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ORIGINAL ARTICLE

The incremental value of magnetic resonance imaging for breast surgery planning

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Abstract
Purpose The aim of this study was to evaluate the effect of breast magnetic resonance imaging (MRI) on preoperative or intraoperative surgical planning.
Methods One hundred and sixty females with breast cancer were enrolled in the study. The contribution of MRI compared to MMG and USG, their histopathological concordance, and their impact on surgical treatment were evaluated prospectively.
Results In 48 (30.0%) of the patients, MRI identified suspicious lesions that were not detected by MMG and USG. The diagnosis by MRI was accurate in 17 (10.6%) of them, while in remaining 31 patients (19.4%) the additional lesions found by MRI and interpreted as malignant were found not to be malignant. The pathological accordance of MRI and MMG compared with USG were 69.3 and 70.0%, respectively, whereas individually, MMG and USG were in accordance with the pathological examination in 52.9 and 67.9% of the cases, respectively.
Conclusions Assessment of the tumor size, multifocality, multicentricity, and presence of ductal carcinoma in situ by MRI may lead to misinterpretations in the majority of patients. The surgical approach should not be changed based solely on MRI findings. An accurately interpreted MMG combined with USG may be sufficient in most cases.

Keywords Magnetic resonance imaging · Breast cancer · Surgical planning

Introduction

Magnetic resonance imaging (MRI) has been increasingly used in the preoperative evaluation of both the ipsilateral and contralateral breast in newly diagnosed breast cancer patients [1–3]. Although MRI can identify occult breast disease and plays a role in deciding on the surgical plan in about one-fifth of the patients, most recent studies do not validate the use of the technique, as there is still a subset of clinical circumstances in which the efficacy of breast MRI is still under investigation [2, 4, 5]. MRI is also used for the confirmation of MMG, USG and/or biopsy findings [6–8]. In recent studies, it has been stated that MRI leads to a more extensive surgical excision than the other two modalities [9–11]. The aim of this study was to evaluate the role of MRI in planning the surgical approach for patients with recently diagnosed breast cancer in comparison to other radiological modalities.

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Methods:

Selection and description of participants

One hundred and sixty consecutive females with a diagnosis of breast cancer were enrolled in this prospective study between August 2007 and December 2009 in the General Surgery Department of Istanbul Medical Faculty at Istanbul University. Patients with locally advanced breast cancer, and those who had no findings by either USG or MRI, while only demonstrating microcalcifications on MMG, were excluded.

All of the index lesions were visualized on MMG or USG. The diagnosis was confirmed by either fine-needle aspiration cytology or percutaneous core biopsy, including USG-guided procedures, or excisional biopsy, followed by MRI prior to definitive surgical treatment. Patients with contralateral breast cancer and those undergoing neoadjuvant chemotherapy prior to surgical excision were excluded.

The classification was made according to age, patients grouped as those aged 40 years of age and older, and those younger than 40 and according to the composition of the breast. Group A included patients with lipomatous and moderately dense breasts and Group B included those with dense or extensively dense breasts. The changes in management decisions were categorized as follows: (1) the management decision was changed from lumpectomy to mastectomy due to multicentric or extensive multifocal disease detected on MRI, (2) lumpectomy was changed to a wider excision because the primary lesion was detected as multifocal or more extensive on MRI, (3) contralateral surgery was added because of a new lesion found on MRI that was otherwise undetected,(4) the management decision was changed due to benign lesions detected either by MRI or MMG/USG, (5) neither MMG/USG nor MRI had an incremental value on treatment planning, but a recurrent surgery was performed because of positive surgical margins on histopathological examination. This last group was categorized as 'others' (Table 3).

When a change in the decision plan was made, the findings on MMG, USG, MRI, and the final histopathology were compared to determine whether the change was beneficial or unnecessary. The changes made were classified as beneficial if the histopathological results correlated only with MRI findings, and as unnecessary if there was no correlation between the histopathological and MRI findings (Table 3).

