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ORIGINAL ARTICLE

3.0 Tesla *vs* 1.5 Tesla breast magnetic resonance imaging in newly diagnosed breast cancer patients

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Abstract

AIM: To compare 3.0 Tesla (T) *vs* 1.5T magnetic resonance (MR) imaging systems in newly diagnosed breast cancer patients.

METHODS: Upon Institutional Review Board approval, a Health Insurance Portability and Accountability Act-compliant retrospective review of 147 consecutive 3.0T MR examinations and 98 consecutive 1.5T MR examinations in patients with newly diagnosed breast cancer between 7/2009 and 5/2010 was performed. Eleven patients who underwent neoadjuvant chemotherapy in the 3.0T group were excluded. Mammographically occult suspicious lesions (BIRADS Code 4 and 5) additional to the index cancer in the ipsilateral and contralateral breast were identified. Lesion characteristics and pathologic diagnoses were recorded, and results achieved with both systems compared. Statistical significance was analyzed using Fisher's exact test.

RESULTS: In the 3.0T group, 206 suspicious lesions were identified in 55% (75/136) of patients and 96% (198/206) of these lesions were biopsied. In the 1.5T group, 98 suspicious lesions were identified in 53% (52/98) of patients and 90% (88/98) of these lesions were biopsied. Biopsy results yielded additional malignancies in 24% of patients in the 3.0T group *vs* 14% of patients in the 1.5T group (33/136 *vs* 14/98, P = 0.07). Average size and histology of the additional cancers was comparable. Of patients who had a suspicious MR imaging study, additional cancers were found in 44% of patients in the 3.0T group *vs* 27% in the 1.5T group (33/75 *vs* 14/52, P = 0.06), yielding a higher positive predictive value (PPV) for biopsies performed with the 3.0T system.

CONCLUSION: 3.0T MR imaging detected more additional malignancies in patients with newly diagnosed breast cancer and yielded a higher PPV for biopsies performed with the 3.0T system.

Key words: Breast; Breast cancer; Cancer staging; Outcome; Magnetic resonance imaging; Breast magnetic resonance imaging; 3 Tesla; Technical

Core tip: 3.0 Tesla (T) breast magnetic resonance (MR) imaging offers superior image quality through improved signal-to-noise ratio and resolution. In a comparison of two nearly identical patient populations of women with newly diagnosed breast cancer, a greater number of suspicious lesions and mammographically occult malignancies were detected using an optimized 3.0T system compared to a conventional 1.5T system. The positive predictive value of an abnormal MR imaging study was higher for 3.0T MR imaging compared to 1.5T imaging. These results attest to a clinical benefit and higher accuracy achievable with a 3.0T magnet.

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INTRODUCTION

High-power magnets greater than 1.5 Tesla (T) are becoming increasingly available for magnetic resonance imaging (MRI) of the breast. Among magnets in this category, 3.0T systems are the most commonly employed in clinical practice. Magnetic power influences imaging parameters, such as signal-to-noise ratio, spatial resolution, and sequence acquisition time[1-5]. It is valuable, therefore, to understand the potential advantages and disadvantages of these newer systems and to compare their performance to the more familiar 1.5T scanners.

Patients with newly diagnosed breast cancer may benefit from pre-operative breast MRI to search for additional mammographically occult malignancies[6-34]. Unsuspected multifocal and multicentric malignancies are seen within the same breast as the index cancer in 6%-34%[22,27-34] of patients, and in the contralateral breast in 3%-9%[12,15,17,35] of patients with a recent breast cancer diagnosis. The detection of these additional malignancies can alter surgical management, necessitating wider local excision or mastectomy in 8%-33%[22] of women in this pre-surgical population.

This study was undertaken to evaluate the performance of 3.0T *vs* 1.5T MRI systems in the detection of additional mammographically occult malignancies in patients with newly diagnosed breast cancer.

MATERIALS AND METHODS

Patient selection

With institutional review board approval, a Health Insurance Portability and Accountability Act-compliant retrospective review was performed and the requirement for informed patient consent was waived. The study was conducted on 98 consecutive 1.5T MRI examinations between July 1, 2009 and December 19, 2009 and 147 consecutive 3.0T MRI examinations between December 20, 2009 and May 31, 2010 performed at a single institution in 245 women with newly diagnosed breast cancer. Eleven patients in the 3.0T patient group were treated with neoadjuvant chemotherapy prior to surgical excision. Due to the lack of pre-chemotherapy pathologic evaluation of the additional suspicious lesions seen in these patients, this subpopulation was excluded, yielding a total of 136 patients in the 3.0T study group.

