Magnetic Resonance Imaging of the Breast: Current Indications

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Abstract

Breast magnetic resonance imaging (MRI) plays an increasing role in the management of selected breast cancer patients. MRI is recognized as the most sensitive modality for the detection of invasive breast cancer. Several valuable clinical applications of MRI have emerged for breast cancer detection and diagnosis from clinical investigations.

Breast MRI is helpful for women diagnosed with breast cancer who contemplate breast conserving surgery; it provides valuable information on the extent of the disease.

MRI can also help assess for residual invasive cancer in patients who have undergone lumpectomy with positive margins at pathology. It is very reliable in differentiating scar tissue from recurrence at the lumpectomy site.

MRI is also reliable in finding a breast cancer in women with axillary nodal metastases and unknown primary tumour.

MRI can help to monitor the response to chemotherapy. Breast MRI could be a better screening tool than mammography in women with very high risks of developing breast cancer, such as breast cancer gene carriers and patients treated with chest radiation.

Other potential uses of MRI include evaluation of the integrity of silicone breast implants and evaluation of the parenchyma in women with silicone gel implants or free injection of silicone gel.

However, like any other technique, breast MRI has some drawbacks, including low-to-moderate specificity, high costs, and variability in technique and interpretation. Radiologists must have a clear understanding of valid indications and selection criteria to use this technique appropriately.

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Abrégé

L'importance de l'imagerie par résonance magnétique (IRM) dans l'investigation du cancer du sein se confirme dans la pratique courante.

L'IRM est la modalité la plus sensible dans la détection des cancers infiltrants.

La littérature confirme que l'IRM est maintenant indiquée dans plusieurs situations cliniques de dépistage ou de diagnostic du cancer du sein. Notamment, l'IRM permet une évaluation de l'extension de la maladie chez les patientes avec un diagnostic de cancer du sein infiltrant pour qui une chirurgie conservatrice est envisagée.

L'IRM offre une évaluation de la glande résiduelle chez les patientes opérées pour cancer du sein et qui présentent des marges positives ou serrées à la chirurgie. L'IRM est particulièrement efficace dans la détection de récidive de cancer au site de tumorectomie ou pour détecter un cancer du sein chez les patientes présentant des ganglions axillaires métastatiques sans évidence de cancer à l'imagerie conventionnelle. L'IRM permet d'analyser la réponse à la chimiothérapie et ainsi permet un ajustement rapide de la thérapie et une meilleure planification de la chirurgie. L'IRM est utile chez les patientes porteuses de prothèses mammaires soit pour évaluer l'intégrité des prothèses ou pour détecter un cancer dans la glande.

Toutefois, comme toute autre technique, l'IRM a aussi ses limites dont sa spécificité, son coût et les disparités dans les critères d'interprétation et les standards techniques. Les radiologistes oeuvrant en imagerie du sein se doivent d'être informés du potentiel et de l'utilité de l'IRM pour l'investigation du cancer du sein et en connaître les indications et les limites.

Magnetic resonance imaging (MRI) of the breast has evolved significantly in recent years, and its early anticipated potential is being confirmed every day in clinical practice. MRI is recognized as a very sensitive imaging modality for the detection of invasive breast cancer.[1] Our best screening tool, mammography, shows great variability in detecting breast cancer. Breast density, age, and hormone replacement therapy in the subject, as well as technical factors and the biological subtypes of cancer, are factors known to affect the sensitivity as well as the specificity of mammography.[2]

Further, for some women, mammography is unable to accurately depict the extent of disease, particularly in patients with dense breast or with lobular carcinoma.

From clinical investigations, several valuable MRI clinical applications have emerged for breast cancer detection and diagnosis. However, the technique is not without drawbacks, including low-to-moderate specificity, high costs, and variability in technique and interpretation.[1] Radiologists involved in breast imaging must have a clear understanding of valid indications and selection criteria for breast MRI.

This article reviews the indications for breast MRI. Some of the clinical situations where breast MRI is not indicated are also discussed.

Current Indications for Breast MRI

Preoperative Planning for Breast-Conserving Surgery in Women With Infiltrating Breast Cancer

Breast-conserving surgery followed by breast irradiation is the treatment of choice for women with relatively small breast cancers, provided that the margins of resection are tumour-free and an acceptable cosmetic result can be obtained. The long-term survival rate among these women is the same as that for women who undergo radical mastectomy.[3,4] However, if cancer is left in the breast at the time of surgery, the risk of cancer recurrence is increased, despite the administration of radiation therapy.