Technical information

The findings on MRI, MMG and USG were compared to determine whether a previously unknown, suspicious lesion was detected on MRI. If so, a further comparison was made to determine if the new lesion was in the contralateral or ipsilateral breast, and whether it was multifocal or multicentric. A preoperative evaluation of all patients and all of the surgical procedures, either mastectomy or breast-conserving surgery, were performed by a single center breast unit team that comprised breast surgeons and radiologists experienced in breast imaging. The MRI device used had a power of 1.5 T (Symphony, Siemens, Erlangen, Germany) and was equipped with a dedicated double breast coil. Patients were imaged in the prone position. Initially, a T2-weighted fat-saturated Turbo Spin Echo (TSE) sequence was performed in the axial plane (TR: 4,000, TE: 98, 256 × 256 matrix, 4-mm slice thickness, FOV: 30). This sequence was followed by a pre-contrast axial T1-weighted FLASH 3D sequence (TR: 9.8, TE: 4.7, 218 × 256 matrix, 2.5-mm slice thickness, FOV: 32). Then, 0.1 mmol/kg of gadopentate dimeglumine (Magnevist, Schering) was injected intravenously and the FLASH 3D sequence was repeated 5 times with the same parameters used in the pre-contrast acquisition. Each dynamic sequence took approximately 90 s. Finally, a sagittal T1-weighted, fat-saturated TSE sequence was performed (TR: 650, TE: 15, 192 × 256 matrix, FOV: 30). Following the acquisition, the axial pre-contrast FLASH 3D sequence was subtracted from all of the axial post-contrast FLASH 3D images on a workstation (Syngo, Siemens, Erlangen, Germany). The main evaluation was conducted using these subtracted images.

Statistical analysis

The statistical analysis was performed using the SPSS 15.0 (SPSS Inc., Chicago, IL, USA) software program. A Chi-square analysis was used to identify and compare the factors. For all statistical comparisons, a p value ≤ 0.05 was considered to be significant.

Results

The mean age of the patients was 45 years (range 21–83). Invasive ductal carcinoma was reported in 113 cases (70.6%), invasive lobular carcinoma in 7 (4.4%), mixed type in 14 (8.75%), ductal carcinoma in situ in 4 (2.5%) and other types of breast carcinoma in 22 patients (13.75%). The demographic characteristics of the patients are summarized in Table 1.

False positive (FP) and false negative (FN) results obtained by MRI constituted 11.3% (18/160) and 9.4% (15/160) of the cases, respectively. With regard to breast density, MRI resulted in 10 (10.0%) FP and 7 (7.0%) FN results in Group A (n 100) and 8 (13.3%) FP and 8 (13.3%)

Table 1 The patients' characteristics

Factor	Number	Percentage (%)
Mean age (range)	45 (21–83)	
Mean age at menopause (range)	48 (42–56)	
Lactation		
>12 months	45	28.1
Menopausal status		
Pre-menopausal	94	58.75
Post-menopausal	66	41.25
Use of hormone replacement therapy		
>12 months	6	4.3
Palpable mass		
Present	130	81.25
Absent	30	18.75
Histopathology		
IDC	113	70.6
ILC	7	4.4
Mixed type	14	8.75
DCIS	4	2.5
Other types of breast cancer[a]	22	13.75
Surgery		
BCS	101	63.1
Mastectomy	59	36.9
Re-excision	39	24.4

IDC invasive ductal carcinoma, *ILC* invasive lobular carcinoma, *DCIS* ductal carcinoma in situ, *BCS* breast-conserving surgery

[a] Mucinous, papillary and signet ring cell types of breast cancer

Table 2 The number of lesions detected by MMG, USG and MRI

	MMG (*n*)	USG (*n*)	MRI (*n*)
Unifocal lesions	95	101	82
Multifocal lesions	15	31	30
Multicentric lesions	5	11	17
Benign lesions	2	13	12
DCIS	2	–	2
DCIS around unifocal tumor	12	3	14
Axillary lymph node affected	3	–	–
Bilateral lesions	0	1	3
No abnormality	26	–	–

MMG mammography, *USG* ultrasound, *MRI* magnetic resonance imaging

FN results in Group B (*n* 60). There was no statistically significant relationship between the breast density and FN or FP MRI findings ($p = 0.81$, $p = 0.26$).

