 patients with no false-negative results in the successful biopsies. The

authors also reported that small lesion size was not a limitation of the procedure.[13]

Lehman et al[3] conducted a study of 38 biopsies with the ATEC system and reported no complications with any procedures. The average biopsy lasted 38 minutes.[3]

## Breast MR Technique

Technique is important to ensure sensitivity, specificity and overall effectiveness of breast MR procedures. Major considerations are field strength choice, ensuring proper resolution and contrast, scan time in relation to contrast injection and proper use of breast coils. The radiologic technologist's patient interaction and management also are important factors.[6,35] Breast MR offers many challenges in balancing volume, slice thickness and temporal vs spatial resolution. This occurs within the environment of patient safety and comfort considerations.[5,35]

### *Field Strength*

Historically, most breast MR examinations were performed with 1.0-T or 1.5-T magnets. Today, however, 1.5-T strength is the norm and 1.5 T or higher is preferred.[5,31,35] The ACR guideline on breast MR states that improvements in other components of the scanning process have improved scan quality at field strengths below 1.0 T. But higher-strength magnets produce better chemical fat suppression and offer better homogeneity.[35]

In fact, 3.0-T field strength further improves breast MR, particularly specificity. Pulse sequences that offer high spatial resolution images must be acquired in a short amount of time to obtain optimum arterial phase contrast between an enhancing lesion and adjacent enhancing fibroglandular tissue. These time constraints and signal-to-noise ratio (SNR) requirements limit the maximum spatial resolution that 1.5-T magnets can achieve.

At 3.0 T, an MR system offers a higher SNR, but it also produces physical effects that must be resolved before a quality image can be captured and interpreted. Kuhl et al[31] conducted contrast-enhanced breast MR on 37 women to establish a pulse sequence and compare MR imaging at the higher field strength with MR imaging of the same patients at 1.5 T. They found that the higher spatial resolution attained at 3.0 T helped improve the classification of 10 out of 51 lesions.[31]

The ACR guideline for breast MR states that "the synergy between field strength of 3.0 T, parallel imaging and phased array coils provides satisfactory spatial resolution when imaging both breasts. Therefore, higher field strength is preferred because of better fat suppression and decreased motion artifacts."[35]

### *Imaging Volume*

Standard breast MR may be unilateral or bilateral but requires imaging the entire breast to ensure depiction of the lesion in question from previous studies and to adequately depict potential signs of cancer in the axillary tail, chest wall and nipple. Gaps between slices should be avoided.[5]

### *Resolution and Image Contrast*

Capturing adequate resolution requires a pulse sequence that covers all of the breast volume and offers high spatial and temporal resolution.[5,23] The acquisition speed, or temporal resolution, directly competes with the demands of spatial resolution. Pulse sequences must make compromises between the 2 types of resolution to produce the optimum image. Standard dynamic bilateral protocols use temporal resolution of about 1 minute per dynamic acquisition.[23]

Speed is important to obtain postcontrast injection images within minutes.[6] Most breast MR procedures acquire 1 sequence of images before contrast injection and 3 sequences following injection.[12,51] Practitioners continue to publish investigations on balancing temporal resolution to allow for capturing these postcontrast sequences without sacrificing the spatial resolution demanded to adequately view thin slices and detail.[2,23] Acquisition strategies such as volume imaging for breast assessment, also known as VIBRANT, or sensitivity encoding (SENSE), are being tested in many clinical settings.[23]

The ACR guideline on breast MR recommends resolution high enough to avoid volume-averaging artifacts. The guideline suggests that slice thickness should be 3 mm or less and in-plane pixel resolution should be 1.5 mm or less.[35]

### *Contrast Enhancement and Fat Suppression*

Standard breast MR uses nonionic gadolinium contrast agents.[6,35] The contrast is administered intravenously, normally at a dose of at least 0.1 mmol/kg. The contrast will be followed by a saline flush. Before injecting contrast, a precontrast scan normally is obtained. Another scan is obtained immediately postcontrast (no more than 5 minutes after injection) to determine the presence of lesion enhancement. Other scans normally are obtained at specified intervals. Gadolinium contrast usually is not necessary in evaluating breast implants.[18,35]

A study by Medved et al[2] reported that high spectral and spatial resolution (HiSS) echo-planar spectroscopic imaging provided diagnostically useful breast images before contrast agent injection. (See Fig. 6.) Current

