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ORIGINAL ARTICLE

Breast MRI: intraindividual comparative study at 1.5 and 3.0T; Initial experience

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Summary

Purpose: *To prospectively and intraindividually compare breast magnetic resonance imaging (MRI) at 1.5 Tesla (T) and 3.0T.*

Methods: *A prospective intraindividual Ethics Committee-approved study was performed in 31 women (average age 58.6±12.3 years), with 114 lesions (9 benign, 105 breast cancers; 24 patients with unilateral and 7 with bilateral cancers). Axial bilateral breast high-spatial resolution contrast-enhanced dynamic MRI was performed at 1.5T using 3 dimensional (3D) dynamic gradient-echo sequences in all patients (spatial resolution 1.1×0.7×2 mm; temporal resolution 41 sec per dynamic acquisition), and after 24-48 h at 3.0T (0.6×0.6×1.7 mm; temporal resolution 65 and 72 sec per dynamic acquisition). Contrast enhancement ratio, number and features of enhancing lesions, image quality and reliability were compared by two radiologists independently.*

Results: 102 cancer lesions were detected at 1.5T and 105 cancer lesions were detected in 31 patients at 3.0T. One cancer lesion was observed at 1.5T which was missed at 3.0T, and 3 cancer lesions and one high-risk lesion (LCIS) were detected at 3.0T while missed at 1.5T. Enhancement rates were significantly higher at 1.5T (224.5±100.2) compared to 3.0T (133.7±38.3). Better image quality was observed at 3.0T. Interobserver reliability was higher at 3.0T (p= 0.684) compared to 1.5T (p= 0.351).

Conclusion: *Detection of breast cancer shows a trend of better performance at 3.0T than at 1.5T.*

Key words: breast cancer, breast MRI, comparative study, multifocal carcinoma

Introduction

Over the past two decades, MRI of the breast has found a substantial place in preoperative staging of the ipsi- and contralateral breast in patients with Breast Imaging Reporting and Data system (BI-RADS) categories 5 and 6 lesions [1]. In addition, MRI has been shown to be favorable for screening women at increased risk for breast cancer (strong family history of breast cancer, carriers of BRCA 1 and BRCA 2, or with a personal history of cancer) [2]. Other patients who benefit from MR screening include those with implants, scar tissue, or very dense breast, which can interfere with mammographic interpretation [3]. One reason why MRI of the breast has assumed an important role in preoperative assessment is its high sensitivity, which in some studies approaches 100% [4]. The specificity is however lower and is estimated to range from 20-100%, depending on the technique and diagnostic criteria [5]. Current research work, based on morphologic and kinetic data analysis, reported that the specificity of 3.0T breast MRI was 74%, and after adjustment for the breast vascularity score, it significantly increased to 87% without affecting sensitivity [6]. Higher specificity could also be obtained by using high spatial resolution sequences which allows detailed morphologic analysis of observed lesions [7]. A critical component of the study is to provide high-spatial resolution images within a period of time that is relatively short, so that the optimum arterial phase contrast between the enhancing lesion and surrounding tissue is obtained.

The majority of studies on breast MRI have been performed at 1.5T [8-14]. The higher signal-to-noise at 3.0T can translate to higher spatial resolution, greater temporal resolution, or both [15]. Nonetheless, there is a paucity of literature that has attempted to define ad-

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vantages of 3.0T over 1.5T. To our knowledge, there has been only one study that prospectively compared 1.5T and 3.0T MRI of the breast, which used T1-weighted two-dimensional (2D) gradient-echo pulse sequences [7]. T1-weighted 3D gradient echo pulse-sequence allows thinner sections (or partitions) to be acquired, which is important for breast imaging [16].

The purpose of our study was to prospectively compare dynamic contrast-material MRI of the breast at 3.0T and 1.5T within the same individual using 3D gradient echo techniques to define if an advantage of 3.0T imaging could be determined.

Methods

We conducted an Ethics Committee-approved intraindividual comparative study on patients who underwent contrast-enhanced dynamic subtraction MRI first at 1.5T, and then, within 24-48 h, repeated MRI at 3.0T. Confidentiality of patient medical information was strictly adhered to. Our study included 31 patients older than 18 years of age (average 58.6±12.3), with no contraindications for MRI. Informed consent was obtained from all the patients after the nature of the procedure had been fully explained.

Patients were referred for contrast-enhanced MRI for preoperative staging of mammographic and ultrasonographic BI-RADS 4, 5 and 6 lesions. The major indication for MRI was suspected multicentricity of breast lesions. All patients underwent breast surgery within 7 days after the second MRI.

