Positive Predictive Value of BI-RADS MR Imaging[1]

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Purpose: To evaluate the positive predictive values (PPVs) of Breast Imaging and Reporting Data Systems (BI-RADS) assessment categories for breast magnetic resonance (MR) imaging and to identify the BI-RADS MR imaging lesion features most predictive of cancer.

Materials and Methods: This institutional review board–approved HIPAA-compliant prospective multicenter study was performed with written informed consent. Breast MR imaging studies of the contralateral breast in women with a recent diagnosis of breast cancer were prospectively evaluated. Contralateral breast MR imaging BI-RADS assessment categories, morphologic descriptors for foci, masses, non-masslike enhancement (NMLE), and kinetic features were assessed for predictive values for malignancy. PPV of each imaging characteristic of interest was estimated, and logistic regression analysis was used to examine the predictive ability of combinations of characteristics.

Results: Of 969 participants, 71.3% had a BI-RADS category 1 or 2 assessment; 10.9%, a BI-RADS category 3 assessment; 10.0%, a BI-RADS category 4 or 5 assessment; and 7.7%, a BI-RADS category 0 assessment on the basis of initial MR images. Thirty-one cancers were detected with MR imaging. Overall PPV for BI-RADS category 4 and 5 lesions was 0.278, with 17 cancers in patients with a BI-RADS category 4 lesion (PPV, 0.205) and 10 cancers in patients with a BI-RADS category 5 lesion (PPV, 0.714). Of the cancers, one was a focus, 17 were masses, and 13 were NMLEs. For masses, irregular shape, irregular margins, spiculated margins, and marked internal enhancement were most predictive of malignancy. For NMLEs, ductal, clumped, and reticular or dendritic enhancement were the features most frequently seen with malignancy. Kinetic enhancement features were less predictive of malignancy than were morphologic features.

Conclusion: Standardized terminology of the BI-RADS lexicon enables quantification of the likelihood of malignancy for MR imaging–detected lesions through careful evaluation of lesion features. In particular, BI-RADS assessment categories and morphologic descriptors for masses and NMLE were useful in estimating the probability of cancer.

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The Breast Imaging Reporting and Data System (BI-RADS) lexicon was initially developed by the American College of Radiology to standardize terminology used to report findings on mammograms (1). The most recent edition (2) expanded the lexicon to include breast ultrasonographic (US) and breast magnetic resonance (MR) imaging studies. The MR imaging lexicon includes terms used to describe morphologic characteristics of breast lesions (*focus*, *mass*, *non-masslike enhancement* [NMLE]) and kinetic features (*initial enhancement*, *delayed enhancement*) and defines final assessment categories to describe the level of suspicion regarding MR findings. The lexicon has been evaluated, and it has been found useful in quantification of the likelihood of carcinoma for mammographic (3) and US (4) abnormalities. This study was undertaken to evaluate the positive predictive values (PPVs) of BI-RADS assessment categories for breast MR imaging and to identify the BI-RADS MR imaging lesion features most predictive of cancer. Breast Imaging Reporting and Data System.

Advances in Knowledge

- In a large prospective multicenter trial of screening breast MR imaging, the mass lesion features most predictive of malignancy were irregular shape (positive predictive value [PPV], 0.306), spiculated margins (PPV, 0.333), and marked internal enhancement (PPV, 0.231); the type of NMLE most likely to represent cancer was ductal enhancement (PPV, 0.500).
- The likelihood of cancer was higher for rapid initial enhancement in comparison with slow initial enhancement (odds ratio [OR], 3.402), and both plateau (PPV, 0.152), and washout (PPV, 0.178) patterns of delayed enhancement were associated with cancer.
- Among patients with BI-RADS category 4 or 5 lesions, 28% had breast cancer.

Materials and Methods

This Health Insurance Portability and Accountability Act–compliant prospective multicenter study was performed after institutional review board approval was obtained at each center and after every patient provided written informed consent. The patient population consisted of women enrolled in American College of Radiology Imaging Network protocol 6667, entitled *MR Imaging Evaluation of the Contralateral Breast in Women with a Recent Diagnosis of Breast Cancer*. Participants were accrued for this study from April 1, 2003, to June 10, 2004 (5). There were 25 sites included in the study with 50 total readers. Participating radiologists had to have interpreted a minimum of 50 breast MR imaging studies and had to have performed at least five MR-guided breast biopsies.