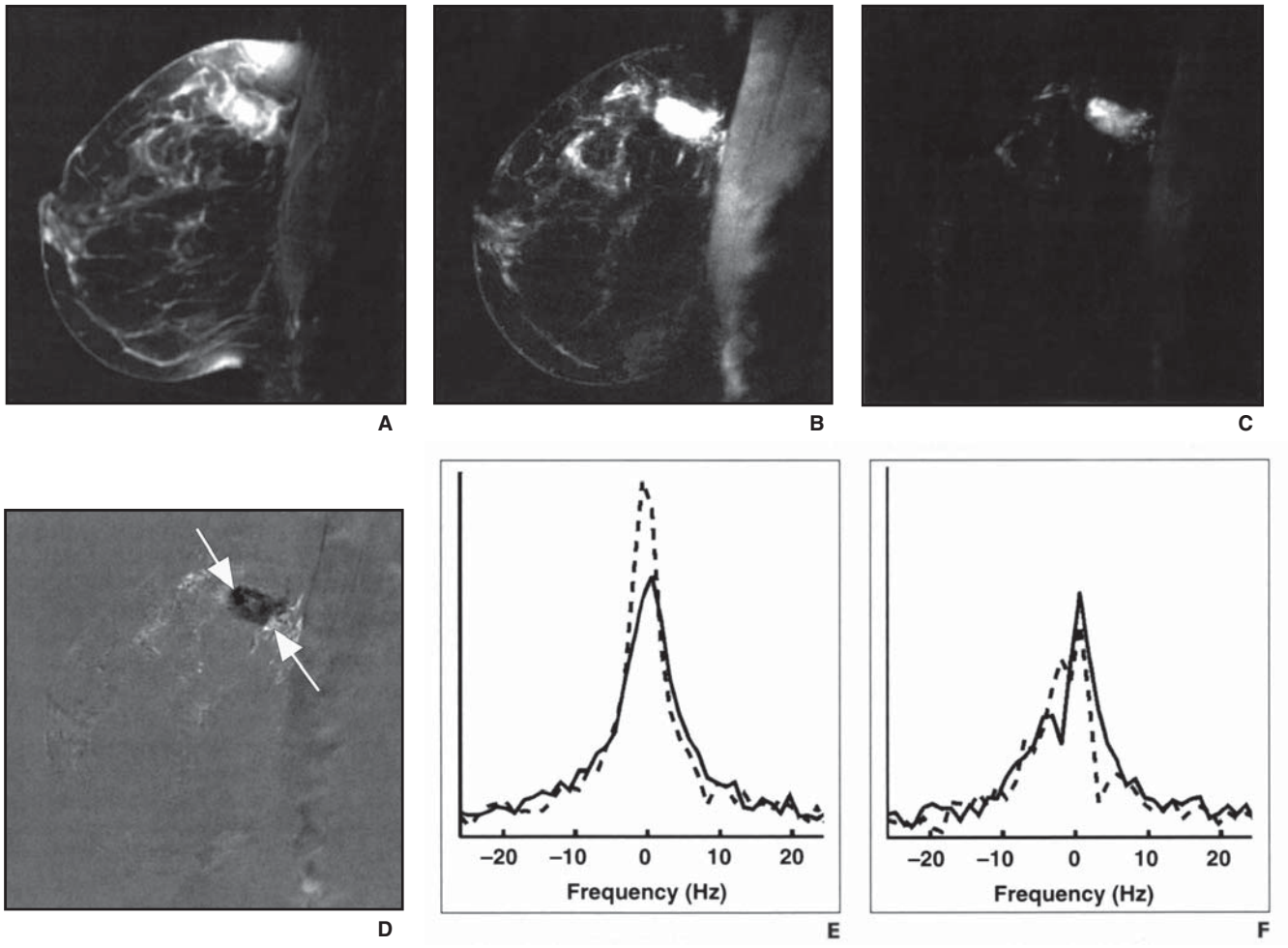



**Fig. 6.** *Forty-year-old woman at high risk for breast cancer who presented with palpable invasive ductal carcinoma mass. All images are shown in sagittal projection. A. Conventional postcontrast T1-weighted magnetic resonance (MR) image. B and C. Precontrast high spectral and spatial resolution (HiSS) images of same slice as A, displayed using different window settings to show general breast anatomy (B) and to show inherent contrast within lesion (C). D. Image shows difference between 3-minute postcontrast and precontrast HiSS images. Image reveals spatial inhomogeneity of contrast agent affect on water resonance that was observed 3 minutes after injection and resulted in peak height decreases (dark) in some regions and increases (bright) in other regions. Arrows point to 2 voxels of water resonance as shown in E and F. E and F. Images illustrate water resonance measured for 2 voxels indicated by arrows in D before (dashed line) and after (solid line) administration of contrast material for comparison. In the voxel depicted in E, there appears to be a single water resonance that is slightly shifted and homogeneously broadened after contrast agent administration. In the voxel depicted in F, 2 components can be observed: 1 is broadened and shifted and the other shows a small increase in height after contrast agent administration. The changes observed are above the noise level and can be used as a source of MR contrast. E and F are shown on an arbitrary scale. (Reprinted with permission from: Medved M, Newstead GM, Abe H, Zamora MA, Olopade OI, Karczmar GS. High spectral and spatial resolution MRI of breast lesions: preliminary clinical experience.* AJR Am J Roentgenol. *2006;186(1):36.)*

scanning and processing times for the technique are long, but speed improvements are considered likely.[2]

Stromal tissue in breast is replaced by fat tissue as people age. Fat suppression is important in breast MR technique, as high-fat density can obscure contrast enhancement.[6] Image subtraction, or subtracting the image captured before the administration of contrast from the postcontrast images, may subtract the fat

signal. But sole reliance on subtraction can result in misregistration.[6,35]

Most high-resolution MR protocols use chemical fat suppression methods with established algorithms that capture lesion-enhancement patterns.[52] Some protocols use both chemical fat suppression and image subtraction. The ACR guideline states that motion correction may help reduce artifacts encountered with image subtraction.[35]

*Breast Coils*

Special dedicated surface breast coils have been developed for breast MR. They help reduce slice thickness and improve resolution.[5] Double breast coils allow bilateral imaging. Coils apply slight compression to the medial and lateral breast surfaces to reduce motion artifact as the patient lies in the prone position.[6] The ACR guideline states that all breast MR examinations should be performed with a dedicated coil unless obesity or other considerations require procedure modifications.[35]

*Scheduling Considerations*

During the first half of a woman's menstrual cycle the breast contains more dense cellular stroma and closed ductal lumens. In the latter half of the cycle the breast parenchyma become loose and the ducts dilate, increasing parenchymal enhancement on breast MR. When possible, breast MR scans should be performed 7 to 10 days after menses begins.[4,35]

Hormonal therapy also may obscure distinguishing enhancement between breast tissues. Some breast imaging centers recommend that a patient remain off therapy for 4 weeks or more before obtaining a breast MR scan.[4]

## MR Biopsy Technique

To perform MR-guided biopsy with a coil, the lesion site generally is located from precontrast and postcontrast scans. The precise image that best shows the needle guide may be digitally added to the subtraction image of the lesion. Marker tubes are integrated into the coil and support selection of the hole for needle insertion. The procedure requires moving the patient in and out of the magnet bore and calculating the lesion depth and location – a process that can take at least 1 hour.[5,53]

With MR vacuum-assisted biopsy, the sampling device is inserted through the same sheath as the obturator that identifies the location of the target lesion. The ATEC system hand piece uses pneumatics to continuously sample tissue and aspirate and lavage the sample tissue through the cutting chamber with lidocaine and saline. This device automatically delivers the tissue sample to a collection chamber and delivers anesthetic to the lesion sample. The outside of the device is coated in plastic. (See Fig. 7.)

**Fig. 7.** *The ATEC Breast Biopsy and Excision System. (Image courtesy of Suros Surgical Systems Inc., Indianapolis, Ind.)*

## Role of the Technologist

The radiologic technologist who performs breast MR should be certified as an MR technologist or be appropriately certified, educated and licensed in radiologic technology and have 6 months of supervised clinical MR scanning experience. In addition, breast MR technologists should have access to expertise in breast imaging diagnosis and intervention and access to conventional breast imaging technology, including mammography, breast ultrasound, stereotactic biopsy and ultrasound-guided biopsy.[35,54]

One of the technologist's roles in breast MR is ensuring patient comfort and safety. This may involve obtaining a patient history, completing patient registration, obtaining informed consent, conducting patient preparation and positioning the patient for the examination. Patient consent and history take on particular importance for breast MR. Information must be obtained to ensure that no contraindications to the procedure exist, particularly those that might make the procedure unsafe. The patient should be asked to sign a form regarding this information as part of the consent process. Allergies to gadolinium are rare, but should be asked about and noted.[5,6,35,54] Additionally, some patients suffer from claustrophobia, which should be noted. These patients may require sedation or other medication to relieve anxiety.[35]

*Patient Safety*

An implant and device classification system was designed in 1997 to assist technologists and physicians in determining the safety of these items in the MR environment. Two categories were created: MR safe and MR compatible. In 2005, the American Society for Testing and Materials International created a new set of terms and icons to better categorize implants and devices for MR safety:[55]

- MR safe. These items pose no known hazards in MR environments and may be determined safe through scientifically based rationale. MR-safe items include nonconducting, nonmetallic and nonmagnetic items. They are noted by an icon with the letters "MR" in green on a white square with a green border or the letters "MR" in white within a green square.
- MR conditional. These items pose no known demonstrated hazards in the MR environment. Their safety falls within specified conditions of use, such as static magnetic field strength. MR-conditional items are represented by the letters "MR" in black inside a yellow triangle with a black border. Labeling must include testing results that characterize the item's behavior in the MR environment.
- MR unsafe. These items are known to pose hazards in all MR environments. An example is a pair of ferromagnetic scissors. MR-unsafe items are represented by the letters "MR" in black on a white field inside a red circle with a diagonal red band.