All 245 patients were referred for pre-operative MR imaging because their clinical and mammographic evaluation at the time of diagnosis indicated a single index cancer confined to one quadrant of the breast, making them a potential candidate for breast conserving surgery. At our institution, the decision to perform pre-operative breast MRI on a newly diagnosed breast cancer patient is made by the referring breast surgeon. Our surgeons vary in the degree to which they utilize breast MRI and in the selection criteria they employ to determine which patients should be referred for this examination. During the time interval of this study, the referring surgeons at our institution and their practice patterns with regard to utilization of pre-operative breast MRI remained unchanged. Within this patient population, 127 studies with suspicious lesions additional to the known cancer, resulting in a BI-RADS Code 4 or 5 assessment, were selected for further analysis. Pathology results of all biopsied additional suspicious lesions were recorded.

MR imaging equipment and technique

Before December 19, 2009, breast MRI examinations were performed with the patient prone using a 1.5T magnet (Signa, GE Healthcare Medical Systems, Waukesha, WI, United States) and 4-channel *in vivo* dedicated surface breast coil (*In vivo*, Gainesville, FL, United States). After December 20, 2009, all breast MRI examinations were performed using a new 3.0T magnet (Magnetom Verio, Siemens Medical Solutions, Erlangen, Germany) and 8-channel Sentinelle Vanguard dedicated surface breast coil (Sentinelle Medical Division of Hologic, Toronto, Canada). The standard imaging protocol (Table 1) with both systems included a localizing sequence, followed by axial T1-weighted gradient-echo and T2-weighted images through both breasts. Fat suppressed axial gradient-echo T1-weighted images were obtained before and then two times at 15 s and 6 min following a rapid bolus injection of 0.1 mmol/L gadopentatate dimeglumine (Magnevist; Bayer HealthCare Pharmaceuticals, Wayne, NJ, United States) per kilogram of body weight delivered *via* an in-dwelling intravenous catheter at a rate of 2 mL/s. Post-processing included subtraction of the unenhanced images from the dynamic axial T1 sequence on a pixel-by-pixel basis. All MRI examinations were interpreted according to published criteria[37] by the same group of 7 radiologists specializing in breast imaging with 1-16 years of experience.

Data collection

Patient demographic data, including age and breast cancer risk factors, were extracted from patient questionnaires completed at the time of MRI or from the electronic medical record. Breast cancer risk was categorized according to National Cancer Institute (NCI) guidelines and technologist entry into our PenRad mammography reporting system (PenRad, Minnetonka, MN, United States). When a family history of breast cancer was reported, the degree of risk was categorized according to NCI guidelines as weak, intermediate, or strong.

The location, size, and histology of the newly diagnosed index cancer were noted. MRI characteristics of suspicious lesions, including lesion type, kinetics, size and location, were determined on the basis of MRI reports. In some cases, where a required lesion descriptor was not included in the report, the images were reviewed on a picture archiving and communication system workstation (Synapse, Fujifilm Corporation, Edison, NJ,

Table 1 1.5 and 3.0 Tesla magnetic resonance imaging protocol

Parameter	Axial T2	Axial T1 3D GRE no FS	Axial T1 pre 3D GRE	Axial T1 post 3D GRE
1.5 Tesla				
TR (ms)	5811	8.3	5.2	5.2
TE (ms)	60	4.5	2.42	2.42
Fat saturation	STIR	No	Yes	Yes
Flip angle	165	20	10	10
Field of view (mm)	340	340	340	340
Matrix	384 × 230	320 × 320	320 × 320	320 × 320
Slice thickness (mm)	5	1	1	1
Voxel size (mm^3)	0.8 × 1.4 × 5.0	1.0 × 1.0 × 1.0	1.0 × 1.0 × 1.0	1.0 × 1.0 × 1.0
Bandwidth (Hz/pixel)	250	347	391	391
Imaging time (min:s)	2:50	2:50	2:26	2:26
3.0 Tesla				
TR (ms)	11660	4.57	4.57	3.99
TE (ms)	69	2.46	2.46	1.61
Fat saturation	STIR	No	Yes	Yes
Flip angle	120	10	10	9
Field of view (mm)	324	323	323	323
Matrix	384 × 384	448 × 448	448 × 448	448 × 448
Slice thickness (mm)	3	0.7	0.7	0.7
Voxel size (mm^3)	0.8 × 0.8 × 3.0	0.7 × 0.7 × 0.7	0.7 × 0.7 × 0.7	0.7 × 0.7 × 0.7
Bandwidth (Hz/pixel)	246	319	698	698
Imaging time (min:s)	2:45	2:33	2:33	2:33

TR: Repetition time; TE: Echo time; GRE: Gradient echo sequence; FS: Fat suppression.

United States) by a consensus of 2 radiologists (Butler RS and Chen C) with 14 and 1 years of MRI experience, respectively. Lesion type was defined as a mass, focus or nonmass-like enhancement. The delayed enhancement kinetics were classified as a persistent, plateau, or washout pattern. The location of all suspicious lesions was recorded as multifocal, multicentric, or contralateral relative to the index cancer.