Studies comparing mammography, ultrasound, and MRI have shown that MRI is superior to the other modalities in evaluating the size and extent of disease.[5] For a woman diagnosed with breast cancer who is contemplating breast-conserving surgery, further evaluation with MRI can demonstrate more extensive disease than suspected, especially in subtypes such as invasive lobular cancer,[6] in women with dense breasts, or in the presence of large (T2 and T3) tumours.[6,7] This additional information is essential to the surgeon for planning more precisely the extent of resection and thereby decreasing the reoperation rate.[6,7] MRI also offers multiplanar reconstructions, permitting a more comprehensive understanding of a tumour's location and extent. The additional information obtained with MRI, such as tumour extension to the chest wall or to the nipple or identification of multicentric or bilateral disease, which traditionally evaded detection by conventional imaging, can drastically alter patient management and confirm the need for preoperative chemotherapy, mastectomy, and, occasionally, contralateral surgery. Incidental contralateral synchronous cancers have been found in 3% to 6% of women.[8] In our view, bilateral MRI should always be performed; it is now possible with the newest magnets and without compromising temporal or spatial resolution. Although one recent study showed that obtaining a preoperative MRI subsequently led to decreased local recurrence of cancer,[9] to our knowledge, no studies have yet demonstrated that the change in management resulting from additional information obtained by MRI is ultimately beneficial in terms of decreasing overall mortality. It has been shown that MRI modifies surgical management in an average of 19% of cases.[10] It is important to stress that, of those 19% of cases, modifications in management were felt to be deleterious to the patient in 6% because of false-positive findings. Breast MRI has low specificity, ranging from 37% to 97%.[8] Angiogenic activity, the pathophysiologic basis for the magnetic resonance (MR) detection of breast cancer, is not unique to malignant tumours, and the degree of angiogenic activity among tumours is variable. MRI findings should absolutely be proven histologically before any treatment decision is applied; suspicious areas can be marked for surgical biopsy or biopsied under MR guidance (see "Breast Procedures Guided by Magnetic Resonance Imaging"on page 310–319).

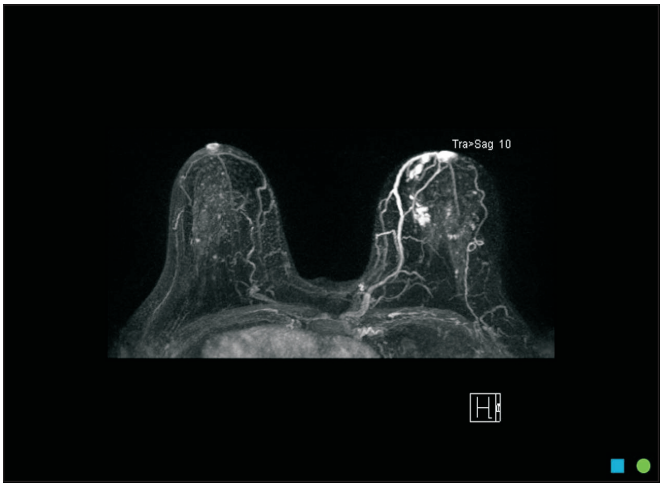
Preoperative Planning for Breast-Conserving Surgery in Women With In Situ Breast Cancer

Whether MRI is useful in the diagnosis of ductal carcinoma in situ (DCIS) is still controversial. MRI is able to detect some DCIS (some carcinomas that calcify and others that do not), improving evaluation of the extent of disease over evaluation through mammography and ultrasound. Until recently, studies reporting on the accuracy of MRI in detecting DCIS were quite variable, with sensitivity estimates ranging from 20% to 95%.[11] Westerhof and colleagues reported that, in patients diagnosed with DCIS, MRI was 88% accurate in detecting residual disease, 82% accurate in detecting invasive disease, and 90% accurate in detecting multicentric disease.[11] In 2 recent studies, the false-negative rates for the MRI detection of DCIS were 12% and 23.5%.[11,12]

The clinical significance of MRI-detected DCIS is unknown. To this day, all DCIS lesions are treated as potentially lethal, because 30% to 50% of DCIS will progress to invasive carcinoma.[11] Clearly, the optimal treatment for this heterogeneous group of neoplastic lesions is still evolving.

MRI is unable to distinguish benign from malignant microcalcifications, so the decision to biopsy should be made exclusively on the basis of mammographic appearance, even without corresponding MRI enhancement. Conversely, an area of suspicious linear enhancement on MRI must be biopsied under MRI guidance, despite a negative mammogram. MRI

Figure 1 Paget's disease. Maximum intensity projection image from a contrast-enhanced breast magnetic resonance imaging (MRI) of a 45-year-old patient known to have biopsy-proven Paget's disease of the right nipple (at the right of the image) demonstrating more extensive disease (proven multiple ductal in situ and infiltrative foci) than previously expected after conventional imaging. Notice the enhancement of the right nipple.



may be particularly useful after an initial diagnosis of DCIS in women who present with Paget's disease. In this unusual breast cancer presentation, mammography is normal in more than 40% of cases. Standard treatment is to perform surgical excision of the nipple–areolar complex and posterior tissue, but disease extends beyond the retroareolar region in 75% of cases.[13] MRI can demonstrate the extent of disease and identify invasive cancer not suspected on conventional imaging[14] (Figure 1).