The ACR guideline on breast MR references the ACR White Paper on MR Safety for more information, as well as current peer-reviewed literature on MR safety.[35]

*Patient Positioning*

Patients are usually placed in the prone position for most breast MR procedures. This reduces motion artifacts from respiration. The breast or area to be imaged should be placed as close to the center of the coil as possible, and the breast should be pulled as far away from the chest wall as possible.[5,6] When feasible, both arms should be beside the body to help reduce motion. When only one breast is imaged with a single breast coil, the patient can be placed in a slightly oblique prone position with the arm on the side of the imaged breast beside the body and the other arm raised up and tucked under the head. Small cushions also may be used for head support.[5]

*Examination*

The radiologic technologist is responsible for completing the examination under direction of a radiologist and according to established protocols. The ACR Practice Guideline for the Performance of Magnetic Resonance Imaging of the Breast, state licensing and health regulations, facility policies and procedures, and ASRT practice standards all act in concert to guide the individual roles and responsibilities of technologists before, during and after the examination.

Breast MR technologists also may be responsible for regular quality control monitoring of equipment and procedures in accordance with various agencies, the ACR, Joint Commission on Accreditation of Healthcare Organizations and internal policies and procedures.

## Interpretation and Findings

Interpreting breast MR images can be a challenging task. Increased blood flow to any lesion causes increased contrast media uptake.[17] Interpretation is made in conjunction with clinical history and other breast imaging studies when available.[12,41]

*Kinetic and Morphologic Analysis*

One of the benefits of MR is its ability to show both morphologic and kinetic features; most interpreters rely on a combination of these features to diagnose breast lesions. Morphology arises from the high spatial resolution afforded by MR imaging and deals with how the lesion looks, while kinetic features arise from temporal resolution or dynamic imaging and address how the lesion handles contrast uptake and washout.[8,17]

Technique decisions concerning temporal vs spatial resolution directly affect interpretation. While many of the characteristics used by radiologists to distinguish breast MR findings rely on high spatial resolution, or morphology, some information about kinetic behavior also supports the decision.[1,56]

Morphologic features of lesions have to do with their shape, margins and internal architecture. Examples that may indicate malignancy include spiculated margins, rim or central enhancement and enhancing septations within a mass. For nonmass lesions, malignancy might be indicated by segmented or clumped ductal enhancement. Lesion enhancement kinetics are the enhancement rate early after contrast injection and the signal intensity course pattern in the intermediate phase and at a late postcontrast phase. Some kinetic features that may suggest malignancy include rapid contrast uptake and washout. Uptake is considered rapid if it

occurs within 2 minutes. Washout also can occur within 2 minutes in malignant lesions.[17,23]

*Defining Characteristics*

Comparisons of breast MR effectiveness have been plagued to some degree by differing terminology used to describe MR patterns. In 2003 the ACR published a lexicon with breast MR descriptions to assist radiologists in identifying features that may be suspicious vs those that may represent benign conditions.[17] These descriptors are used by radiologists as part of the Breast Imaging Reporting and Data System (BI-RADS).[12] Investigators have further developed common breast MR findings. Fischer and colleagues assigned point values that related to the level of malignancy suspicion. These scores can be translated to BI-RADS categories. For example, a lesion with an ill-defined margin (1 point), heterogenous enhancement pattern (1 point) and a signal intensity time course of washout (2 points) would receive 4 total points, placing it in BI-RADS category 4, suspicious of malignancy.[53,57]

The lexicon still involves interpretation and variability among observers. An item included in the description involves kinetic curve assessment by plotting the region of interest. This analysis involves visual assessment of the enhancement pattern on several postcontrast images, which may not be sensitive to mild or focal washout.[58] As breast MR technique improves and investigators continue to refine descriptions and scoring, the objectivity and uniformity among interpreters will likely improve.[8,12,58]

Table 2
**Selected Breast Magnetic Resonance Findings[8,58,59]**

| Benign Features | Malignant Features |
|---|---|
| Round or oval, lobular-shaped mass | Irregularly shaped mass; linear, stellate mass |
| Well-defined margin | Ill-defined margin |
| Hyperintense on T2 weighting | Hypointense on T2 weighting |
| No edema | Unifocal, unilateral edema |
| Mass with homogeneous internal enhancement, nonenhancing septa | Mass with rim enhancement, heterogeneous |
| Continued signal intensity increase at 3 to 8 minutes after contrast administration | Washout |
| Nonmass-like enhancement that is diffuse or focal | Nonmass-like enhancement that is linear-ductal or segmental, regional |
| Negative hook sign | Positive hook sign |

*Features and Findings*

Interpreting breast MR images requires an understanding of common benign and malignant findings.[57] (See Table 2.) As stated, investigators have assigned standardized terminology and scoring to many of these features to help categorize findings. Malich et al[8] expanded Fischer's scoring system to add recently reported MR signs of breast lesions and compare them with other well-known signs.

A blooming sign is a lesion with sharply shaped borders that enhances about 1 minute after contrast injection and loses sharpness 7 minutes after contrast injection.[59] A blooming sign appeared in 63% of 641 retrospectively evaluated MR imaging studies of tumors that were found to be malignant at pathological analysis; the sign occurred in 14% of benign lesions.[8] As a result, the authors calculated that the blooming sign was a stronger sign of malignancy and assigned it a corresponding point value.

The hook sign appeared in 33% of the malignant cases and in only 5% of the benign ones. (See Fig. 8.) Subsequently, the authors assigned this finding a relatively high point value for sign of malignancy. The hook sign may result from inclusion of the Cooper ligaments in the malignant process. Invasive cancers are more likely to show the hook sign, but scars following surgical treatment, biopsy and minimally invasive diagnostic or treatment procedures can mimic the hook sign.[8] Other features and findings include:

- Invasive cancers. A study by Bartella et al[12] listed the MR findings and histology of clinically and mammographically occult invasive breast cancers. More of those detected on MR were nonmass (57%) than mass (43%) lesions. A higher percentage had plateau vs washout kinetics and heterogeneous vs rim enhancement of the lesions identified as ILC; 73% presented as nonmass lesions. Most of the invasive lesions were minimal breast cancers.[12]
- Ductal carcinoma in situ. Approximately 15% to 20% of all detected breast cancers are ductal carci-

noma in situ (DCIS).[4] This type of cancer occurs more in BRCA2 carriers than in BRCA1 carriers.[60] Most DCIS lesions are clinically occult and are found on mammography as microcalcifications. Fewer studies have focused on DCIS than on more invasive breast cancers. Breast MR has been found effective in detecting DCIS, including tumors smaller than 3 cm. Breast MR also may be used for perioperative management of patients with DCIS.[4] As many as 90% of patients with Paget disease of the breast have a concurrent malignancy. Mammography is limited in its ability to depict underlying DCIS in patients with Paget disease, but MR can demonstrate nonfocal enhancement with a washout enhancement pattern.[61]

DCIS shows many of the same signs as invasive cancers, but may differ from IDC in showing 2 areas of suspicious enhancement.[4,15] (See Fig. 9.) DCIS lesions may show kinetic curves that are similar to benign lesions, complicating diagnosis.[57] A feature that helps distinguish DCIS on MR (vs mammography or ultrasound) is that MR may detect DCIS before it calcifies. In this case, the cancer appears as ductal enhancement or "clumped enhancement."[17]

- Fibrocystic change of the breast. The interpreter must distinguish benign breast characteristics from malignant lesions. Fibrocystic change of the breast (FCC) is the most common benign breast disease, affecting as many as 50% of women at some point in their lives. FCC can mimic breast cancer on a mammogram. Although it has a wide range of features, it most often will present as a mass- or nonmass-like regional enhancing lesion that has benign enhancing kinetics.[57]

*Breast Implant MR Imaging*

More than 700 types of breast prostheses have been used over the years. Various complications can arise, some of which can be diagnosed by clinical examination. Normal implants appear on MR images with a smooth, clearly defined margin. Silicone has medium signal intensity and saline has low signal intensity. They should be encompassed by a thin fibrous capsule with low signal intensity. Radial folds do not indicate rupture.