Eligible women with negative findings at mammography and at clinical examination of the contralateral breast within 90 days of new diagnosis of breast cancer underwent MR imaging of the contralateral breast within 60 days after diagnosis. Women were excluded from the study if they had undergone breast MR imaging within 12 months before enrollment, if they were pregnant, or if they had a contraindication to MR imaging (an implanted magnetic device or severe claustrophobia). Additional exclusion criteria were a breast cancer diagnosis made more than 60 days before enrollment or chemotherapy or hormonal therapy for breast cancer within 6 months before enrollment.

Lesions detected with MR imaging were classified according to BI-RADS descriptors for MR imaging, including morphologic and kinetic features. Foci were described as areas of discrete enhancement smaller than 5 mm in size. Masses were described by shape (round, oval, lobulated, irregular), margins (smooth, irregular, spiculated), internal enhancement (homogeneous, heterogeneous, rim enhancement, dark internal septations, enhanced internal septations, central internal enhancement), and degree of enhancement (mild, <25% signal intensity increase compared with unenhanced signal intensity; moderate, 25%–50% signal intensity increase; marked, >50% signal intensity increase). NMLE was described by the type of enhancement (focal area, linear, ductal, segmental, regional, multiple regions, diffuse), its symmetry, and its internal enhancement characteristics (homogeneous, heterogeneous, stippled or punctate, clumped, and reticular or dendritic). The kinetic features for lesions were evaluated and included both the initial enhancement features and the delayed enhancement features, although not all sites collected these data. Additional data collected characterized associated MR imaging findings, such as skin and nipple changes, presence of edema, and chest wall involvement. The most suspicious features were used to categorize

Implication for Patient Care

- Careful evaluation of morphologic and kinetic features of breast MR imaging lesions with the BI-RADS lexicon enables differentiation of most benign and malignant lesions.

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Abbreviations:
BI-RADS = Breast Imaging and Reporting Data System
CI = confidence interval
NMLE = non-masslike enhancement
OR = odds ratio
PPV = positive predictive value

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each lesion according to the BI-RADS assessment categories.

Participants with BI-RADS category 1 or 2 lesions required no further evaluation. Participants with BI-RADS category 3 lesions were recommended for 6-month follow-up MR imaging. Participants with BI-RADS category 4 or 5 lesions were recommended for biopsy. In most of these patients, a targeted US study was performed to determine if a US correlate was present to enable US-guided biopsy. Otherwise, MR-guided biopsy was performed. In some cases, participants went directly to surgical biopsy or mastectomy due to patient or physician preference.

Participants who underwent needle biopsy and in whom histologic analysis yielded atypical, high-risk, or malignant results were referred for surgical excision. Follow-up imaging results and histopathologic data were reviewed and correlated with the MR imaging BI-RADS assessment for each participant.

Data at 1-year follow-up were sought for all patients, regardless of BI-RADS assessment, as part of the study protocol.

Data were recorded on standardized American College of Radiology Imaging Network data collection forms and were entered online into the American College of Radiology Imaging Network database. For the reference standard, findings were considered positive for cancer if pathologic review of tissue from a biopsy performed within 365 days of screening MR imaging yielded a diagnosis of ductal carcinoma in situ or invasive cancer. Statistical analysis was performed at the Biostatistics Center of Brown University by using statistical software (SAS, version 9.1.3; SAS Institute, Cary, NC). The analysis proceeded in two steps: First, the PPV of each imaging characteristic of interest was estimated as the proportion of all known cases with cancer among those who exhibited the particular characteristic at initial MR imaging. Exact 95% confidence intervals (CIs) were calculated for each PPV estimate. Second, logistic regression analysis was used to examine the predictive ability of combinations of characteristics.

Results

Evaluation of Cancers with BI-RADS Assessment Categories

A total of 969 participants underwent breast MR imaging and comprised the analysis set. All patients had prior normal mammograms obtained within 90 days of enrollment. Of the 969 patients, 71.3% (n = 691) had a BI-RADS category 1 (n = 478) or 2 (n = 213) assessment. No further evaluation was recommended by the reading radiologist, but 1-year follow-up data were sought for all patients as part of the study protocol. Data were obtained for 408 of 478 (85.4%) patients with BI-RADS category 1 assessment and 179 of 213 (84.0%) patients with BI-RADS category 2 assessment. Malignancy was identified in two participants with BI-RADS category 1 assessment at biopsy within the 1st year after screening (0.4%) and in none of the participants with BI-RADS category 2 assessment.