Second-look ultrasound examinations were performed for suspicious MRI lesions at the discretion of the interpreting radiologist. When a sonographic correlate was identified, percutaneous core-needle biopsy was performed using a 14-gauge hand-held biopsy needle (Achieve Automatic Biopsy Systems, Cardinal Health, Dublin, OH, United States). For suspicious MRI lesions with no sonographic correlate, the histologic diagnosis was obtained by MR-guided 9-gauge vacuum-assisted core needle biopsy (ATEC, Suros Division of Hologic, Indianapolis, IN, United States) or by surgical excision. Five MRI lesions were felt to correspond to mammographic calcifications, with the diagnosis confirmed using stereotactic 8-gauge vacuum-assisted core needle biopsy (Mammotome ST, Devicor Medical Products, Inc., Cincinnati, OH, United States). In cases of suspicious MRI lesions for which no histologic diagnosis was made, the reason for the lack of biopsy was recorded.

Statistical analysis

Pathology results were categorized as benign, high-risk benign, or malignant. The high-risk benign category included atypical ductal hyperplasia, lobular intraepithelial neoplasia, papillary lesions, and complex sclerosing lesions. When a surgical excision was performed for high-risk benign lesions diagnosed by core needle biopsy, the pathology of the surgical specimen was reviewed and the lesion was reclassified according to the final pathology. The incidence of MR-imaging detected multifocal, multicentric, and contralateral cancers was calculated for the 1.5T and 3.0T groups. The size and histology of the additional cancers was also recorded and compared. Statistical analysis of results was performed using R (R Foundation for Statistical Computing, Vienna, Austria) and the difference between the two cohorts was analyzed for statistical significance using Fisher's exact test with a $P < 0.05$ considered to indicate a significant difference.

RESULTS

Patient and index cancer data

The demographic characteristics of the 1.5T and 3.0T patient populations were comparable, with no statistically significant differences in age or family history of breast cancer (Table 2). The distribution of sizes and histologic types of the index cancers were also similar in the two study groups (Table 2). Among the 98 index cancers in the 1.5T patient population, the average size was 17.3 mm (range 4-70 mm) whereas the mean size of the 136 index cancers in the 3.0T group was 18.1 mm (range 3-92 mm). Invasive ductal carcinoma was the most common histology in both patient cohorts, with 67 (68%) such cancers among the 1.5T patients and 83 (61%) in the 3.0T group.

Suspicious lesions

Although data was collected from consecutive time intervals of nearly equal length, a larger number of cases (147 *vs* 98) was observed on the 3.0T system (Table 3). Accordingly, a greater number of suspicious lesions (206

Table 2 Patient and index cancer characteristics *n* (%)

Characteristic	1.5 Tesla	3.0 Tesla	*P* value
Age (yr)			
median (range)	56 (35-85)	55 (26-85)	0.59
Family history of breast cancer			
None	77 (79)	101 (74)	0.53
Weak[1]	10 (10)	19 (14)	0.43
Intermediate[2]	5 (5)	11 (8)	0.44
Strong[3]	6 (6)	5 (4)	0.53
Index cancer size (mm)			
Mean (range)	17.3 (4.0-70.0)	18.1 (3.0-92.0)	0.68
Index cancer histology			
Invasive ductal carcinoma	67 (68)	91 (67)	0.13
Not otherwise specified	65 (66)	86 (63)	0.14
Mucinous type	1 (1)	3 (2)	
Medullary type	0	1 (0.7)	
Papillary type	0	1 (0.7)	
Tubular type	1 (1)	0	
Invasive lobular carcinoma	3 (3)	3 (2)	0.11
Mixed invasive lobular and ductal carcinoma	3 (3)	5 (4)	0.70
Ductal carcinoma *in situ*	25 (26)	37 (27)	0.56

[1]Weak family history: second degree or other relatives; [2]Intermediate family history: single post-menopausal first-degree relative; [3]Strong family history: premenopausal first-degree relative or multiple post-menopausal first-degree relatives. Unless otherwise indicated, data are number of patients and data in parentheses are percentages.

Table 3 Suspicious lesion characteristics *n* (%)

Characteristic	1.5 Tesla	3.0 Tesla	*P* value
Suspicious lesions (*n*)	98	206	0.001
Average number/imaged patient	1 (98/98)	1.4 (206/136)	
Range	0-6	0-8	
Size (mm)			
mean (range)	11.9 (3-60)	10.5 (3-94)	0.27
Biopsied lesions	88 (90)	198 (96)	0.04
Average number/biopsied patient	1.7 (88/52)	2.6 (198/75)	
Method of biopsy			
MRI–guided needle biopsy	43 (49)	87 (44)	0.44
Ultrasound-guided needle biopsy	13 (15)	37 (19)	0.50
Stereotactic needle biopsy	3 (3)	2 (1)	0.18
Surgical biopsy	29 (33)	72 (36)	0.60
Reason for no biopsy			
Another representative lesion biopsied	6	4	
Not visualized at MRI-guided biopsy	2	3	
Benign correlate on ultrasound	1	1	
Lost to follow-up	1	0	
Morphology			
Mass	37 (38)	87 (42)	0.53
Nonmass-like enhancement	40 (41)	62 (30)	0.07
Focus	21 (21)	57 (28)	0.26
Kinetics			
Wash-out	22 (22)	60 (29)	0.27
Plateau	41 (42)	71 (35)	0.25
Persistent	35 (36)	75 (36)	1.00
Distribution			
Multifocal	34 (35)	80 (39)	0.53
Multicentric	33 (34)	50 (24)	0.10
Contralateral	31 (32)	76 (37)	0.44