Implant rupture can be intracapsular or extracapsular. Intracapsular rupture will be demonstrated by breakdown of the implant shell without silicone migrating beyond the fibrous capsule. Curvilinear hypointense lines within the capsule represent the collapsed implant shell and may be called the "wavy line" sign or "linguini" sign. Sometimes a small tear can be seen, but the shell is not yet collapsed into the gel.

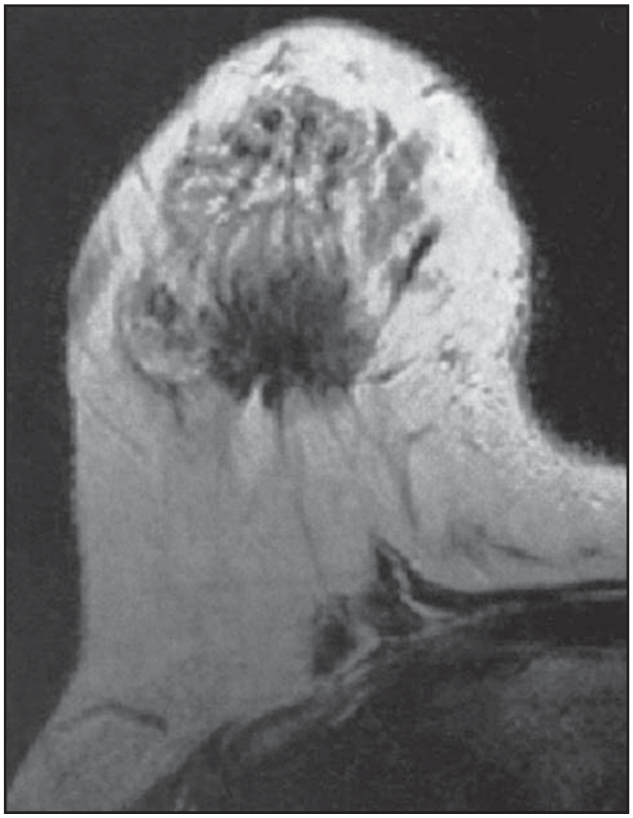


**Fig. 8.** *T2-weighted image of spiculated breast cancer with hook-like connection of malignant lesion to pectoral muscle. (Reprinted with permission from: Malich A, Fischer DR, Wurdinger S, et al. Potential MRI interpretation of benign from malignant breast masses.* AJR Am J Roentgenol. *2005;185(4):967.)*

Extracapsular rupture is defined as silicone extrusion outside the fibrous scar. The axilla is a common region for silicone gel accumulation, but reports have demonstrated silicone migrating to the abdominal wall and extremities. Breast MR can depict even small foci of silicone a few millimeters in size outside the fibrous scar.[62]

Paraffin-related changes from liquid paraffin implant failures exhibit hypointensity on T1-weighted images, hyperintensity on T2-weighted images and hyperintensity on T2-weighted fat-suppressed images. Patients with recent paraffin injections may have these findings confused with fibrocystic changes.[40]

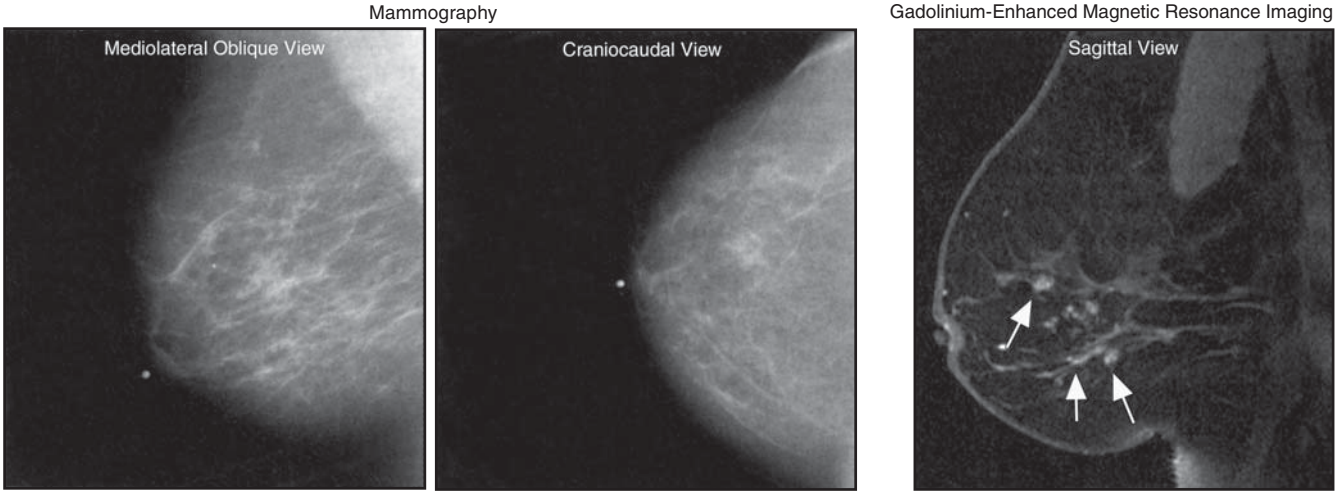



**Fig. 9.** *False-negative mammogram in a 63-year-old BRCA2 mutation carrier demonstrating normal-appearing breasts that are composed of mostly fat (25% fibroglandular density), classified as Breast Imaging Reporting and Data System (BI-RADS) 1. Sagittal, gadolinium-enhanced, fat-suppressed, 3-D spoiled gradient recalled magnetic resonance (MR) image of the right breast reveals clumped enhancement of more than 3.4 cm in a ductal distribution (arrows), classified as BI-RADS 4. MR imaging-guided wire localization and excisional biopsy revealed ductal carcinoma in situ. (Reprinted with permission from: Warner E, Plewes DB, Hill KA, et al. Surveillance of BRCA1 and BRCA2 mutation carriers with magnetic resonance imaging, ultrasound, mammography and clinical breast examination.* JAMA. *2004;292(11):1322.)*

*Male Breast Cancer*

Male breast cancer MR findings are similar to female breast cancer findings, though gynecomastia is a common male breast condition. Gynecomastia generally demonstrates low signal intensity with an internal architecture similar to normal fibroglandular breast tissue. Male breast cancer may demonstrate rim enhancement, irregular shape, irregular margins and particularly rapid enhancement soon after contrast administration and washout. (See Fig. 10.)