The tumor characteristics are shown in Table 2. In 112 patients (70.0%), the results of MMG and USG were in concordance with the MRI findings. MRI detected various suspicious lesions that were not detected on MMG and USG in 48 patients (30.0%). The change in the surgical plan according to the diagnosis by MRI was correct in 10.6% of the patients (17/160). Additional lesions found on MRI in 19.4% (31/160) of cases were misdiagnosed, which led to an incorrect or unnecessary change in the surgical plan.

In the first group, there were 11 patients (6.9%) for whom the MRI findings suggested that the procedure should be changed from lumpectomy to mastectomy. It was beneficial to perform mastectomy instead of breast-conserving surgery in 6 cases (3.8%). Mastectomy was unnecessary in 5 (3.1%), which was performed based on the MRI findings of multicentricity in three cases and extensive ductal carcinoma in situ around the index tumor in two cases, as no multicentric focus or extensive in situ carcinoma was found in the histopathological examination of the specimen (Table 3).

In the second group which required wider excision according to MRI findings, the procedure was beneficial for 6 patients (3.8%), in whom it was shown that there was no multicentric tumor, but a multifocal lesion or a more extensive primary lesion, which resulted in the performance of breast-conserving surgery. MRI was harmful for 20 patients (12.5%), and had indicated that there was extensive local distribution of the tumor warranting mastectomy. However, the surgical and pathological experience led to preservation of the breast with tissue shifts after wide optimal excisions (Table 3).

In the third group, there were 4 patients (2.5%) with contralateral MRI findings. The use of MRI was beneficial in one patient (0.6%) because it discovered a unifocal tumor, but it resulted in unnecessary excisional biopsies in three patients (1.9%) due to overdiagnosis (Table 3).

In the fourth group, there were 7 (4.4%) patients with lesions that were classified as benign. MRI was beneficial in 4 patients (2.5%) because it detected carcinoma in the lesions diagnosed as benign by MMG and USG. However, MRI misdiagnosed malignant lesions as benign in three cases (1.9%) which were diagnosed correctly by MMG and USG. The diagnosis of malignancy was confirmed by a histopathological evaluation.

In the fifth group, all three modalities failed. Even though the tumor was shown by all three imaging methods, 5 patients (3.13%) had to undergo multiple re-excisions, with two resulting in mastectomy. Because an extension of disease could not be precisely determined before the operation, multiple procedures therefore had to be carried out during surgery (Table 3).

In total, MRI detected 48 (30.0%) additional suspicious lesions that were not detected on MMG and USG. The lesions were diagnosed accurately in 17 patients (10.6%), and the surgical approach was changed in these patients, resulting in a survival change due to a decrease in the rate of misdiagnosis. However, in 31 cases (19.4%), a false

Table 3 The beneficial and unnecessary changes in surgical decisions related to the MRI findings

All additional procedures related to MRI findings (30.0%, $n = 48$)	Beneficial changes (accurate) (10.6%, $n = 17$)	Unnecessary changes (misdiagnosed) (19.4%, $n = 31$)
Change from lumpectomy to mastectomy (6.9%, $n = 11$)	(3.8%, $n = 6$)	(3.13%, $n = 5$)
Wider excision[a] (16.3%, $n = 26$)	(3.8%, $n = 6$)	(12.5%, $n = 20$)
Contralateral surgery (2.5%, $n = 4$)	(0.6%, $n = 1$)	(1.9%, $n = 3$)
Excision of benign lesions (4.4%, $n = 7$)	(2.5%, $n = 4$)	(1.9%, $n = 3$)
Others (recurrent surgery) (3.13%, $n = 5$)	0	(3.13%, $n = 5$)