Unless otherwise indicated, data are number of patients and data in parentheses are percentages. MRI: Magnetic resonance imaging.

vs 98) was recorded in the 3.0T population. In addition to the increase in volume, there was also an independent increase in the number of suspicious lesions per patient [1.4 (range 0.0-8.0) *vs* 1.0 (range 0.0-6.0)] seen with the 3.0T system ($P = 0.001$, square root transformed). Lesion size was smaller but not significantly different in the 3.0T patients [10.5 mm (range 3.0-94.0 mm) *vs* the 1.5T patients 11.9 mm (range 3.0-60.0 mm)].

Almost all of the BI-RADS Code 4 and 5 lesions for which biopsy was recommended [88 of 98 (90%) in the 1.5T group and 198 of 206 (96%) in the 3.0T cohort] were histologically evaluated. The most common method of biopsy was MRI-guided 9-gauge vacuum-assisted core needle biopsy, which was performed in 43 (49%) of 1.5T lesions and 87 (44%) of 3.0T findings. The second most common method of obtaining a pathologic diagnosis was by surgical excision, which was carried out for 29 (33%) of 1.5T abnormalities and 72 (36%) of 3.0T lesions. Ultrasound-guided hand-held 14-gauge core needle biopsy was performed for 13 (15%) and 37 (19%) of suspicious MRI lesions in the 1.5T and 3.0T group, respectively, as these lesions had an identifiable sonographic correlate on second-look ultrasound. A small number of MRI lesions [3 (3%) of 1.5T lesions and 2 (1%) of 3.0T findings] were retrospectively correlated with mammographic calcifications and biopsied with stereotactic vacuum-assisted 8-gauge core needle biopsy. A total of 10 lesions in the 1.5T cohort and 8 lesions in the 3.0T group were not biopsied. Seven findings in 1.5T patients and 4 findings in 3.0T patients were not biopsied because the suspicious lesion was within a region of multiple similar findings, and it was elected to biopsy a single representative lesion within this region. Two 1.5T lesions and three 3.0T lesions were not reproduced on repeat MRI at the time of scheduled MR biopsy. Two of these patients had MRI follow-up one year after the cancelled biopsy, and all have had mammographic follow-up for at least 2 years since the cancelled biopsy, with no new cancers presenting in this subgroup. One lesion in each group was felt to correspond to a benign inflammatory cyst on second-look ultrasound. Finally, one patient with a single additional suspicious lesion in the 1.5T group was lost to follow-up.

There was no statistically significant difference in the morphology or kinetic behavior of the suspicious lesions seen in the two cohorts, as detailed in Table 3. MRI suspicious findings were also similarly distributed relative to the index cancer in the two patient groups.

Cancers

A total of 23 additional malignancies were detected with the 1.5T system, while 54 unsuspected cancers were discovered with the 3.0T system, yielding a positive biopsy rate of 26% and 27%, respectively (Table 4). The average

Table 4 Magnetic resonance imaging-detected cancer characteristics *n* (%)

Characteristic	1.5 Tesla	3.0 Tesla	*P* value
Cancers (*n*)	23	54	
Positive biopsy rate	23/88 (26)	54/198 (27)	0.89
Size (mm)			
mean (range)	12.4 (3-50)	10.9 (4-70)	0.65
Method of biopsy			
MRI-guided needle biopsy	4 (17)	10 (19)	
Ultrasound-guided needle biopsy	6 (26)	19 (35)	
Stereotactic needle biopsy	1 (4)	1 (2)	
Surgical biopsy	12 (52)	24 (44)	
Morphology			
Mass	13 (57)	29 (53)	1.00
Nonmass-like enhancement	3 (13)	14 (26)	0.25
Focus	7 (30)	11 (20)	0.38
Kinetics			
Wash-out	6 (26)	19 (35)	0.65
Plateau	10 (44)	21 (39)	0.80
Persistent	7 (30)	14 (26)	0.78
Distribution			
Multifocal	16 (70)	33 (61)	0.61
Multicentric	4 (17)	12 (22)	0.76
Contralateral	3 (13)	9 (17)	1.00
Histology			
Infiltrating ductal carcinoma	14 (61)	30 (55)	0.80
Infiltrating lobular carcinoma	0 (0)	1 (2)	1.00
Ductal carcinoma *in situ*	9 (39)	23 (43)	0.81

Unless otherwise indicated, data are number of patients and data in parentheses are percentages. MRI: Magnetic resonance imaging.

size of these cancers of 12.4 mm in the 1.5T patients and 10.9 mm in the 3.0T group was smaller, but not statistically significant in the 3.0T group.