Identification of Tumour Recurrence at the Lumpectomy Site After Breast-Conserving Surgery

Tumour recurrence after breast-conserving surgery occurs earlier at the lumpectomy site than elsewhere in the breast. The sensitivity of mammography for detecting local recurrence at the lumpectomy site is around 60% to 70%.[15] The diagnosis of recurrence at ultrasound is often difficult because scar tissue manifests as shadowing, limiting the examination and, in some cases, mimicking tumour recurrence (Figure 2). MRI can help resolve this clinical difficulty by differentiating nonenhancing scar or fat necrosis from enhancing recurrent tumour. The performance of MRI in differentiating scar from recurrence has been reported with sensitivities of 93% to 100% and specificities of 88% to 100%.[15] One potential source of false-positive results is related to the normal benign enhancement of the lumpectomy scar, which may contain vascularized granulation tissue for as long as 9 to 18 months after surgery and which may be confused with enhancement at the site of surgery signifying tumour recurrence.[15] With granulation tissue, enhancement tends to be more regular and homogeneous around the surgery cavity. Fortunately, tumour recurrence is usually not a concern in the early postoperative period.

Assessment of Residual Disease in Women With Close or Positive Margins After Breast-Conserving Surgery

MRI can help assess for possible residual invasive cancer in patients who have undergone lumpectomy and with positive margins at pathology.

It is strongly recommended that the amount of residual tumour be evaluated to decide whether the patient remains a candidate for breast-conserving surgery. This information is valuable to the radiation oncologist, who may propose brachytherapy to selected patients as an alternative to external breast irradiation. Although the accuracy of MRI has been shown to be maximal at 35 to 42 days after surgery,[16] patient and surgeon will often ask for an earlier scan. An examination performed within days after surgery takes advantage of the surgical cavity (a low-signal collection on T1-weighted images), which serves as a contrast for enhancing residual tumour. MRI has proven useful in determining the extent of residual disease both in women with invasive cancer and in women with DCIS,[8] even when there are no residual malignant calcifications on the postoperative mammogram.

Assessing the Response to Neoadjuvant Chemotherapy

Today, preoperative neoadjuvant chemotherapy is often offered as a first-line treatment for women with large (greater than 3 cm) or locally advanced primary breast carcinoma. This treatment is used to reduce tumour size, which in turn may allow the surgeon to offer breast-conserving surgery. A complete pathologic response following chemotherapy is strongly predictive of excellent long-term survival.[16] After chemotherapy, decreased or delayed enhancement is observed in tumours because cytotoxic agents affect vascularization and vascular wall permeability.

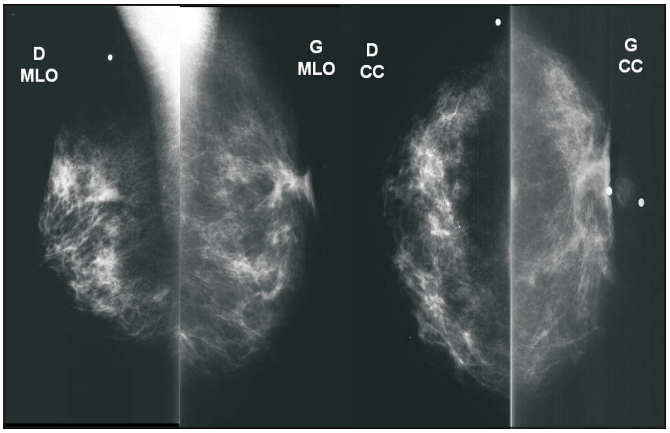
The clinical implications of accurately monitoring the response to neoadjuvant therapy are numerous. It allows for quick adjustments to the drug regimen plan and for optimal timing and planning of surgery. Determining the final size of the tumour after neoadjuvant treatment allows the surgeon to remove the entire tumour without leaving residual disease in the breast.

Early studies revealed that breast MRI was more accurate than physical examination and mammography in assessing the response to chemotherapy and determining the presence of residual tumour.[17] Some studies showed that MRI could accurately document tumour response to chemotherapy as early as within the first 6 weeks after chemotherapy onset.[18]

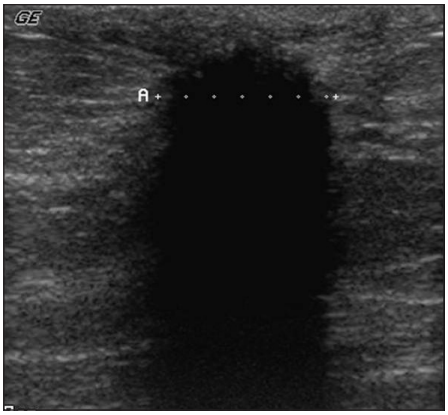
Other studies showed different results and were less optimistic about the utility of MRI in evaluating response to chemotherapy.[18,19] Changes owing to chemotherapy can appear identical to those of the primary breast carcinoma.[18] There is still

Figure 2 Assessing tumour recurrence at lumpectomy site. A 52-year-old patient 6 years after left lumpectomy for invasive ductal carcinoma. A left lump is felt at the lumpectomy site.