[a] No change in the surgical approach, but wider excisions were performed

Table 4 The histopathological concordance rates of different radiological modalities

	Pathological compliance (n, %)
MMG	74 (52.9%)
USG	95 (67.9%)
MMG + USG	98 (70.0%)
MRI	97 (69.3%)

diagnosis was made by MRI, and the surgical plan was misdirected (Table 3). The concordance of radiological methods with the histopathological results was 52.9% for MMG, 67.9% for USG, 70.0% for the combination of MMG and USG, and 69.3% for MRI. No significant difference was found between these three diagnostic methods (Table 4).

Discussion

The results of preoperative breast MRI can alter the selection of therapeutic procedures, but all alterations are not beneficial for the patient and the decision making team. Unnecessary operations for benign lesions and unnecessary mastectomies for misdiagnosed lesions are disadvantageous [6, 9, 12–16]. Additional imaging studies and biopsies can delay surgery by several days or weeks. Although it is unlikely to affect the course of the disease, both the delay and false positive findings detected lead to increased patient anxiety [17, 18].

The power of this study comes from the fact that it is prospectively designed, and that the evaluation of MRI findings was performed by the same radiologist, and the evaluation of specimens was performed by the same pathology team. In the study by Sardanelli and co-workers [19], MRI was concluded to be more sensitive than mammography for the detection of malignant foci in fibroglandular and dense breasts compared with fatty breasts. In contrast, Deurloo et al. [12] showed that mammographic breast density was not correlated with the complementary value of MRI to assess the tumor extent. In our study, there was no significant difference between the dense and lipomatous breasts in the rates of false positive and negative results of MRI, but in breasts with moderate density, both rates were found to be higher for MRI (FP 13.3 vs. 10.0%; FN 13.3 vs. 7.0%). However, larger studies are required to determine the influence of breast density on the patient benefit from breast MRI. [12].

The false positive ratio was found to be 5.5% in the meta-analysis by Houssima [5]. Siegman et al. [9] and Bedrosian et al. [20] reported 10.1 and 7.5% false positive rates for MRI in detecting lesions, respectively. Our current false positive (11.3%) and false negative (9.4%) rates for MRI were similar to those of other studies.

In their meta-analysis of 19 studies, Houssami et al. [5] have shown that the median prevalence of detection of additional foci of cancer within the affected breast with preoperative MRI is 16% (interquartile range 6–34%) based on 2,610 female patients with recently diagnosed cancer. The detection of additional lesions is important because it may change the decision about the type of surgery to be performed. In our study, MRI detected additional suspicious lesions, not shown in MMG and USG, in 30.0% of the cases. The differences between studies may be due to the different MRI techniques used in different centers. MRI examination changed the surgical therapy selected in 7.8 to 33.3% of cases in the studies analyzed by Houssami et al. [5], and virtually always in the direction to a more extensive surgery, such as a wider excision or a mastectomy that would not otherwise have been performed. Pengel et al. [21] showed that there was an MRI-induced treatment change in 11% of patients (to mastectomy in 8.7% and to a wider excision in 2.3%). In contrast, Bleicher and colleagues [10] found no significant difference in the likelihood of requiring conversion from BCS to mastectomy based on preoperative MRI findings. In different series, the rate of changing the treatment modality from BCS to mastectomy was reported to increase from 6.5 to 25% with the application of MRI [7, 20, 22, 23]. In our study, MRI changed surgical therapy from BCS to mastectomy in 6.9% of the cases. Some

patients with multifocal disease underwent wider excisions for better local control. The incidence of performing wider excisions has increased from 3 to 13.5% with MRI for additional lesions found [7, 20, 22, 23]. Our data were similar, in that MRI-directed wider excisions were performed in 16.3% of the patients in our study.