A total of 106 participants (10.9%) had a BI-RADS category 3 assessment, and short-term follow-up MR imaging was recommended. Of these patients, 95.2% (n = 101) underwent either biopsy or additional evaluation and follow-up. A total of 71 participants underwent short-interval follow-up MR imaging, defined as follow-up MR imaging less than 8 months after initial MR imaging. Of the remaining 35 patients, 13 underwent mastectomy or biopsy; 17 underwent imaging follow-up more than 8 months after initial MR imaging with mammography (n = 6), US (n = 9), or MR imaging (n = 2); and five were lost to follow-up. One malignant lesion was identified in a patient who was undergoing mastectomy and yielded a PPV of 0.009 (95% CI: 0, 0.051).

A total of 97 participants (10.0%) had a BI-RADS category 4 (n = 83) or 5 (n = 14) assessment and were recommended for biopsy. Of the 83 patients with a BI-RADS category 4 assessment, 72 (86.7%) underwent biopsy, and 17 malignancies were diagnosed, yielding a PPV of 0.205 (95% CI: 0.124, 0.308). Of the remaining 11 patients, seven underwent targeted US, two underwent annual mammography, one underwent short-interval follow-up MR imaging, and one underwent 6-month follow-up targeted US, all with negative results. All patients with a BI-RADS category 5 assessment underwent biopsy, with malignancy diagnosed in 10 of the 14 patients, yielding a PPV of 0.714 (95% CI: 0.419, 0.916).

A total of 75 participants (7.7%) had a BI-RADS category 0 assessment at initial MR imaging. In the immediate period after MR imaging, 70 of these patients underwent targeted US, two underwent biopsy, two underwent mammography, and one was lost to follow-up. Eventually, short-interval follow-up MR imaging was performed in 22 participants and biopsy was performed in 41. Biopsies consisted of 30 core-needle biopsies, four surgical excisional biopsies, five mastectomies, and two fine-needle aspirations. A malignant diagnosis was made in three of these 75 participants, yielding a PPV of 0.040 (95% CI: 0.008, 0.112) (Table 1).

Evaluation of Cancers with Lesion Morphology

A total of 278 participants had lesions on the initial MR images that were assessed as BI-RADS category 0, 3, 4, or 5 lesions. Of these 278 lesions, 52 (18.7%) were foci, 121 (43.5%) were masses, 102 (36.7%) were NMLE, one (0.4%) was due to precontrast ductal high signal intensity, and two (0.7%) had no findings. Cancer was found in 31 of the 278 patients. The cancers included one focus (PPV, 0.019; 95% CI: 0, 0.103), 17 masses (PPV, 0.140; 95% CI: 0.084, 0.215), and 13 areas of NMLE (PPV, 0.127; 95% CI: 0.07, 0.208) (Table 2). In logistic regression analysis, foci were less likely to be cancers than were masses (odds ratio [OR], 0.120; 95% CI: 0.016, 0.927), but the likelihood of cancer was not significantly different between masses and NMLE lesions.

Masses.—The mass shape with the highest PPV for cancer was irregular shape (PPV, 0.306; 95% CI: 0.163, 0.481), while oval shape had the lowest PPV for cancer (PPV, 0.051; 95% CI: 0.006, 0.173) (Table 3). In regard to mass margins, the highest PPVs for

Table 1

Evaluation of Cancers by BI-RADS Categories

BI-RADS Category	Definition	No. of Patients	No. of Patients with Imaging Follow-up*	No. of Patients with Cancer	PPV†
3	Probably benign finding, short-interval follow-up	106 (10.9)	91 (85.8)	1	0.009 (0.000, 0.051)
4	Suspicious abnormality, biopsy should be considered	83 (8.6)	67 (79.8)	17	0.205 (0.124, 0.308)
5	Highly suggestive of malignancy	14 (1.4)	11 (78.6)	10	0.714 (0.419, 0.916)
0	Incomplete, need additional evaluation	75 (7.7)	62 (82.7)	3	0.040 (0.008, 0.112)

Note.—Unless otherwise indicated, data in parentheses are percentages.