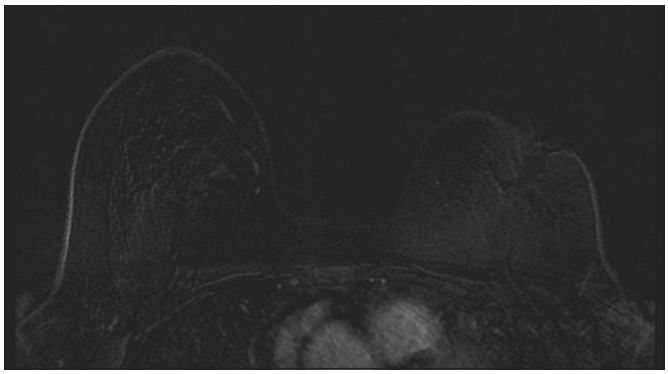
A: Mammogram shows postoperative changes in the left upper outer quadrant from the lumpectomy



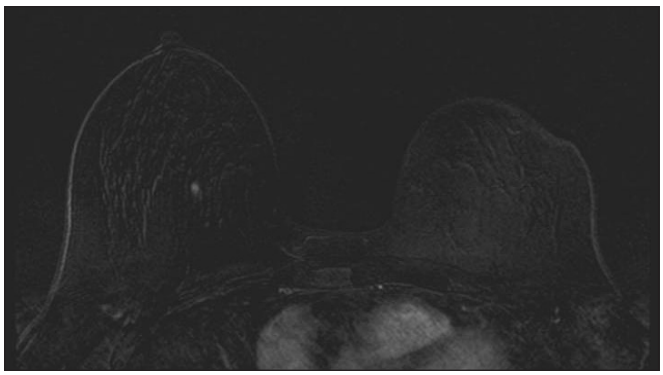
B: Ultrasound of the scar inconclusive, showing a hypoechoic mass with shadowing



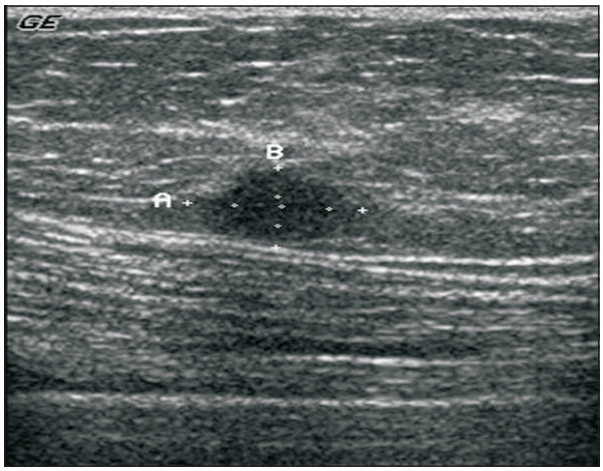
C: Axial T1-weighted, contrast-enhanced, subtracted MRI image confirms absence of recurrence around or in the scar



D: Demonstrates a small posterior enhancing mass in the right inner upper quadrant of the right breast



E: A second-look ultrasound confirms a 1-cm hypoechoic mass in the posterior mammary zone at 11 o'clock, correlating with the MRI findings. Ultrasound-guided 14-gauge automated core biopsy was performed and yielded a small invasive ductal cancer.



F: Radiograph shows the biopsy marker left after the breast ultrasound-guided biopsy, but no noticeable lesion identified

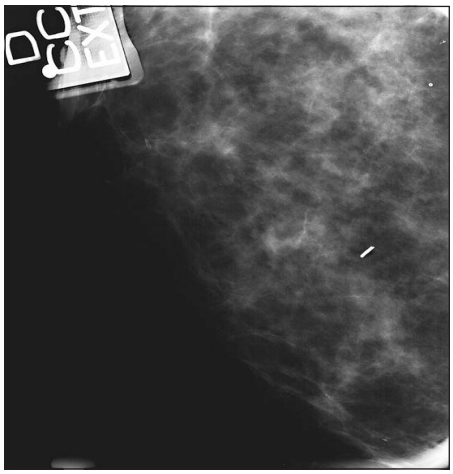
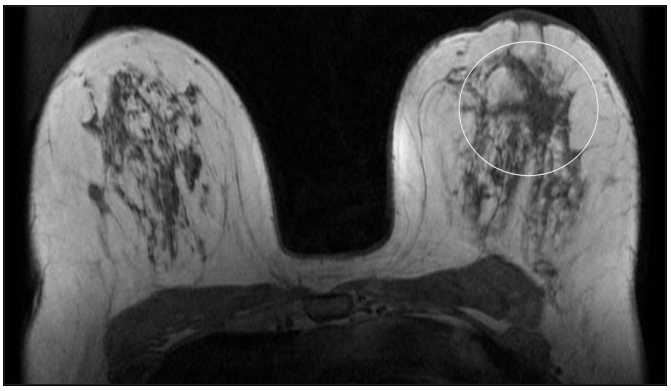
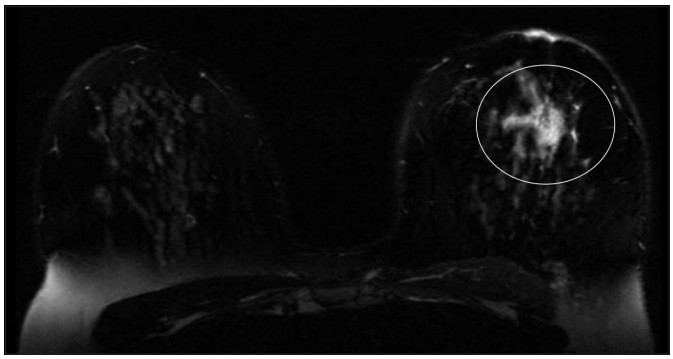