## Breast MR Innovation

Breast MR technology and innovation continue to evolve. DeMartini et al[63] presented their findings on the accuracy of breast MR imaging with computer-aided evaluation (CAE) at the 2005 Radiological Society of North America meeting. The authors evaluated 154 suspicious breast lesions detectable only on MR with and without CAE, then performed biopsies of the lesions under MR guidance. The computer-generated analysis recorded the presence or absence of "significant enhancement" at enhancement thresholds.

The computer's significant enhancement method showed 93% sensitivity for predicting malignancy. The authors reported that CAE also improved specificity.[63] (See Figs. 11 and 12.) An additional study by Deurloo et al[64] in 2005 showed that computerized analysis complements clinical reading by radiologists, making CAE feasible and assisting in improving detection of clinically occult lesions.[64]

Increased field strengths and the protocols to support their use will enhance breast MR. Parallel imaging with SENSE is needed to support 3.0-T breast MR, but will result in higher image quality.[31] MR spectroscopy has successfully been used in breast MR imaging studies for lesions measuring 1 cm or larger.[27] Spiral MR is another emerging technology that could make a 1.5-T magnet produce images equivalent to a much more powerful magnet by allowing for 3 times the SNR approximately 33% of the time. This could fill the voxels more efficiently.[65]

Concerns about interpreter variability in assessing the time-course kinetic curve may be resolved by quantitative assessment and modeling with color overlays. These tools help the radiologist rapidly assess the data and identify areas of concern.[44]

Many of the challenges of MR also may evolve, though some may decrease as the use of this powerful tool becomes more widespread. The possibility of an expanded or refined role for breast MR in screening remains. In a 2004 interview, Steve Harms, M.D., had the following concerns: "Well, the costs of MR are

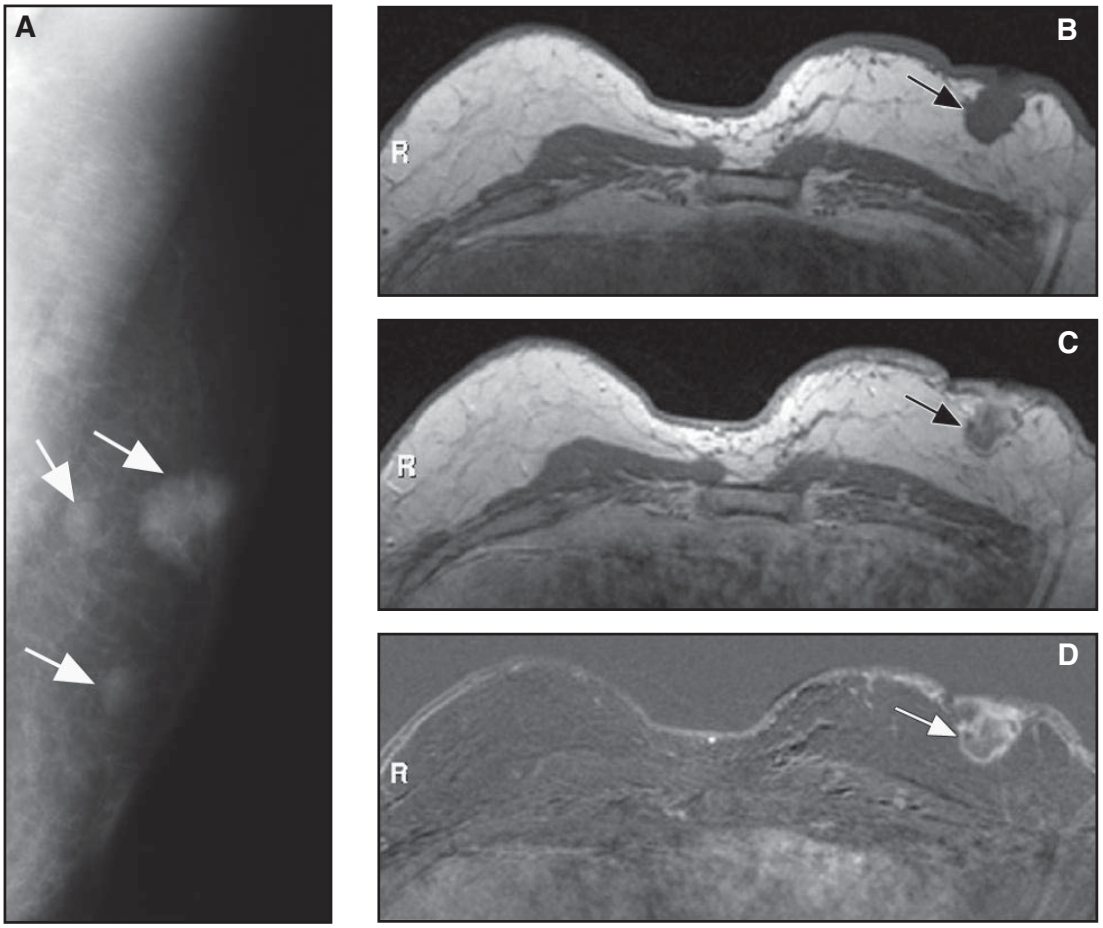
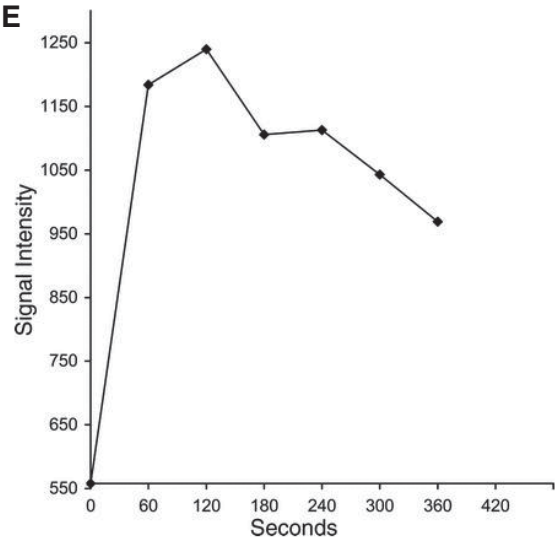



**Fig. 10.** *Palpable mass in left breast of 58-year-old man. Mammography and high-frequency ultrasound (not shown) showed multifocal breast cancer (BI-RADS category 5); breast magnetic resonance (MR) yielded the same diagnosis. Histologic examination revealed ductal invasive breast cancer. A. Oblique mammogram shows 3 lesions (arrows) suspicious for multifocal breast cancer. B and C. Transverse and pre- and postcontrast T1-weighted gradient-echo dynamic MR images (260/4.6, 90° flip angle) show a mass (arrow in B) and an irregular mass (arrow in C) with rim enhancement. D. Transverse dynamic subtracted MR image shows irregular mass (arrow) with rim enhancement. E. Signal intensity time-curve demonstrates washout. (Reprinted with permission from: Morakkabati-Spitz N, Schild HH, Leutner CC, von Falkenhausen M, Lutterbey G, Kuhl CK. Dynamic contrast-enhanced breast MR imaging in men: preliminary results.* Radiology. *2006;238(2):441.)*