* A participant is considered to have completed follow-up (n = 818) if she reported having undergone breast imaging (mammography, US, or MR imaging) at least 9 months after initial MR imaging. In addition, 91 women underwent mastectomy of the contralateral breast, and 21 underwent breast imaging imaging between 3 and 9 months after initial MR imaging.

† Data in parentheses are 95% CIs.

Table 2

Evaluation of Cancers by Lesion Morphology for BI-RADS Category 0, 3, 4, and 5 Assessments

Morphology	No. of Patients*	No. of Patients with Cancer	PPV†
Focus	52 (18.7)	1	0.019 (0.0004, 0.103)
Mass	121 (43.5)	17	0.140 (0.084, 0.215)
NMLE	102 (36.7)	13	0.127 (0.070, 0.208)
Precontrast ductal high signal intensity	1 (0.4)	0	0 (0, 0.975)
No morphology findings reported	2 (0.7)	0	0 (0, 0.842)

* Data in parentheses are percentages.

† Data in parentheses are 95% CIs.

cancer were found with irregular margins (PPV, 0.196; 95% CI: 0.098, 0.331) and spiculated margins (PPV, 0.333; 95% CI: 0.099, 0.651). The lowe st PPV was found with smooth margins (PPV, 0.052; 95% CI: 0.011, 0.144). Masses with marked internal enhancement as opposed to minimal or moderate internal enhancement were most likely to represent cancer (PPV, 0.231; 95% CI: 0.111, 0.393) (Table 3). In logistic regression analysis, the likelihood of cancer was not significantly different between categories defined by shape, margin, or degree of enhancement.

NMLE.—The type of NMLE most likely to represent cancer was ductal enhancement (PPV, 0.500; 95% CI: 0.187, 0.813). Regional (PPV, 0.043; 95% CI: 0.001, 0.219), multiple regions (PPV, 0; 95% CI: 0, 0.459), and diffuse (PPV, 0; 95% CI: 0, 0.602) patterns of NMLE were associated with the lowest probability of cancer. Asymmetry of NMLE was not highly predictive of cancer, with a PPV of only 0.144 (95% CI: 0.079, 0.234). Furthermore, there were no cases of symmetric NMLE that proved to be cancer. The internal enhancement characteristics of NMLE most associated with cancer were clumped enhancement, which was found in seven of the 23 NMLE cancers (PPV, 0.304; 95% CI: 0.132, 0.529), and reticular or dendritic enhancement, which was found in two of the seven NMLE cancers (PPV, 0.286; 95% CI: 0.037, 0.710). Homogeneous (PPV, 0.053; 95% CI: 0.001, 0.260), heterogeneous (PPV, 0.075; 95% CI: 0.016, 0.204), and stippled or punctate (PPV, 0; 95% CI: 0, 0.247) patterns of enhancement were associated with the lowest probability of cancer (Table 4). At logistic regression analysis, the likelihood of cancer was not shown to be significantly different between NMLE categories.

Associated MR findings.—None of the cancers was associated with skin thickening, skin or nipple retraction, edema, or chest wall invasion.

Evaluation of Cancers with Lesion Kinetics

For the 278 participants with BI-RADS category 0, 3, 4, or 5 assessment at initial MR imaging, kinetic information was collected for 201 patients in the initial enhancement phase (slow, n = 40; medium, n = 82; rapid, n = 79) and for 209 patients in the delayed enhancement phase (persistent, n = 98; plateau, n = 66; washout, n = 45). Twelve of the 31 cancers demonstrated rapid initial enhancement (PPV, 0.152; 95% CI: 0.081, 0.250), whereas cancer was identified in only two patients with slow initial enhancement (PPV, 0.050; 95% CI: 0.006, 0.169) (Table 5).