Figure 3 Assessing response to neoadjuvant chemotherapy: a 36-year-old woman undergoing neoadjuvant chemotherapy for a locally advanced left breast cancer showing no clinical response to treatment

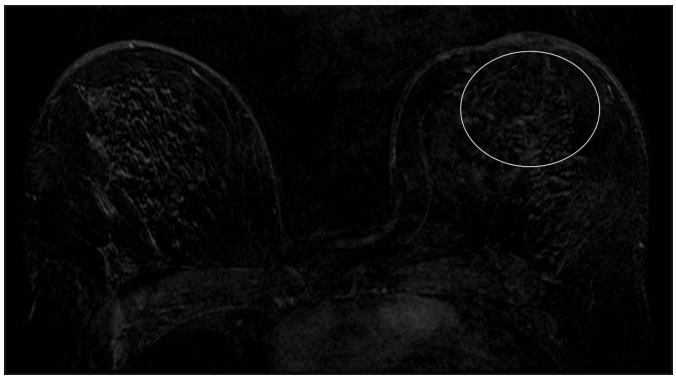
A: Axial T1-weighted MRI image shows a left hypointense irregular retroareolar mass



B: Axial T2 = weighted MRI image of the mass shows a hyperintense signal, indicating considerable edema around and in the tumour.



C: Axial T1-weighted, contrast-enhanced, subtracted MRI image confirms absence of enhancement in favour of a good response to chemotherapy, despite the stability of the mass size. Pathologic analysis confirms no residual cancer foci in fibrous mass.



some debate regarding the best way to determine and quantify residual tumour. Ideally, MRI evaluation should be performed before and after chemotherapy to allow for a better analysis of the changes in contrast enhancement uptake and washout induced by chemotherapy.

Tumour nonenhancement after treatment does not exclude the presence of microscopic residual disease at the end of chemotherapy.[18]

At this time, we can confidently say that MRI can be valuable as a predictor of tumour response or in identifying complete failure to respond to chemotherapy. MRI is especially helpful in patients who show a lack of clinical response (Figure 3). A multiinstitutional study from the American College of Radiology Imaging Network (ACRIN study 6657) is ongoing and evaluates use of breast MRI in patients undergoing neoadjuvant chemotherapy.

Investigational work is underway using MR spectroscopy and perfusion imaging on higher-field magnets.[20] Measuring the concentration of choline-containing compounds in the tumour could be a more accurate tool for measuring response to chemotherapy.

Occult Primary Cancer

Fewer than 2% of all breast cancers present with metastatic axillary adenopathy without evidence of tumour in the breast on physical examination or on conventional imaging.[21] Mastectomy is the standard treatment for these tumours, because whole breast irradiation, although having the same survival rate as mastectomy, has a higher rate of local recurrence (19% to 23%).[22] Overall, the primary cancer is found in the mastectomy specimen in only two-thirds of women.[22] For the remaining third, a nonbreast primary tumour or a breast tumour too small to be detected on histological analysis is assumed to be present. Studies showed that MRI can identify the site of a breast primary tumour in most women (75% to 86%) presenting with metastatic axillary adenopathy,[8,19,22] thus allowing patients to receive the optimal treatment. When a breast cancer is found, breast-conservation therapy will often be proposed instead of mastectomy because many of these tumours are relatively small (Figure 4). A patient with a negative MRI could be treated by radiation alone rather than by mastectomy, but long-term clinical trials are still needed to evaluate these options.

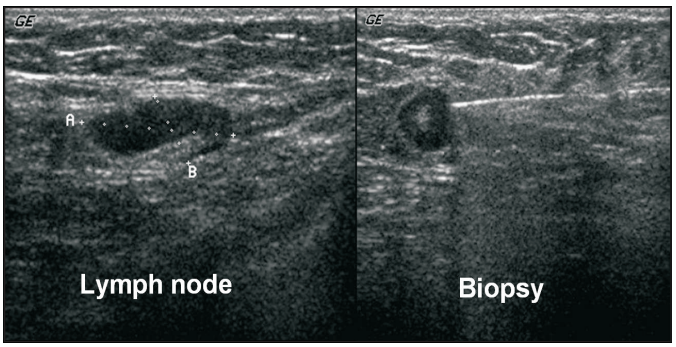
Screening High-Risk Women

To date, studies of MRI screening have concentrated on women with very high risk of developing breast cancer (as high as 80%), such as breast cancer gene carriers and patients with Hodgkin's disease treated with chest radiation. These patients are mostly young women with dense breasts, in whom mammography is known to have decreased performance.