The rate of the correct and incorrect surgical changes is more important than the surgical treatment changes. The European Society of Breast Cancer Specialists (EUSOMA) has reported a correct change in treatment (different surgical access, wider excision, excision of another lesion in the same or contralateral breast) in 12–32% of patients, while an incorrect change has been recorded in 3–30% of patients who have undergone a preoperative breast MRI [7, 12, 20, 24–29]. In the meta-analysis of 19 studies by Houssami et al., true conversion from wide local excision to mastectomy was performed in 8.1% of cases (range 5.9–11.3%) and from wide local excision to more extensive surgery in 11.3% of cases with multifocal/multicentric disease (range 6.8–18.3%). Due to the false positive detection of lesions by MRI (in patients who did not actually have additional malignancy on histology) conversion from a wide local excision to mastectomy was made in 1.1% of cases (95% CI 0.3–3.6) and from a wide local excision to more extensive surgery in 5.5% of cases (95% CI 3.1–9.5) [5]. Berg and colleagues [7] found that 12% of patients underwent a medically unnecessary mastectomy rather than undergoing further workup of abnormal MRI findings. Petit and colleagues reported that the type operation in 36 of 410 patients who were believed to be candidates for breast-conserving surgery was converted to mastectomy because of additional lesions detected by MRI. In 23 cases, confirmation of malignancy by biopsy for the additional lesion was not performed, and more than half of those revealed no additional cancer [30].

If we evaluate all of our patients examined by MRI, 10.6% of the additional lesions detected were accurately diagnosed, and 19.4% were misdiagnosed. Conversion from breast-conserving surgery to mastectomy was performed in 6.9% of the cases, 3.8% of which were appropriate because of multicentricity and extensive in situ cancer, while mastectomy was unnecessary in 3.13% of the cases. The low rate of unnecessary surgical approaches can be explained by the performance of surgery by a dedicated breast team, which clearly led to a reduction in the unnecessary interventions. The cancer foci visualized only by MRI should not be a reason for performing mastectomy in all patients [31]. Although MRI-guided biopsy of the additional lesions or of the additional extent of a known cancer can decrease the mastectomy rates [31], pre-operative MRI should only be offered by institutions that can offer MRI-guided biopsy in such circumstances [31, 32]. Although it is clear that the problem associated with inappropriately performed surgery because of false positive MRI results can be minimized by biopsy confirmation, there are some practical difficulties associated with this approach [33].

In our series, MRI directed 16.25% of the cases to wider excisions, more than the rate in other series. In total, 12.5% of these changes were unnecessary, while 3.8% were beneficial. Regardless of how the imaging modalities define the local extent of the disease (unicentric, multifocal, extensive in situ carcinoma), optimal excision can only be performed in the operating room with the cooperation of the surgeon and the pathologist, even with multiple re-excisions. Liberman and colleagues [27] also noted that most of the additional tumors detected were in the same quadrant as the index lesion. These findings correlate well with the observations of Holland and colleagues [34], indicating that 96% of pathologically detected tumor foci were found within 4 cm of the index tumor. In our opinion, the determination of the surgical approach is more important than tumor size detected according to the MRI findings. The close cooperation of the surgeon and the pathologist and also the experience of the surgeon are essential in ensuring the best preoperative and intraoperative evaluation of breast carcinoma. In the cases with multifocal lesions, we believe that satisfactory collaboration between the surgeon and pathologist may therefore prevent recurrent interventions.

Several single institution studies [1, 2, 24, 35] and one large multicenter study [36] have shown that MRI can detect otherwise occult contralateral malignancy in about 3–4% of breast cancer patients. However, in the multicenter study, biopsy recommendations for contralateral lesions were made for 13% of patients [36]. In a meta-analysis of MRI of the contralateral breast, Brennan and colleagues [37] reported a 9.3% incidence of abnormalities detected by MRI in the contralateral breast (true-positive plus false positive), with a positive predictive value of 47.9%.