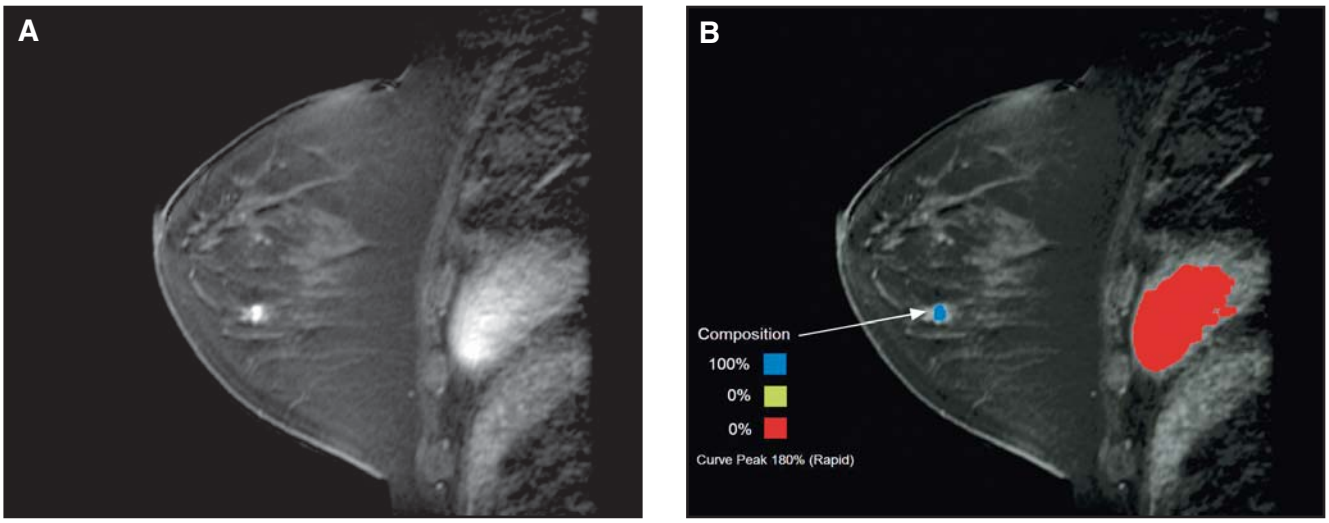



**Fig. 11.** *Magnetic resonance (MR) images of a newly diagnosed carcinoma in the left breast at 6 o'clock. A. Sagittal, fat-suppressed, T1-weighted, 3-D spoiled gradient recalled immediate postgadolinium image demonstrates an additional enhancing irregular mass at 3 o'clock. B. Same image with computer-aided evaluation (CAE) applied demonstrates the lesion meets the minimum enhancement threshold of 100%, indicated by the presence of color overlay at the site. CAE-generated enhancement synopsis in the lower left demonstrates the lesion enhancement profile (arrow) with 100% persistent enhancement. CAE-generated initial peak enhancement is also displayed. The lesion also met the enhancement threshold of 50% (not shown). MR biopsy demonstrated infiltrating ductal carcinoma, confirming multicentric malignancy. (Image courtesy of Wendy DeMartini, M.D., University of Washington Medical Center, Seattle, Wash. From: DeMartini W, Williams T, Lehman C, Peacock S, Partridge S. Analysis of a computer-aided evaluation program for breast MRI in discriminating benign from malignant lesions [abstract].* RSNA. *2005; SSM01-03.)*

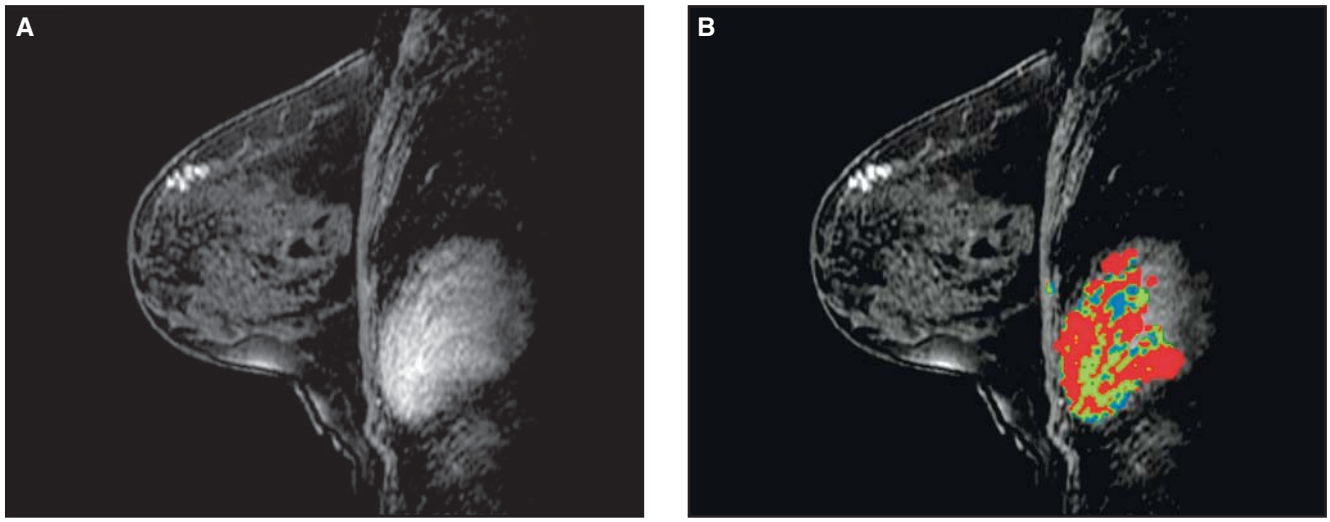



**Fig. 12.** *Magnetic resonance (MR) images of a left breast in a 51-year-old asymptomatic woman with a history of prior right breast carcinoma. A. Sagittal, fat-suppressed, T1-weighted, 3-D spoiled gradient recalled immediate postgadolinium image demonstrates nonmass-like segmental enhancement in the upper inner quadrant. B. Same image with computer-aided evaluation applied demonstrates the lesion does not meet the minimum enhancement threshold of 100%, indicated by lack of color overlay at the site. The lesion also did meet the enhancement threshold of 50% (not shown). MR biopsy demonstrated benign fibrosis and ductal hyperplasia. (Image courtesy of Wendy DeMartini, M.D., University of Washington Medical Center, Seattle, Wash. From: DeMartini W, Williams T, Lehman C, Peacock S, Partridge S. Analysis of a computer-aided evaluation program for breast MRI in discriminating benign from malignant lesions [abstract].* RSNA. *2005; SSM01-03.)*

higher, and that's a measured consideration. However, there are also pretty high costs associated with the downstream effects of misdiagnosis. In other words, if you miss a curable cancer then the treatment costs are much higher downstream. And, of course, the costs of false-positive diagnostic studies are also high, and prophylactic mastectomy has a pretty high cost. These factors have all been taken into account, and the group from Stanford Healthcare Policy and Research have analyzed this. MR can be very cost-effective, provided it's done with a select group of patients."[32]

For now, it is certain that breast MR will continue to complement mammography and ultrasound as a distinct and valuable imaging tool in the diagnosis and management of breast cancer.