At logistic regression analysis, the likelihood of cancer was higher for rapid initial enhancement than for slow initial enhancement (OR, 3.402; 95% CI: 0.723, 16.010) and higher for medium enhancement than for slow enhancement (OR, 2.054; 95% CI: 0.415, 10.151); however, neither OR was significant. Both plateau (PPV, 0.152; 95% CI: 0.075, 0.261) and washout (PPV, 0.178; 95% CI: 0.080, 0.321) patterns of delayed enhancement were associated with cancer. Lesions with persistent enhancement were significantly less likely to be cancers than were

lesions with washout enhancement (OR, 0.249; 95% CI: 0.076, 0.810). The estimated OR for lesions with plateau enhancement versus those with washout enhancement was also slightly less than 1 (OR, 0.826; 95% CI: 0.298, 2.286).

Discussion

Breast MR imaging has increased in clinical importance relatively recently. One of the main advantages of breast MR imaging is its high sensitivity in the detection of breast cancer, with some reports setting its sensitivity as high as 94%–100% (6,7). However, the specificity of breast MR imaging has been reported to be much lower because of overlapping features in benign and malignant breast lesions (8–10). Diagnostic criteria used in the differentiation of benign and malignant lesions on breast MR images include both morphologic and kinetic features.

A number of studies have evaluated the predictive value of morphologic and kinetic features at breast MR imaging in the diagnostic setting (11–16). Most were performed before publication of the American College of Radiology BI-RADS MR imaging lexicon, although many of the findings from these reports were eventually incorporated into the lexicon. A more recent single-institution study by Gutierrez et al (16) investigated the predictive values of BI-RADS MR imaging descriptors among lesions initially detected with MR imaging and determined to be BI-RADS category 4 or 5 lesions. To our knowledge, we are the first to evaluate the utility of the published BI-RADS lexicon in a large prospective multicenter study of a screening population, including the PPVs of lesion descriptors and the assessment categories.

There have been several published reports on the PPV of BI-RADS for mammography and US in which researchers evaluated lesion descriptors and final assessment categories. Liberman et al (3) studied the standardized terminology of the BI-RADS lexicon for mammography and found use of the lexicon enabled "quantification of the likelihood of carcinoma in an impalpable [mammographically detected] breast lesion." The frequency of carcinoma was higher for category 5 lesions (81%) than for all other lesions, but it was lower than the frequency as defined by the BI-RADS lexicon for mammography (ie, >95% chance of malignancy).

Table 3

Evaluation of Cancers by Mass Features for BI-RADS Category 0, 3, 4, and 5 Assessments

Mass Feature	No. of Patients*	No. of Patients with Cancer	PPV†
Shape			
Round	20 (16.5)	2	0.100 (0.012, 0.317)
Oval	39 (32.2)	2	0.051 (0.006, 0.173)
Lobulated	26 (21.5)	2	0.077 (0.009, 0.251)
Irregular	36 (29.8)	11	0.306 (0.163, 0.481)
Margin			
Smooth	58 (47.9)	3	0.052 (0.011, 0.144)
Irregular	51 (42.1)	10	0.196 (0.098, 0.331)
Spiculated	12 (9.9)	4	0.333 (0.099, 0.651)
Degree of enhancement			
Minimal	12 (9.9)	1	0.083 (0.002, 0.385)
Moderate	70 (57.9)	7	0.100 (0.041, 0.195)
Marked	39 (32.2)	9	0.231 (0.111, 0.393)

* Data in parentheses are percentages.

† Data in parentheses are 95% CIs.

Table 4

Evaluation of Cancers by NMLE Features for BI-RADS Category 0, 3, 4, and 5 Assessments

NMLE Feature	No. of Patients*	No. of Patients with Cancer	PPV†
Type			
Focal area	27 (26.5)	3	0.111 (0.024, 0.292)
Linear	12 (11.8)	2	0.167 (0.021, 0.484)
Ductal	10 (9.8)	5	0.500 (0.187, 0.813)
Segmental	20 (19.6)	2	0.100 (0.012, 0.317)
Regional	23 (22.6)	1	0.043 (0.001, 0.219)
Multiple regions	6 (5.9)	0	0 (0, 0.459)
Diffuse	4 (3.9)	0	0 (0, 0.602)
Degree of symmetry			
Not applicable	2 (2.0)	0	0 (0, 0.842)
Symmetric	10 (9.8)	0	0 (0, 0.308)
Asymmetric	90 (88.2)	13	0.144 (0.079, 0.234)
Internal enhancement characteristics			
Homogeneous	19 (18.6)	1	0.053 (0.001, 0.260)
Heterogeneous	40 (39.2)	3	0.075 (0.016, 0.204)
Stippled or punctate	13 (12.8)	0	0 (0, 0.247)
Clumped	23 (22.6)	7	0.304 (0.132, 0.529)
Reticular or dendritic	7 (6.9)	2	0.286 (0.037, 0.710)

* Data in parentheses are percentages.