In our study, one (0.6%) appropriate surgical intervention was applied when clinically and mammographically occult contralateral disease was detected by breast MRI. Contralateral breast tumors were detected by MRI in another 3 patients (1.9%), and unnecessary excisional biopsies were performed. MRI detected unifocal tumor in 4 patients (2.5%), although MMG and USG defined them as benign lesions, and beneficial lumpectomies were performed as intraoperative frozen sectioning of the masses revealed invasive tumor. In contrast, USG and MMG defined unifocal lesions, but MRI indicated that the lesions were benign in 3 patients (1.9%) that were diagnosed as carcinoma following lumpectomy. Although the sensitivity of breast MRI in the detection of malignant lesions is 97–100%, the specificity was found to be 50–80%

[24, 38, 39]. For that reason, the differential diagnosis of small foci seen on MRI but not detected by physical examination or by USG and MMG is difficult, and increases the rate of unnecessary biopsies.

In our study, the lesions other than the index lesion (multifocal/multicentric/contralateral) detected only by MRI were proven benign or malignant only after surgery. We could not make a preoperative diagnosis at that time, since we had not yet started to perform MRI-guided breast biopsy procedures. Although some studies have revealed that MRI findings were more reliable for the determination of tumor size, the results of our series do not support this finding. Sometimes, the abnormal findings detected on MRI are accepted directly to be a tumor focus without being confirmed by a histopathological analysis. Ultimately, the question is whether the benefits of breast MRI outweigh the costs, including the additional diagnostic procedures performed as a result of MRI findings, the more aggressive surgical treatment, and the potential psychosocial costs of increased emotional distress [4]. These findings strongly suggest that MRI is capable of finding some, but not all, of the tumor foci identified with detailed histopathological sectioning [33].

In conclusion, our current data and the previous studies suggest that MRI should not take the place of the routine imaging protocols for patients before lumpectomy, except for limited indications. Although the current data are insufficient to justify any specific recommendations for the use of breast MRI in breast-conserving surgery, selective use depends on the knowledge of multidisciplinary experience. Which individual cases may cause problems should be decided by a detailed breast examination incorporating imaging findings. Surgeons should take part in the evaluation of the results of all imaging modalities, and correlations with the operative and histopathological findings should be provided to gain experience in making a decision about what to do and when.

Conflict of interest None of the authors have any conflict of interest.