Published studies have demonstrated the ability of MRI to detect cancers in high-risk women before they are seen by

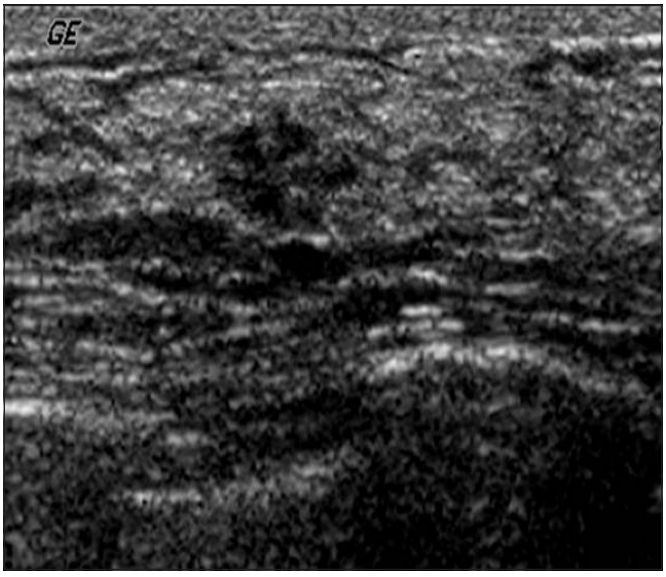
Figure 4 Occult breast cancer: a 46-year-old woman with small palpable left axillary nodes

A: Left breast ultrasound (not shown) normal but confirms presence of enlarged left axillary nodes with thickened cortex (left); ultrasound-guided 16-gauge automated core biopsy (right) confirms lymph node metastases from infiltrating ductal carcinoma



B: Axial T1-weighted, contrast-enhanced, subtracted MRI image confirms small posterior enhancing mass in the retroareolar region of the left breast

C: A second-look ultrasound demonstrates central 8-mm hypoechoic nodule in the posterior mammary zone, proven to be an infiltrative ductal carcinoma at subsequent ultrasound-guided core biopsy



D: Radiograph confirms removal of biopsy marker left in place at the time of the biopsy

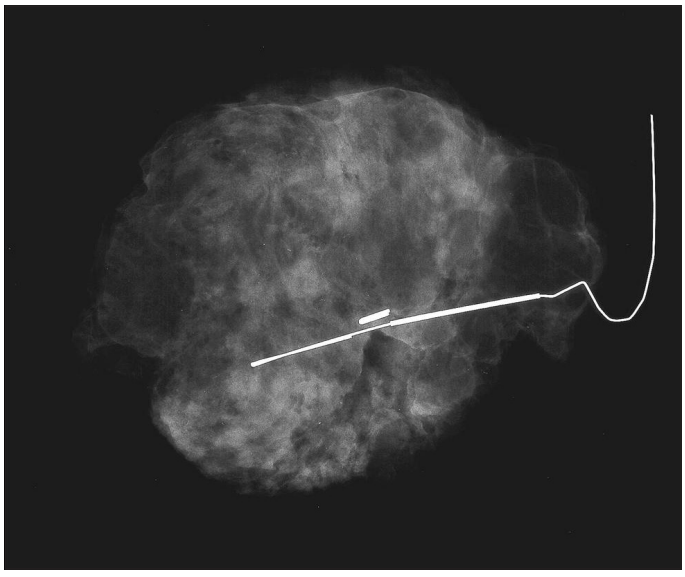
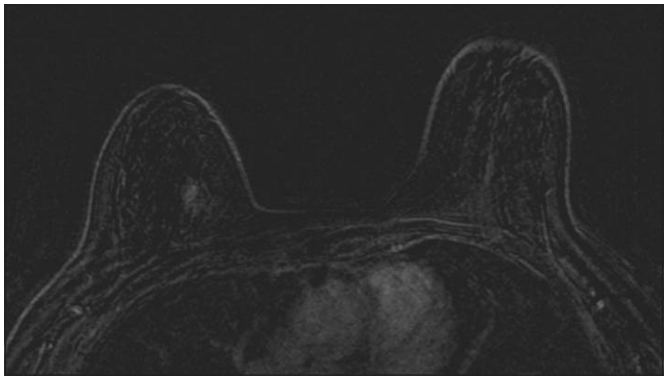
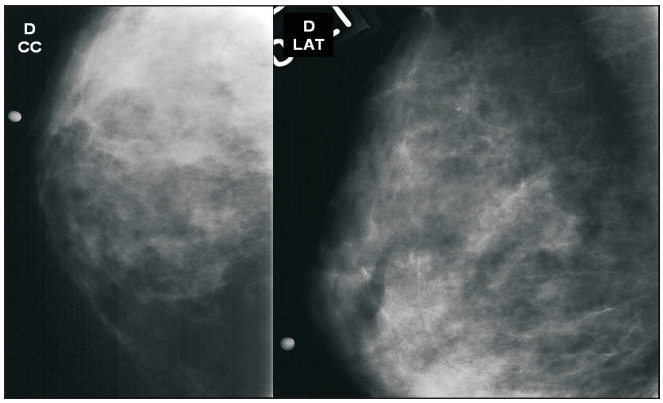


Figure 5 High-risk patient: a young gene mutation carrier enrolled in the magnetic resonance (MR) screening research program for high-risk patients at our institution. She had a lumpectomy for a left breast cancer 2 years earlier. Her mammogram and breast ultrasound (not shown) were normal