## References

1. Pediconi F, Catalano C, Venditti F, et al. Color-coded automated signal intensity curves for detection of breast lesions. *Invest Radiol.* 2005;40(7):448-457.
2. Medved M, Newstead GM, Abe H, Zamora MA, Olopade OI, Karczmar GS. High spectral and spatial resolution MRI of breast lesions: preliminary clinical experience. *AJR Am J Roentgenol.* 2006;186(1):30-37.
3. Lehman CD, DePeri ER, Peacock S, McDonough MD, DeMartini WB, Shook J. Clinical experience with MRI-guided vacuum-assisted breast biopsy. *AJR Am J Roentgenol.* 2005;184(6):1782-1787.
4. Chung A, Saouaf R, Scharre K, Phillips E. The impact of MRI on the treatment of DCIS. *Am Surg.* 2005;71(9):705-710.
5. Heywang-Köbrunner SH, Beck R. *Contrast-enhanced MRI of the Breast.* 2nd ed. New York: Springer; 1996.
6. Shah SK, Shah SK, Greatrex KV. Current role of magnetic resonance imaging in breast imaging: a primer for the primary care physician. *J Am Board Fam Pract.* 2005;18(6):478-490.
7. Schneider G. Chest. In: Runge VM, ed. *Clinical MRI.* Philadelphia, Pa: WB Saunders Co; 2002:243-257.
8. Malich A, Fischer DR, Wurdinger S, et al. Potential MRI interpretation of benign from malignant breast masses. *AJR Am J Roentgenol.* 2005;185(4):964-970.
9. Klaas KK, Kaufman BM. MR mammography: screening tool or diagnostic adjunct? Available at: www.auntminnie.com. Accessed February 9, 2006.
10. Berg WA, Gutierrez L, NessAiver MS, et al. Diagnostic accuracy of mammography, clinical examination, US, and MR imaging in preoperative assessment of breast cancer. *Radiology.* 2004;233(3):800-849.
11. Wright H, Listinsky J, Rim A, et al. Magnetic resonance imaging as a diagnostic tool for breast cancer in premenopausal women. *Am J Surg.* 2005;190(4):572-575.
12. Bartella L, Liberman L, Morris EA, Dershaw DD. Nonpalpable mammographically occult invasive breast cancers detected by MRI. *AJR Am J Roentgenol.* 2006;186(3):865-890.
13. Perlet C, Heywang-Köbrunner SH, Heinig A, et al. Magnetic resonance-guided, vacuum-assisted breast biopsy. Results from a European multicenter study of 538 lesions. *Cancer.* 2006;106(5):982-990.
14. Pal S. Experts' reaction of AHRQ breast imaging report range from 'ho hum' to 'dangerous'. Available at: www.auntminnie.com. Accessed March 1, 2006.
15. Buchanan CL, Morris EA, Dorn PL, Borgen PI, Van Zee KJ. Utility of breast magnetic resonance imaging in patients with occult primary breast cancer. *Ann Surg Oncol.* 2005;12(12):1045-1053.
16. Woodhams R, Matsunaga K, Kan S, et al. ADC mapping of benign and malignant breast tumors. *Magn Reson Med Sci.* 2005;4(1):35-42.
17. Morris E. Breast MRI for cancer screening in high-risk patients. *Appl Radiol.* 2005;34(5):S4-S9.
18. Pediconi F, Catalano C, Occhiato R, et al. Breast lesion detection and characterization at contrast-enhanced MR mammography: gadobenate dimeglumine versus gadopentetate dimeglumine. *Radiology.* 2005;237(1):45-56.
19. Hlawatsch A, Teifke A, Schmidt M, Thelen M. Preoperative assessment of breast cancer: sonography versus MR imaging. *AJR Am J Roentgenol.* 2002;179(6):1493-1501.
20. Subcommittee on screening of women at high risk of breast cancer. American Society of Breast Disease policy statement: The use of magnetic resonance imaging of the breast (MRIB) for screening of women at high risk of breast cancer. Available at: www.asbd.org/images/ASBD_Policy_Statement_MRIB_for_High-Risk_Women.pdf. Accessed May 19, 2006.
21. Manton DJ, Chaturvedi A, Hubbard A, et al. Neoadjuvant chemotherapy in breast cancer: early response prediction with quantitative MR imaging and spectroscopy. *Br J Cancer.* 2006;94(3):427-435.
22. Furman-Haran E, Schechtman E, Kelcz F, Kirshenbaum K, Degani H. Magnetic resonance imaging reveals functional diversity of the vasculature in benign and malignant breast lesions. *Cancer.* 2005;104(4):708-718.
23. Kuhl CK, Schild HH, Morakkabati N. Dynamic bilateral contrast-enhanced MR imaging of the breast: trade-off between spatial and temporal resolution. *Radiology.* 2005;236(3):789-800.
24. Huang W, Fisher PR, Dulaimy K, Tudorica LA, O'Hea B, Button TM. Detection of breast malignancy: diagnostic MR protocol for improved specificity. *Radiology.* 2004;232(2):585-591.
25. Quan ML, Sclafani L, Heerdt AS, Fey JV, Morris EA, Borgen PI. Magnetic resonance imaging detects unsuspected disease in patients with invasive lobular cancer. *Ann Surg Oncol.* 2003;10(9):1048-1053.
26. Liberman L, Mason G, Morris EA, Dershaw DD. Does size matter? Positive predictive value of MRI-detected breast lesions as a function of lesion size. *AJR Am J Roentgenol.*

2006;186:426(2)-430.