MRI-guided core needle biopsy diagnosed 4 (17%) cancers in the 1.5T cohort and 10 (19%) malignancies in the 3.0T group. Six (26%) malignancies in the 1.5T group and 19 (35%) cancers in the 3.0T group were diagnosed with ultrasound-guided core needle biopsy. Stereotactic core needle biopsy detected 1 (4%) cancer in the 1.5T group and 1 (2%) cancer in the 3.0T cohort. Surgical excision revealed 12 (52%) malignancies in the 1.5T patients and 24 (44%) malignancies in the 3.0T population.

The MRI finding of a mass was the most common morphology of cancers seen with both systems and the kinetic behavior of cancers in both groups was similar, as described in Table 4. The distribution of additional malignancies relative to the index cancer was not statistically different between the two cohorts, with 16 (70%) *vs* 33 (61%) multifocal cancers, 4 (17%) *vs* 12 (22%) multicentric cancers, and 3 (13%) *vs* 9 (17%) contralateral malignancies in the 1.5T and 3.0T group, respectively.

In both groups, the most common histology of MRI detected cancers was infiltrating ductal carcinoma, as shown in Table 4.

Patient outcomes

The outcomes for newly diagnosed breast cancer patients imaged with both systems are summarized in Table 5. Among patients imaged with the 1.5T system, 9 (9%) had multifocal cancers and 4 (4%) had multicentric cancers, for a total of 13 (13%) patients with additional MRI detected malignancies in the ipsilateral breast. By contrast, among women imaged with the 3.0T system, 22 (16%) had multifocal malignancies and 9 (7%) had multicentric ones, resulting in a total of 31 (23%) patients with ipsilateral MRI detected cancers. This difference approaches statistical significance with a *P* value of 0.09, suggesting a trend toward improved detection of mammographically occult ipsilateral cancers in women with newly diagnosed breast cancer imaged with the 3.0T system. Similarly, among patients in the 1.5T group, 3 (3%) had contralateral cancers, compared to 7 (5%) in the 3.0T cohort, although this difference was not statistically significant ($P = 0.53$). A trend approaching statistical significance with a *P* value of 0.07 was seen, however, when ipsilateral and contralateral cancers are combined for a total number of 14 (14%) additional cancers detected in the 1.5T group compared to 33 (24%) in the 3.0T cohort. In addition, 13 (13%) patients imaged with the 1.5T system and 12 (9%) patients imaged with the 3.0T magnet had high-risk lesions.

Table 5 Patient biopsy outcomes *n* (%)

Characteristic	1.5 Tesla	3.0 Tesla	*P* value
Imaged patients	98	136	
Benign	25 (26)	30 (22)	0.20
High-risk	13 (13)	12 (9)	1.00
Malignant	14 (14)	33 (24)	0.07
Multifocal	9 (9)	22 (16)	0.17
Multicentric	4 (4)	9 (7)	0.57
Ipsilateral	13 (13)	31 (23)	0.09
Contralateral	3 (3)	7 (5)	0.53
Biopsied patients	52 (53)	75 (55)	0.79
Benign	25 (48)	30 (40)	0.47
High-risk	13 (25)	12 (16)	0.26
Malignant	14 (27)	33 (44)	0.06
Multifocal	9 (17)	22 (29)	0.14
Multicentric	4 (8)	9 (12)	0.56
Ipsilateral	13 (25)	31 (41)	0.06
Contralateral	3 (6)	7 (9)	0.52
PPV of abnormal MRI	14/52 (27)	33/75 (44)	0.06

Unless otherwise indicated, data are number of patients and data in parentheses are percentages. MRI: Magnetic resonance imaging; PPV: Positive predictive value.

A similar percentage of patients were biopsied in both groups and, as discussed above, a similar positive biopsy rate of 26% and 27% was observed in the 1.5T and 3.0T cohorts, respectively. However, the positive predictive value of an abnormal MRI was 14/52 (27%) for patients imaged with the 1.5T magnet compared to 33/75 (44%) in the 3.0T group ($P = 0.06$), likely due to the greater number of suspicious lesions biopsied per patient in the 3.0T group. Of biopsied patients in the 1.5T population, 25 (48%) had benign results, 13 (25%) had high-risk lesions, and 14 (27%) had malignant findings,