† Data in parentheses are 95% CIs.

Table 5

Evaluation of Cancers by Kinetic Features for BI-RADS Category 0, 3, 4, and 5 Assessments

Kinetic Feature	No. of Patients*	No. of Patients with Cancer	PPV†
Initial enhancement phase (n = 201)‡			
Slow	40 (19.9)	2	0.050 (0.006, 0.169)
Medium	82 (40.8)	8	0.098 (0.043, 0.183)
Rapid	79 (39.3)	12	0.152 (0.081, 0.250)
Total	201 (100)	22	
Delayed enhancement phase (n = 209)§			
Persistent	98 (46.9)	5	0.051 (0.017, 0.115)
Plateau	66 (31.6)	10	0.152 (0.075, 0.261)
Washout	45 (21.5)	8	0.178 (0.080, 0.321)
Total	209 (100)	23	…

* Data in parentheses are percentages.

† Data in parentheses are 95% CIs.

‡ Features of the initial enhancement phase were not recorded for 77 of the 278 patients with BI-RADS category 0, 3, 4 or 5 assessment. Nine of these 77 patients had cancer.

§ Features of the delayed enhancement phase were not recorded for 69 of the 278 patients with BI-RADS category 0, 3, 4 or 5 assessment. Eight of these 69 patients had cancer.

Their report described spiculated margins and irregular shape as the lesion descriptors most associated with malignant masses and linear morphology and linear and segmental distribution as the lesion descriptors most predictive of malignant calcifications. More recently, Burnside et al (17) retrospectively evaluated the new microcalcification descriptors in the 4th edition of BI-RADS, and Bent and colleagues (18) retrospectively reviewed the PPV of BI-RADS microcalcification descriptors in the digital environment. Both groups concluded that BI-RADS morphology and distribution descriptors can aid in assessing the risk of malignancy.

Similarly, Hong et al (4) evaluated the PPV and negative predictive value of features for the BI-RADS lexicon for US. They found that careful analysis of multiple lesion descriptors was useful to differentiate benign from malignant solid masses. They described spiculated margins, irregular shape, and nonparallel orientation as the features most likely to represent malignancy.

As with mammography and US, accurate interpretation and reporting of breast MR findings requires standardized terminology and a systematic approach to lesion categorization.

In our study, cancers manifested more frequently as masses than as NMLE lesions or foci. Masses with irregular shapes and those with irregular or spiculated margins had the highest likelihood of malignancy. By understanding which of these features is most predictive of malignancy, the specificity of breast MR imaging may be improved. Our findings are similar to those of prior investigators and indicate that irregular or spiculated margins are associated with greater likelihood of malignancy. In a study of diagnostic breast MR imaging by Liberman et al (11), a spiculated margin was the most suspicious feature identified with a PPV of 0.80, which was higher than that in our investigation. Wedegärtner et al (13) reported an irregular lesion contour to be the most reliable morphologic feature of malignancy. Schnall et al (12) found spiculated margins to be a highly predictive imaging feature of cancer, and Gutierrez et al (16) found irregular or spiculated margins conferred the highest probability of malignancy among BI-RADS mass descriptors. In a retrospective study, Tozaki et al (19) found spiculated margins (100%) and irregular shape (97%) to be among the features with the highest predictive value for carcinoma.