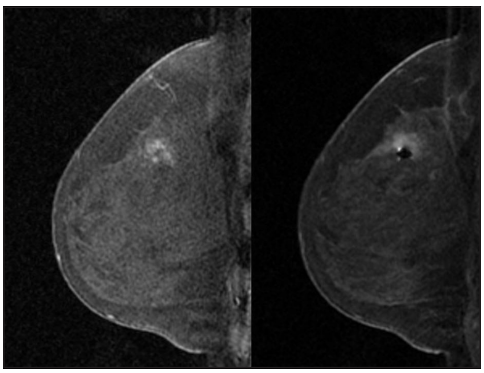
A: Axial T1-weighted, contrast-enhanced, subtracted MRI image shows small, wedge-shaped enhancing focus in the upper inner quadrant of right breast



B: No lesion visible on cephalo caudal or lateral magnification views or on second-look ultrasound (not shown)



C: Sagittal T1-weighted, contrast-enhanced, fat-suppressed images show the enhancing focus (left) and the needle in the lesion during the MRI-guided vacuum-assisted biopsy (right). A ductal carcinoma in situ grade 3 is confirmed.



mammography, sonography, or physical examination.[23] The clinical impact of MRI is still not established and is the subject of ongoing studies. Given the limitations of mammography, there is considerable interest in using breast MRI as a screening tool for breast cancer. The exact role of MRI in screening for breast cancer is still under investigation.

There is no evidence so far to support MRI screening of the average-risk woman. MRI is an expensive examination with lower positive predictive value than mammography and requires injection of intravenous contrast. The added value of breast MRI in screening women with mammographically dense breasts is unknown.

Women With Breast Augmentation

Identifying Implant Rupture. In a metaanalysis comparing the performance of the various imaging modalities for the detection of implant rupture, the mean sensitivity was 38% for mammography, 59% for ultrasound, and 78% for MRI.[24] MRI has the advantage of allowing for visualization of the posterior aspect of the prosthesis, an area difficult to assess by mammography or ultrasound. Whether implant rupture is clinically important is controversial, and MRI is a costly examination. In our opinion, MRI should be reserved for questionable cases of rupture in women willing to have their implants removed or in women with possible implant complications.

Saline implant rupture is usually clinically obvious because the shape of the breast changes. Normal saline that fills the implant is a physiologic liquid absorbed by the body, and implant rupture has therefore no clinical significance. Consequently, MRI has no value in the evaluation of saline implants.

Evaluation of Breast Tissue. MRI is useful in evaluating the parenchyma of women with augmented breasts because tumour visualization is not adversely affected by implants or silicone. These MR studies require intravenous injection of contrast material and are performed in the same way as for a non-augmented breast. So far, there is limited experience on the use of breast MRI in women with free silicone injection in the breast, and its role as an adjunct to mammography has yet to be determined.

Inappropriate Indications

MRI should not be used to decide whether a lesion seen on conventional imaging should undergo a biopsy.

MRI should not be used to categorize a lesion as probably benign (BIRADS 3) or suspicious (BIRADS 4).

The interpretation criteria for breast MRI have not been validated as they have for mammography and ultrasound,[1] and what constitutes a "probably benign" finding on breast MRI as well as the optimum follow-up strategy for these lesions have yet to be established. The overall accuracy of breast MRI for

various clinical settings has also not yet been established with certainty.[1]

MRI should not be used in place of a well-performed mammography or ultrasound. MRI is expensive and requires intravenous contrast. It is not a first-line examination for solving breast problems.

Summary

Breast MRI plays an increasingly important role in the diagnosis and management of select patients with breast cancer.

Breast MRI allows detection of cancer and provides valuable information on the extent of disease, helping to plan management and therapy. MRI can help in evaluating response to treatment. Other potential uses of MRI include searching for unknown primary tumours in women with axillary nodal metastases, breast screening for high-risk women, evaluating the integrity of silicone breast implant, and evaluating the parenchyma in women with silicone gel implants or free injections of silicone.

Patients should be referred to a tertiary centre where a recognized breast MRI program is available with well-trained breast radiologists who can biopsy or localize abnormalities under MRI guidance. Because of the low-to-moderate specificity of breast MRI, MRI findings must be proven histologically before any treatment decision is applied.