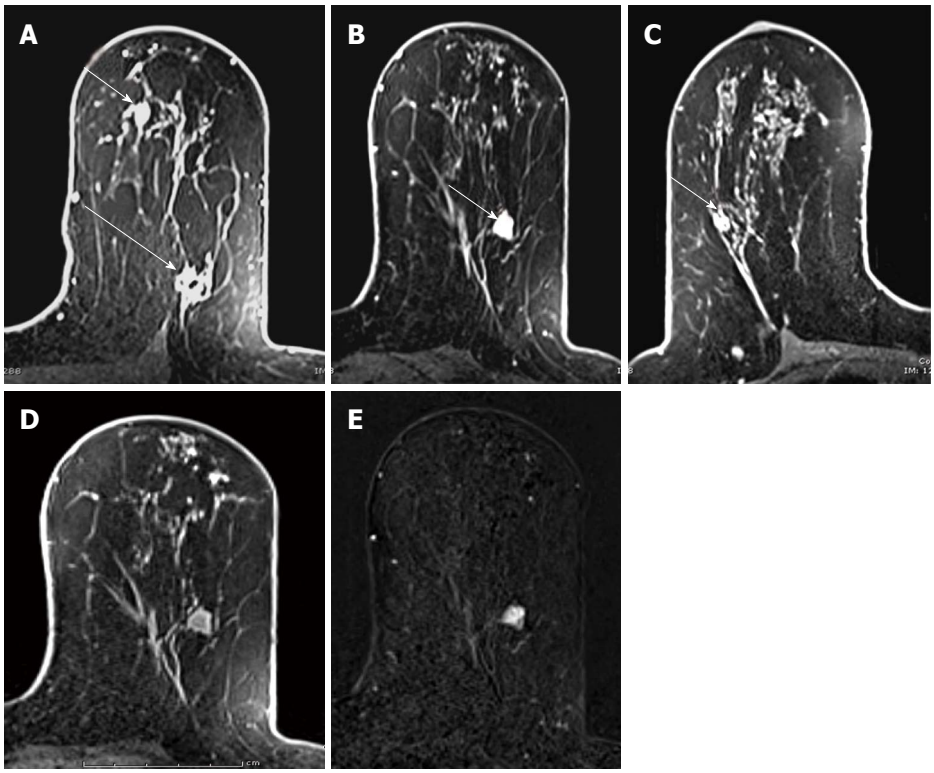

Figure 1 3.0Tesla axial T1-weighted fat-suppressed contrast enhanced images in 62-year-old woman with newly diagnosed left breast infiltrating ductal carcinoma show the index cancer with signal void due to biopsy marker (long arrow) in the superior lateral quadrant and a second mammographically occult multicentric lesion shown to represent DCIS (short arrow) in the superior medial quadrant (A), an additional multicentric lesion proven to represent an additional infiltrating ductal carcinoma (arrow) in the inferior lateral quadrant (B), and a suspicious contralateral lesion (arrow) confirmed as a benign papilloma (C).

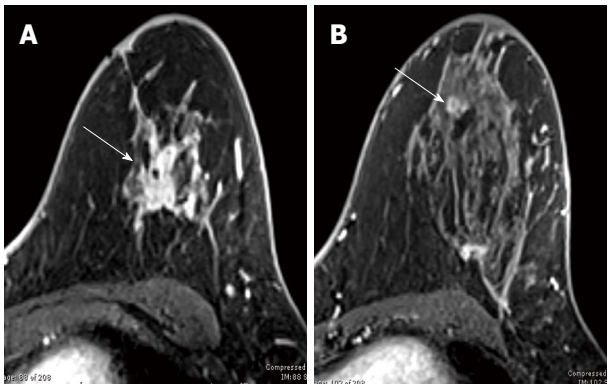

Figure 2 1.5Tesla axial T1-weighted fat-suppressed contrast enhanced subtraction images in 53-year-old woman with newly diagnosed left breast infiltrating ductal carcinoma show a conglomerate of masses with signal void due to biopsy marker (arrow) in the left superior breast (A), and a mammographically occult rim-enhancing lesion (arrow) 2 cm inferior to the index cancer confirmed as an additional infiltrating ductal carcinoma (B). Note the lower contrast and spatial resolution evident on these images compared to the 3.0Tesla system.

with 9 (17%) patients with multifocal, 4 (8%) women with multicentric, and 3 (6%) patients contralateral cancers. In the 3.0T group, 30 (40%) women had benign biopsies, 12 (16%) had high-risk findings, and 33 (44%) had malignant diagnoses, with 22 (29%) patients with multifocal, 9 (12%) women with multicentric, and 7 (9%) patients with contralateral malignancies.

DISCUSSION

The increasing availability of 3.0T MRI systems raises the question of whether this advance in technology leads to improved clinical outcomes in breast cancer care. Breast MRI at 3.0T has both technical advantages and challenges[1,2,4,5,36-38]. The higher magnetic field strength (B_0) produces a proportionate increase in signal-to-noise ratio, allowing for improvements in both spatial and temporal resolution. The greater spectral separation of fat and water at 3.0T imaging enables superior fat suppression, further aiding in the visualization of enhancing lesions. However, technical image quality at 3.0T is challenged by greater B_0 and B_1 field inhomogeneity, and increased susceptibility to artifacts. These potential drawbacks can be overcome by adjusting imaging parameters, such as repetition time, short echo time, flip angle, and bandwidth, at the expense of some of the gains in supernova remnant (SNR) and image acquisition time. In our 3.0T protocol, we do, in fact, utilize a higher bandwidth of 698 for the T1-weighted gradient recalled echo sequence, compared to a bandwidth of 391 on the 1.5T system. After accounting for such parameter adjustments, the SNR remains 1.7-1.8 times greater than imaging at 1.5T[5] (Figures 1 and 2).