References

1. Lee SG, Orel SG, Woo IJ, Cruz-Jove E, Putt ME, Solin LJ, et al. MR imaging screening of the contralateral breast in patients with newly diagnosed breast cancer: preliminary results. Radiology. 2003;226:773–8.
2. Liberman L, Morris EA, Kim CM, Kaplan JB, Abramson AF, Menell JH, et al. MR imaging findings in the contralateral breast of women with recently diagnosed breast cancer. AJR Am J Roentgenol. 2003;180:333–41.
3. Viehweg P, Rotter K, Laniado M, Lampe D, Buchmann J, Kölbl H, et al. MR imaging of the contralateral breast in patients after breast-conserving therapy. Eur Radiol. 2004;14:402–8.
4. Sorbero ME, Dick AW, Beckjord EB, Ahrendt G. Diagnostic breast magnetic resonance imaging and contralateral prophylactic mastectomy. Ann Surg Oncol. 2009;16:1597–605.
5. Houssami N, Ciatto S, Macaskill P, Lord SJ, Warren RM, Dixon JM, et al. Accuracy and surgical impact of magnetic resonance imaging in breast cancer staging: systematic review and meta-analysis in detection of multifocal and multicentric cancer. J Clin Oncol. 2008;26:3248–58.
6. Van Goethem M, Schelfout K, Dijckmans L, Van Der Auwera JC, Weyler J, Verslegers I, et al. MR mammography in the pre-operative staging of breast cancer in patients with dense breast tissue: comparison with mammography and ultrasound. Eur Radiol. 2004;14:809–16.
7. Berg WA, Gutierrez L, NessAiver MS, Carter WB, Bhargavan M, Lewis RS, et al. Diagnostic accuracy of mammography, clinical examination, US and MR imaging in preoperative assessment of breast cancer. Radiology. 2004;233:830–49.
8. Van Goethem M, Tjalma W, Schelfout K, Verslegers I, Biltjes I, Parizel P. Magnetic resonance imaging in breast cancer. Eur J Surg Oncol. 2006;32:901–10.
9. Siegmann KC, Baur A, Vogel U, Kraemer B, Hahn M, Claussen CD. Risk-benefit analysis of preoperative breast MRI in patients with primary breast cancer. Clin Radiol. 2009;64:403–13.
10. Bleicher RJ, Ciocca RM, Egleston BL, Sesa L, Evers K, Sigurdson ER, et al. Association of routine pretreatment magnetic resonance imaging with time to surgery, mastectomy rate, and margin status. J Am Coll Surg. 2009;209:180–7.
11. Bassett LW, Dhaliwal SG, Eradat J, Khan O, Farria DF, Brenner RJ, et al. National trends and practices in breast MRI. AJR Am J Roentgenol. 2008;191:332–9.
12. Deurloo EE, Klein Zeggelink WFA, Teertstra HJ, Peterse JL, Rutgers EJ, Muller SH, et al. Contrast-enhanced MRI in breast cancer patients eligible for breast-conserving therapy: complementary value for subgroups of patients. Eur Radiol. 2006;16:692–701.
13. Libermann L, Breast MR. Imaging in assessing extent of disease. Magn Reson Imaging Clin N Am. 2006;14:339–49.
14. Ozaki S, Tozaki M, Fukuma E, Kawano N, Suzuki T, Yamashiro N, et al. Bilateral breast MRI: is it superior to conventional methods for the detection of contralateral breast cancer? Breast Cancer. 2008;15:169–74.
15. Solin LJ, Orel SG, Hwang W-T, Harris EE, Schnall MD. Relationship of breast magnetic resonance imaging to outcome after breast-conservation treatment with radiation for women with early-stage invasive breast carcinoma or ducal carcinoma in situ. J Clin Oncol. 2008;26:386–91.
16. Tillman GF, Orel SG, Schnall MD, Schultz DJ, Tan JE, Solin LJ. Effect of breast magnetic resonance imaging on the clinical management of women with early-stage breast carcinoma. J Clin Oncol. 2002;20:3413–23.
17. Schell AM, Rosenkranz K, Lewis PJ. Role of breast MRI in the preoperative evaluation of patients with newly diagnosed breast cancer. AJR Am J Roentgenol. 2009;192:1438–44.
18. Lord SJ, Lei W, Craft P, Cawson JN, Morris I, Walleser S, et al. A systematic review of the effectiveness of magnetic resonance imaging (MRI) as an addition to mammography and ultrasound in screening young women at high risk of breast cancer. Eur J Cancer. 2007;43:1905–17.
19. Sardanelli F, Giuseppetti GM, Panizza P, Bazzocchi M, Fausto A, Simonetti G, et al. Sensitivity of MRI versus mammography for detecting foci of multifocal, multicentric breast cancer in fatty and dense breasts using the whole-breast pathologic examination as a gold standard. AJR Am J Roentgenol. 2004;183:1149–57.
20. Bedrosian I, Mick R, Orel SG, Schnall M, Reynolds C, Spitz FR, et al. Changes in the surgical management of patients with breast