References

1. Bartella L, Dershaw DD. Magnetic resonance imaging of invasive breast carcinoma. In: Morris EA, Liberman L, editors. Breast MRI: diagnosis and intervention. New York (NY): Springer; 2005. p 173–83.
2. Helvie MA. Imaging analysis: mammography. In: Harris JR, Lippman ME, Morrow M, Osborne CK, editors. Disease of the breast. Philadelphia (PA): Lippincott Williams and Wilkins; 2004. p 131–48.
3. Veronesi U, Cascinelli N, Mariani L, Greco M, Saccozzi R, Luini A, et al. Twenty-year follow-up of a randomized study comparing breast-conserving surgery with radical mastectomy for early breast cancer. *N Engl J Med* 2002;347:1227–32.
4. Fisher B, Anderson S, Bryant J, Margolese RG, Deutsch M, Fischer ER, et al. Twenty year follow-up of a randomized trial comparing total mastectomy, lumpectomy, and lumpectomy plus irradiation for the treatment of invasive breast cancer. *N Engl J Med* 2002;347:1233–41.
5. Davis PL, Staiger MJ, Harris KB, Ganott MA, Klementaviciene J, McCarty JS Jr, et al. Breast cancer measurements with magnetic resonance imaging, ultrasonography, and mammography. *Breast Cancer Res Treat* 1996;37:1–9.
6. Weinstein SP, Orel SG, Heller R,Reynolds C, Czerniecki B, Lawrence J, et al. MR imaging of the breast in patients with invasive lobular carcinoma. *AJR Am J Roentgenol* 2001;176:399–406.
7. Esserman L, Hylton N, Yassa L, Barclay J, Frankel S, Sickles E, et al. Utility of magnetic resonance imaging in the management of breast cancer: evidence for improved preoperative staging. J *Clin Oncol* 1999;17:110–9.
8. Morris E. Cancer staging with breast MR imaging. *Magn Reson Imaging Clin N Am* 2001;9:333–44.
9. Fischer U, Zachariae O, Baum F, von Heyden D, Funke M, Liersch T. The influence of preoperative MRI of the breasts on recurrence rate in patients with breast cancer. *Eur Radiol* 2004;14:1725–31.
10. Tillman GF, Orel SG, Schnall MD, Schultz DJ, Tan JE, Solin LJ. Effect of the breast magnetic resonance imaging on the clinical management of women with early-stage breast carcinoma. *J Clin Oncol* 2002;20:3413–23.
11. Mennel JH. Ductal carcinoma in situ. In: Morris EA, Liberman I, editors. Breast MRI: diagnosis and intervention. New York (NY): Springer; 2005. p 164–72.
12. Hwang ES, Kinkel K, Esserman L, Lu Y, Weidner N, Hylton NM, et al. Magnetic resonance imaging in patients diagnosed with ductal carcinoma in situ: value in the diagnosis of residual disease, occult invasion, and multicentricity. *Ann Surg Oncol* 2003;10:381–8.
13. Kothari AD, Beechey-Newman N, Hamed H, Fentiman IS, D'Arrigo C, Hanby AM, et al. Paget disease of the nipple, a multifocal manifestation of higher-risk disease. *Cancer* 2002;95:1–7.
14. Frei KA, Bonel HM, Pelte MF, Hylton NM, Kinkel K. Paget disease of the breast: Findings at magnetic resonance imaging and histopathologic correlation. *Invest Radiol* 2005;40:363–7.
15. Orel SG, Schnall MD. MR imaging of the breast for the detection, diagnosis, and staging of the breast cancer. *Radiology* 2001;220:13–30.
16. Esserman L, Kaplan E, Partridge S, Tripathy D, Rugo H, Hwang S, et al. MRI phenotype is associated with response to doxorubicin and cyclophosphamide neoadjuvant chemotherapy in stage III breast cancer. *Ann Surg Oncol* 2001;8:549–59.
17. Frei KA, Kinkel K, Bonel HM, Lu T, Esserman LJ, Hylton NM. MR imaging of the breast in patients with positive margins after lumpectomy; influence of the time interval between lumpectomy and MR imaging. *AJR Am J Roentgenol* 2000;175:1577–84.
18. Partridge SC, Gibbs JE, Lu Y, Esserman LJ, Sudilovsky DA, Hylton NM. Accuracy of MR imaging for revealing residual breast cancer in patients who have undergone neoadjuvant chemotherapy. *AJR Am J Roentgenol* 2002;179:1193–209.
19. Rieber A, Brambs HJ, Gabelmann A, Heilmann V, Kreienberg R, Kuhn T. Breast MRI for monitoring response of primary breast cancer to neoadjuvant chemotherapy. *Eur Radiol* 2002;12:1711–9.
20. Meisamy S, Bolan PJ, Baker EH, Bliss RL, Gulbahce E, Everson LI, et al. Neoadjuvant Chemotherapy of locally advanced breast cancer: predicting response with in vivo H MR Spectroscopy-A pilot study at 4 T. *Radiology* 2004;233:424–31.
21. Morris EA, Schwartz LH, Dershaw DD, Van Zee KJ, Abramson AF, Liberman L. MR Imaging of the breast in patients with occult primary breast carcinoma. *Radiology* 1997;205:437–40.
22. Olson JA Jr, Morris EA, Van Zee KJLinehan DC, Borgen PI. Magnetic resonance imaging facilitates breast conservation for occult breast cancer. *Ann Surg Oncol* 2000;7:411–5.
23. Liberman L. Breast cancer screening with MRI. What are the data for the patients at high-risk. *N Engl J Med* 2004;351:497–500.
24. Goodman CM, Cohen V, Thornyby J, Netscher D. The life span of silicone gel breast implants and a comparison of mammography, ultrasonography, and MRI in detecting implant rupture: a meta-analysis. *Ann Plast Surg* 1998;41:577–86.