Kuhl *et al*[38] evaluated the appearance of 53 lesions in 37 patients imaged at both 1.5T and 3.0T, and reported a higher image quality and diagnostic confidence achieved

with the 3.0T system. In this study, we posed the question of whether this perceived improvement in lesion characterization results in detection of a greater number of occult malignancies in newly diagnosed breast cancer patients at our institution. Although it would be ideal, as in the Kuhl study, to compare results from these two systems in the same patient population, it may be difficult or impractical to subject a large number of newly diagnosed breast cancer patients to repeat breast MRI. In this study, we compared outcomes in two patient populations that were imaged during consecutive time intervals corresponding to the 5.5 mo time period just before and immediately after our switch from a 1.5T to a 3.0T system. These cohorts were nearly identical in age, family history of breast cancer, and size and histology of their index cancer-the demographic and risk factors most likely to influence outcome (Table 2). Thus, we propose that any observed difference in the number of additional detected cancers is likely to reflect the imaging systems, rather than the patients' pre-existing probability of malignancy. Our results show a difference approaching statistical significance in the performance of the 3.0T and 1.5T systems, with additional malignancies detected in 24% of newly diagnosed breast cancer patients on the 3.0T magnet *vs* 14% on the 1.5T magnet ($P = 0.07$). This trend is most apparent for ipsilateral cancers, detected in 23% of women imaged with 3.0T *vs* 13% of those imaged with the 1.5T system ($P = 0.09$).

We emphasize that this study represents a comparison of two imaging systems that differ not only in magnet strength, but also in coil design and sequence parameters. Albeit not a pure comparison of 3.0T *vs* 1.5T magnets, this type of evaluation has the advantage of reflecting the performance of these two systems in the way they would likely be utilized in clinical practice. It has been recognized that a direct comparison of 1.5T and 3.0T magnets would be difficult, since coils for 3.0T systems are different and adjustments in sequence parameters are recommended to optimize image quality[5]. The degree to which each of the above technical factors contributed to the observed increase in the number of additional detected cancers is uncertain, though all are likely to have played a role. The increased signal-to-noise ratio and superior fat suppression achieved with a higher power magnet likely produce an image of greater contrast resolution. The newer 8-channel phased-array breast coil is better equipped than earlier coils to capture the increased signal of the higher power magnet and allow for its translation into higher spatial and temporal resolution. Finally, the adjustments in matrix (320 × 320 *vs* 448 × 448), slice thickness (1 mm *vs* 0.7 mm), and voxel size (1.0 mm × 1.0 mm × 1.0 mm *vs* 0.7 mm × 0.7 mm × 0.7 mm) in the 1.5T *vs* 3.0T protocol, respectively, are likely to have also contributed to an increase in spatial resolution. It is possible that these improvements in resolution allowed the visualization of subtle lobulation or spiculation of margins that otherwise would have appeared smooth, and therefore resulted in a greater number of lesions being characterized as suspicious and a greater number of small additional cancers detected with the 3.0T system.

The positive biopsy rate was nearly identical with the two systems, with 27% of biopsied lesions yielding malignancy on the 3.0T system *vs* 26% on the 1.5T system. Since all studies were interpreted by the same radiologists utilizing the same interpretation criteria for the assessment of suspicious features, it is not surprising that a lesion assessed as suspicious on either system should carry the same likelihood of malignancy. However, a greater number of lesions overall (206 *vs* 98) and a greater number of lesions per patient (1.4 *vs* 1.0) were characterized as suspicious on the 3.0T system compared to the 1.5T system. This difference suggests that suspicious features may have been revealed in a greater number of lesions with the 3.0T system owing to its increased resolution. Therefore, while the positive predictive value (PPV) per suspicious lesion remained the same, the PPV per patient with an abnormal MRI examination increased from 27% to 44% with the 3.0T system due to the presence of a greater number of suspicious lesions per patient and the likelihood that at least one of the suspicious lesions would be malignant. The greater number of additional diagnosed cancers on the 3.0T system, therefore, results from a statistically significant increase in the number of suspicious lesions detected with the 3.0T magnet (Table 3, $P = 0.001$).

This study has several limitations. Our data is drawn from a small population of 98 patients in the 1.5T cohort and 136 patients in the 3.0T group. The ability of 3.0T imaging to improve detection of occult additional malignancies in newly diagnosed breast cancer patients needs to be confirmed in larger prospective randomized controlled trials. We obtained our data retrospectively and, with the exception of cases where the reported findings were incompletely described and the images reviewed, relied on the examination reports for the description and assessment of suspicious MRI lesions. Similarly, we collected our pathology data from the pathology reports and, in the cases of surgical pathology, relied on size and location descriptors to correlate MRI findings with histologic results. Finally, this is a single institution study with all MRI examinations interpreted by breast imaging specialists and our results may not be applicable to all practices.