27. Bartella L, Morris EA, Dershaw DD, et al. Proton MR spectroscopy with choline peak as malignancy marker improves positive predictive value for breast cancer diagnosis: preliminary study. *Radiology.* 2006;239(3):686-692.
28. Storey P. Introduction to magnetic resonance imaging and spectroscopy. In: Prasad PV, ed. *Magnetic Resonance Imaging: Methods and Biologic Applications.* Totowa, NJ: Humana Press Inc; 2006:3-58.
29. Bradley WG. Fundamentals of MRI, Part I. X-ray 2000 Web site. Available at: www.e-radiography.net/index.htm. Accessed May 2, 2006.
30. Seeram E. Magnetic resonance imaging: a primer for radiation therapists. *Radiat Therapist.* 2006;15(1):23-36.
31. Kuhl CK, Jost P, Morakkabati N, Zivanovic O, Schild HH, Gieseke J. Contrast-enhanced MR imaging of the breast at 3.0 and 1.5T in the same patients: initial experience. *Radiology.* 2006;239(3):666-676.
32. MRI vs mammography: live expert interview [transcript]. Medscape Medical News. Available at: www.medscape.com/viewarticle/487883. Accessed April 21, 2006.
33. Leach MO, Boggis CR, Dixon AK, et al. Screening with magnetic resonance imaging and mammography of a UK population at high familial risk of breast cancer: a prospective multicenter cohort study (MARIBS). *Lancet.* 2005;365(9473):1769-1778.
34. Phend C. MRI breast cancer screening interval should vary by risk and breast density: presented at ASBD. Doctor's Guide Web site. Available at: www.docguide.com/news/content.nsf/news/852571020057CCF685257162005A7FC4?OpenDocument&id=48DDE4A73E09A969852568880078C249&c=Breast%20Cancer&count=10. Accessed May 5, 2006.
35. ACR Committee on Breast Cancer. ACR practice guideline for the performance of magnetic resonance imaging (MRI) of the breast. American College of Radiology Web site. Available at: www.acr.org/s_acr/bin.asp?TrackID=&SID=1&DID=17775&CID=549&VID=2&DOC=File.PDF. Accessed April 10, 2006.
36. Kuhl CK, Schrading S, Leutner CC, Morakkabati-Spitz N, et al. Mammography, breast ultrasound and magnetic resonance imaging for surveillance of women at high familial risk for breast cancer. *J Clin Oncol.* 2005;23(33):8469-8476.
37. Smith RA, Saslow D, Sawyer KA, et al. American Cancer Society guidelines for breast cancer screening: Update 2003. *CA Cancer J Clin.* Available at: http://caonline.amcancersoc.org/cgi/content/full/53/3/141. Accessed May 17, 2006.
38. Echevarria JJ, Martin M, Saiz A, et al. Overall breast density in MR mammography: diagnostic and therapeutic implications in breast cancer. *J Comput Assist Tomogr.* 2006;30(1):140-147.
39. Rosenkrantz Hölmich L, Fryzek JP, Kjøller K, et al. The diagnosis of silicone breast implant rupture: clinical findings compared with findings at magnetic resonance imaging. *Ann Plast Surg.* 2005;54(6):583-589.
40. Erguvan-Dogan B, Yang WT. Direct injection of paraffin into the breast: mammographic, sonographic and MRI features of early complications. *AJR Am J Roentgenol.* 2006;186(3):888-894.
41. Lee SG, Orel SG, Woo IJ, et al. MR imaging of the contralateral breast in patients with newly diagnosed breast cancer: preliminary results. *Radiology.* 2003;226(3):773-778.
42. Miller JC. Radiology rounds. Massachusetts General Hospital Department of Radiology. Available at: www.mghradrounds.org/clientuploads/october_2005/october_2005.pdf. Accessed May 12, 2006.
43. Meisamy S, Bolan PJ, Baker EH. Adding in vivo quantitative 1H MR spectroscopy to improve diagnostic accuracy of breast MR imaging: preliminary results of observer performance study at 4.0T. *Radiology.* 2005;236(2):465-475.
44. Keen C. Expanded role looms for 3-D in breast imaging. Available at: www.auntminnie.com. Accessed April 12, 2006.
45. Morakkabati N, Leutner CC, Schmiedel A, Schild HH, Kuhl CK. Breast MR imaging during or soon after radiation therapy. *Radiology.* 2003;229(3):893-901.
46. Padhani AR, Hayes C, Assersohn L, et al. Prediction of clinicopathologic response of breast cancer to primary chemotherapy at contrast-enhance MR imaging: initial clinical results. *Radiology.* 2006;239(2):361-374.
47. Bhattarai N, Kanemaki Y, Kurihara Y, Nakajima Y, Fukuda M, Maeda I. Intraductal papilloma: features on MR ductography using a microscopic coil. *AJR Am J Roentgenol.* 2006;186(1):44-47.
48. Espinosa LA, Daniel BL, Vidarsson L, Zakhour M, Ikeda DM, Herfkens RJ. The lactating breast: contrast-enhanced MR imaging of normal tissue and cancer. *Radiology.* 2005;237(2):429-436.
49. Shi AA, Georgian-Smith D, Cornell LD, et al. Radiological reasoning: male breast mass with calcifications. *AJR Am J Roentgenol.* 2005;185(6 Suppl):S205-S210.
50. Morakkabati-Spitz N, Schild HH, Leutner CC, von Falkenhausen M, Lutterbey G, Kuhl CK. Dynamic contrast-enhanced breast MR imaging in men: preliminary results. *Radiology.* 2006;238(2):4438-445.
51. Menell JH, Morris EA, Dershaw DD, Abramson AF, Brogi E, Liberman L. Determination of the presence and extent of pure ductal carcinoma in situ by mammography and magnetic resonance imaging. *Breast J.* 2005;11(6):382-390.
52. Ma J, Vu AT, Son JB, Choi H, Hazle JD. Fat-suppressed three-dimensional dual echo Dixon technique for contrast agent enhanced MRI. *J Magn Reson Imaging.* 2006;23(1):36-41.
53. Siegmann KC, Gorriz C, Xydeas T, et al. Preoperative magnetic resonance imaging-guided localization of 131 breast lesions with modified embolization coils. *Invest Radiol.* 2005;40(6):368-377.
54. American College of Radiology Guidelines and Standards Committee. ACR practice guideline for performing and interpreting magnetic resonance imaging (MRI). American College of Radiology Web site. Available at: www.acr.org. Accessed May 1, 2006.

55. American Society for Testing and Materials International. Standard practice for marking medical devices and other items for safety in the magnetic resonance environment. Designation: F2503-05. 2005.
56. Schnall MD, Blume J, Bluemke, et al. Diagnostic architectural and dynamic features at breast MR imaging: multicenter study. *Radiology.* 2006;238(1):42-53.
57. van den Bosch MA, Daniel BL, Mariano MN, et al. Magnetic resonance imaging characteristics of fibrocystic change of the breast. *Invest Radiol.* 2005;40(7):436-441.
58. Choi N, Han B, Choe YH, Kim HS. Three-phase dynamic breast magnetic resonance imaging with two-way subtraction. *J Comput Assist Tomogr.* 2005;29(6):834-841.
59. Fischer DR, Wurdinger S, Boetccher J, Malich A, Kaiser WA. Further signs in the evaluation of magnetic resonance mammography: a retrospective study. *Invest Radiol.* 2005;40(7):430-435.
60. Warner E, Plewes DB, Hill KA, et al. Surveillance of BRCA1 and BRCA2 mutation carriers with magnetic resonance imaging, ultrasound, mammography and clinical breast examination. *JAMA.* 2004;292(11):1317-1325.
61. Frei KA, Bonel HM, Pelte MF, Hylton NM, Kinkel K. Paget disease of the breast. *Invest Radiol.* 2005;40(6):363-367.
62. Hilbertz T, Patt R. Imaging of implant failure by MRI. In: Heywang-Köbrunner SH, Beck R. *Contrast-enhanced MRI of the Breast.* 2nd ed. New York: Springer; 1996:207-226.
63. DeMartini W, Williams T, Lehman C, Peacock S, Partridge S. Analysis of a computer-aided evaluation program for breast MRI in discriminating benign from malignant lesions [abstract]. *RSNA.* 2005; SSM01-03.
64. Deurloo EE, Muller SH, Peterse JL, Besnard APE, Gilhuijs KGA. Clinically and mammographically occult breast lesions on MR images: potential effect of computerized assessment on clinical reading. *Radiology.* 2005;234(3):693-701.
65. Phend C. Technology, guidelines cement role for breast MR in cancer screening. Available at: www.auntminnie.com/index.asp?Sec=sup&Sub=mri&Pag=dis&ItemId=71064. (Subscription required.) Accessed May 23, 2006.

*Teresa G. Odle, B.A., is a freelance writer and editor living in Albuquerque, NM. She has worked in health care communication for more than 16 years and is a member of the American Medical Writers Association.*

*Reprint requests may be sent to the American Society of Radiologic Technologists, Communications Department, 15000 Central Ave. SE, Albuquerque, NM 87123-3917.*