In regard to NMLE lesions, Liberman et al (11) reported the highest PPV for segmental enhancement (PPV, 0.67) and clumped linear and ductal enhancement (PPV, 0.31). Again, the PPVs in our screening study were lower. This may reflect a slightly different use of these terms in the BI-RADS lexicon as compared with the use of these terms in the Liberman et al study, as well as differences in study design and patient population. The Liberman et al study was a retrospective analysis performed in the diagnostic setting, whereas our study was a prospective evaluation of a screening population with prior normal mammograms and clinical findings. Hence, the PPVs in our screening group would expectedly be lower because of differences in the prevalence of cancer in these groups. Nevertheless, the types of lesions most predictive of malignancy were similar in both studies. The linear (PPV, 0.167), ductal (PPV, 0.500), and segmental (PPV, 0.100) types of NMLE, as well as lesions with clumped (PPV, 0.304) and reticular or dendritic internal enhancement characteristics (PPV, 0.286), were most suspicious in our study. In a more recent study by Baltzer et al (20), stippled enhancement was found to enable differentiation of benign from malignant lesions. Interestingly, Gutierrez et al (16) found that BI-RADS descriptors for NMLE were not significant predictors of malignancy, but their study included small numbers of NMLE lesions in some descriptor categories. Finally, Rosen and colleagues (21) retrospectively reviewed breast MR imaging studies of women with newly diagnosed cancer. Like us, they found that the most common NMLE patterns of pure DCIS were segmental distribution and clumped internal enhancement.

Regarding the kinetic evaluation of breast MR lesions, we found rapid initial enhancement (PPV, 0.152) and plateau (PPV, 0.152) and washout (PPV, 0.178) delayed enhancement to

be most associated with carcinoma. Liberman et al (11) reported the PPVs for plateau and washout kinetics were 0.24 and 0.33, respectively. Schnall et al (12) reported the OR for plateau and washout kinetics was 1.69 and 2.14, respectively. Like Schnall et al, we found assessment of the morphologic features to be more predictive in the diagnosis of breast cancer than characterization of the kinetic curves. Baltzer et al (20) evaluated only nonmass lesions and reported difficulty in distinguishing benign from malignant lesions on the basis of kinetic information.

Overall, 14 lesions in our study were categorized as BI-RADS category 5 (ie, highly suggestive of malignancy). Ten of these lesions proved cancerous, yielding a PPV of 0.714 for BI-RADS category 5 lesions. A total of 83 lesions were categorized as BI-RADS category 4, with a total of 17 malignancies, resulting in a PPV of 0.205 for BI-RADS category 4 lesions. These results are nearly identical to those reported by Liberman et al (11), who found a PPV of 0.67 for lesions considered highly suggestive of malignancy and a PPV of 0.19 for lesions deemed suspicious. In our study, the rate of malignancy for BI-RADS category 3 lesions was 0.9%, which was consistent with its low predictive value in mammography. No BI-RADS category 2 lesions represented cancer, but two patients with negative MR imaging findings (BI-RADS category 1) were eventually found to have a malignancy. Thus, the NPV for BI-RADS category 1 and 2 lesions was 99%, as determined with the equation 2/(478 + 213), which was consistent with previous reports by Liberman (22) and Lehman et al (5) in which the NPV of a normal or benign breast MR study was also 99%.

Our study had limitations. Not all of the patients completed 1-year follow-up, and some cancers may not have been included in our results. Our PPV values are based on the initial MR imaging BI-RADS categorization and not on the number of patients with follow-up data. While the potential for bias does exist, the percentage of patients who failed to complete follow-up (14.2%–21.4% [15 of 106 patients and three of 14 patients, respectively]) is consistent across all BI-RADS categories. Thus, there does not appear to be a bias between BI-RADS categories. Additionally, some lesion features were associated with few cancer patients, resulting in a low power to detect differences in PPV. Finally, kinetic data were not recorded for many patients, limiting the usefulness of the PPV for these features.

In conclusion, the standardized BI-RADS lexicon for breast MR imaging provides descriptors and assessment categories that can be used to predict the likelihood of malignancy for MR imaging lesions. Similar to results for mammography and US, we found that the PPV of BI-RADS category 5 lesions was significantly higher than that of BI-RADS category 4 lesions but lower than the BI-RADS category 5 definition of 0.95 assessed probability of malignancy. The MR imaging features with the highest predictive value for malignancy are lesion types of mass (irregular shape, irregular and spiculated margins, marked enhancement) and NMLE (ductal type, clumped and reticular or dendritic enhancement) and kinetic features of rapid initial enhancement and washout in the delayed enhancement phase. The BI-RADS assessment categories for MR imaging work well to predict the risk of malignancy. The risk of malignancy for BI-RADS category 3 lesions is well under 2%. BI-RADS category 4 and 5 lesions are at high risk levels and warrant biopsy. The use of the BI-RADS lexicon and assessment categories in MR imaging should be encouraged.

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