In conclusion, the detection of early additional malignancies in the pre-operative patient with a recent breast cancer diagnosis is clinically desirable based on current practice standards. The superior sensitivity of MRI for detecting occult malignancies in newly diagnosed breast cancer patients has been well established. The literature reports a range of 6%-34%[22,27-34] of additional occult ipsilateral cancers and 3%-9%[12,15,17,35] of unsuspected contralateral cancers in this setting. Our results with both systems fall within this reported range.

However, the improvement in image quality achievable with a 3.0T system, which includes improved coil design and high resolution sequence parameters, may translate into the detection of occult malignancies in a greater percentage of women. A trend toward a statistically significant increase in detection was observed in the overall number of additional occult cancers and the number of additional ipsilateral cancers with the 3.0T system, potentially altering surgical management.

The literature on MRI of the breast using a modern 3.0T system is presently limited. Although it is recognized that a 3.0T system can produce images of higher spatial, contrast, and temporal resolution[2,4,38], few investigators have evaluated the impact, if any, of this technical advancement on clinical outcomes in different patient populations[39]. To authors' knowledge, this is the first study to compare the performance of a 3.0T *vs* a 1.5T system in women referred for pre-operative MRI after a recent breast cancer diagnosis. Further research is needed to corroborate these results and define the contributing roles of higher power magnets, coil design, and acquisition parameters in the optimization of image quality, accuracy of MRI interpretation, and potential influence on clinical outcomes.

COMMENTS

Background

3 Tesla (3.0T) magnets are becoming increasingly available for breast magnetic resonance (MR) imaging. The higher power of a 3.0T magnet, compared to a conventional 1.5T magnet, can be harnessed to achieve greater spatial and contrast resolution and faster acquisition times. For accuracy of interpretation, breast MRI requires an assessment of both morphology and contrast enhancement pattern. Greater contrast and spatial resolution aid in the assessment of morphologic features predictive of malignancy, such as margins. Faster acquisition times ensure that imaging can be performed immediately after contrast injection, providing optimal visualization of rapidly enhancing cancers. Therefore, 3.0T MRI provides an opportunity to improve both image quality and clinical outcomes.

Research frontiers

Breast MRI is a valuable tool in the pre-operative assessment of newly diagnosed breast cancer patients. Imaging with an optimized 3.0T system can detect a greater number of mammographically occult malignancies in both the ipsilateral and contralateral breast of these patients, potentially altering surgical management.

Innovations and breakthroughs

Previous authors have reported on the higher image quality and improved lesion visualization achievable with 3.0T MRI compared to conventional 1.5T imaging. Other authors have shown a clinical benefit from pre-operative MRI of newly diagnosed breast cancer patients. In this patient population, MRI reveals additional mammographically occult cancers in both the ipsilateral and contralateral breast. The detection of these unsuspected cancers prior to definite surgery is critical for surgical planning and complete tumor removal. To authors' knowledge, no prior authors have addressed whether the improvement in image quality with a 3.0T system translates into a greater clinical benefit in the pre-operative newly diagnosed breast cancer population. Authors have shown that 3.0T MRI increases the likelihood of detecting additional malignancies and the positive predictive value of an abnormal study, thereby improving the accuracy of breast MRI interpretation.

Applications

This article provides data to support that a 3.0T MRI system is superior to a 1.5T system in the pre-operative evaluation of newly diagnosed breast cancer patients. Furthermore, it specifies the components and techniques utilized to optimize the system, including a dedicated multi-channel breast coil and technical acquisition parameters. As radiologists throughout the global community strive to improve the accuracy of breast MRI interpretation, this article can provide guidance in selecting breast MRI equipment and techniques.

Terminology

3.0T: Tesla is the unit of measurement of magnetic field strength. Prior to the availability of 3.0T magnets, the standard magnetic field strength for breast MRI was 1.5T. Higher magnetic field strength is desirable because it provides higher signal-to-noise ratio, greater resolution and faster acquisition times. Gradient Recalled Echo: a pulse sequence that differs from basic spin echo in that it utilizes a flip angle of less than 90 degrees with no 180 degree refocusing pulse. This difference allows for faster image acquisition times. Flip angle: the angle to which the net proton magnetization is tipped *via* the application of a radiofrequency pulse. A smaller flip angle results in faster image acquisition. Signal-to-noise ratio (SNR): the ratio of desired signal to background noise. The SNR is directly proportional to magnetic field strength. However, adjustments required to compensate for the increased susceptibility to artifact at higher field strengths reduce some of the gain in SNR achieved with a 3.0T system, resulting in a net SNR of 1.7-1.8 times greater than a 1.5T system. Bandwidth: range of MR signal frequencies accepted by the receiver. The bandwidth can be adjusted to optimize image quality. A higher bandwidth is used in 3.0T MRI to reduce artifact at the expense of some of the gain in signal-to-noise ratio.

Peer review

Clinically interesting, well presented, a very good review of the literature.

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