carcinoma based on preoperative magnetic resonance imaging. Cancer. 2003;98:468–73.
21. Pengel KE, Loo CE, Teertstra HJ, Muller SH, Wesseling J, Peterse JL, et al. The impact of preoperative MRI on breast-conserving surgery of invasive cancer: a comparative cohort study. Breast Cancer Res Treat. 2009;116:161–9.
22. Bilimoria KY, Cambic A, Hansen NM, Bethke KP. Evaluating the impact of preoperative breast magnetic resonance imaging on the surgical management of newly diagnosed breast cancers. Arch Surg. 2007;142:441–7.
23. Deurloo EE, Peterse JL, Rutgers EJ, Besnard AP, Muller SH, Gilhuijs KG. Additional breast lesions in patients eligible for breast-conserving therapy by MRI: impact on preoperative management and potential benefit of computerised analysis. Eur J Cancer. 2005;41:1393–401.
24. Fischer U, Kopka L, Grabbe E. Breast carcinoma: effect of preoperative contrast-enhanced MR imaging on the therapeutic approach. Radiology. 1999;213:881–8.
25. Esserman L, Hylton N, Yassa L, Barclay J, Frankel S, Sickles E. Utility of magnetic resonance imaging in the management of breast cancer: evidence for improved preoperative staging. J Clin Oncol. 1999;17:110–9.
26. Tan JE, Orel SG, Schnall MD, Schultz DJ, Solin LJ. Role of magnetic resonance imaging and magnetic resonance imaging-guided surgery in the evaluation of patients with early-stage breast cancer for breast conservation treatment. Am J Clin Oncol. 1999;22:414–8.
27. Liberman L, Morris EA, Dershaw DD, Abramson AF, Tan LK. MR imaging of the ipsilateral breast in women with percutaneously proven breast cancer. AJR Am J Roentgenol. 2003;180:901–10.
28. Del Frate C, Borghese L, Cedolini C, Bestagno A, Puglisi F, Isola M, et al. Role of pre-surgical breast MRI in the management of invasive breast carcinoma. Breast. 2007;16:469–81.
29. Braun M, Polcher M, Schrading S, Zivanovic O, Kowalski T, Flucke U, et al. Influence of preoperative MRI on the surgical management of patients with operable breast cancer. Breast Cancer Res Treat. 2008;111:179–87.
30. Pettit K, Swatske ME, Gao F, Salavaggione L, Gillanders WE, Aft RL, et al. The impact of breast MRI on surgical decision-making: are patients at risk for mastectomy? J Surg Oncol. 2009;100:553–8.
31. Kuhl C, Kuhn W, Braun M, Schild H. Pre-operative staging of breast cancer with breast MRI: one step forward, two steps back? The Breast. 2007;16:34–44.
32. Sakamoto N, Tozaki M, Higa K, Abe S, Ozaki S, Fukuma E. False-negative ultrasound-guided vacuum-assisted biopsy of the breast: difference with US-detected and MRI-detected lesions. Breast Cancer. 2010;17(2):110–7.
33. Bloom S, Morrow M. A Clinical Oncologic Perspective on Breast Magnetic Resonance Imaging. Magn Reson Imaging Clin N Am. 2010;18:277–94.
34. Holland R, Veling SH, Mravunac M, Hendriks JH. Histologic multifocality of Tis, T1–2 breast carcinomas. Implications for clinical trials of breast-conserving surgery. Cancer. 1985;56:979–90.
35. Hollingsworth AB, Stough RG, O'Dell CA, Brekke CE. Breast magnetic resonance imaging for preoperative locoregional staging. Am J Surg. 2008;196:389–97.
36. Lehman CD, Gatsonis C, Kuhl CK, Hendrick RE, Pisano ED, Hanna L, et al. MRI evaluation of the contralateral breast in women with recently diagnosed breast cancer. N Engl J Med. 2007;356:1295–303.
37. Brennan ME, Houssami N, Lord S, Macaskill P, Irwig L, Dixon JM, et al. Magnetic resonance imaging screening of the contralateral breast in women with newly diagnosed breast cancer: systematic review and meta-analysis of incremental cancer detection and impact on surgical management. J Clin Oncol. 2009;27:5640–9.
38. Al-Khawari H, Kovacs A, Athyal R, Al-Manfouhi H, Fayaz MS, Madda JP. Breast magnetic resonance imaging: initial experience in Kuwait. Med Princ Pract. 2009;18:143–8.
39. Lee CH. Problem solving MR imaging of the breast. Radiol Clin North Am. 2004;42:919–34.