MR Imaging

Imaging studies were performed using 1.5T and 3.0T whole-body MRI systems (Avanto 1.5T and Trio 3.0T; Siemens Medical Systems, Erlangen, Germany), with application of the dedicated 8-channel breast surface coils with both systems and breast fixation.

For 1.5T MRI, the protocol consisted of T2-weighted axial sequences to cover the whole volume of both breasts. The dynamic series consisted of T1-weighted 3D gradient-echo pulse sequence (flip angle of 12-15º), with a total of 9 dynamic acquisitions, one obtained before and 8 obtained sequentially after contrast administration, commencing immediately after a bolus injection of 0.1 mmol per kg body weight gadolinium-dimeglumine (Magnevist; Schering/Bayer, Berlin, Germany), with slice thickness of 2 mm and acquisition matrix of 448×282. Spatial resolution was 1.1×0.7×2 mm and temporal resolution was 41 sec per dynamic acquisition. To suppress the signal of fat, image subtraction was performed off-line.

At 3.0T MRI, two different dynamic protocols were performed after the standard T2-weighted axial and T2-weighted fat saturated sagittal sequences. The first protocol, which was used in 15 patients, consisted of T1-weighted 3D gradient-echo FLASH sequence (flip angle of 10º), with a total of 7 dynamic acquisitions, one obtained before and 6 immediately after a bolus injection of 0.1 mmol per kg body weight gadolinium-dimeglumine (Magnevist; Schering, Berlin, Germany), with slice thickness of 1.7 mm and acquisition matrix of 512×512. Voxel size was 0.6×0.6×1.7 mm and temporal resolution of 65 sec per dynamic acquisition. The second protocol, used in 16 patients, consisted of T1-weighted 3D gradient-echo pulse sequence with fat-suppression (VIEWS - Volume Imaging with Enhanced Water Signal) (flip angle of 10º), with a total of 7 dynamic acquisitions, one obtained before and 6 obtained immediately afterwards a bolus injection of 0.1 mmol per kg body weight gadolinium-dimeglumine (Magnevist; Schering, Berlin, Germany), with the thickness of 1.7 mm and the acquisition matrix of 512×512. With this parameter setting, we obtained a voxel size 0.6×0.6×1.7 mm and a temporal resolution of 72 sec per dynamic acquisition.

Data analysis

Image interpretation

Two experienced radiologists prospectively and independently performed image interpretation at the work-station on MR images of the breast. T2 weighted axial and second postcontrast subtracted images were interpreted in a blind fashion as to field strength and patient identification. However, analysis of non subtracted images (FLASH 3D and VIEWS) was performed with recognition of the field strengths. The readers were permitted to adapt display settings in order to achieve conditions for optimal reading. Determination of the number of lesions was made and a BI-RADS category 1-5 was assigned for each lesion. For every data set both readers were provided with all the patients' previous mammographic and ultrasound examinations, in order to ensure a proper clinical setting. The readers were blinded to the final BI-RADS category assigned to the same patient at the other field strength. A consensus reading was performed in cases in which the same lesion was assigned different BI-RADS category.

Lesions were rated suspicious for malignancy according to the criteria for the MRI BI-RADS categorization [1], based on specific morphologic characteristics, such as shape irregularity, spicules, irregular margins, with asymmetric, segmental or ductal configuration, and following contrast, heterogeneous or rim enhancement. Rapid enhancement dynamics were taken into account to corroborate suspicious morphologic findings. Smooth bordered, oval lesions with thin hypointense septations were considered benign lesions, and slow, persistent enhancement dynamics were considered consistent with benign disease except in cases of a morphologically suspicious lesion. "Washout" dynamics strongly suggested malignancy and was considered suspicious, except in the case of a well-defined lesion with dark internal septi.

The final diagnosis was established by excisional biopsy in all 31 patients. Processing and evaluation of breast excision specimens was performed according to standard surgical pathology procedure. Identified lesions, either palpable masses or mammographically detected lesions marked with wire, were histologically examined and reported according to AJCC/UICC TNM system (6th edition) [17].

Image quality

Image quality was assessed using the scale described by Kuhl et al. [7], with 1 being non-diagnostic image quality, to 5 for excellent diagnostic quality, as follows:

1. Image quality was insufficient due to poor signal intensity homogeneity, massive dielectric resonance effects (a presence of a typical pattern of central concentric signal intensity loss or signal void), extensive artifacts resulting in severe loss of signal intensity and poor signal-to-noise ratio (SNR).
2. Poor image quality, in which there was substantial but incomplete signal intensity variation across the field of view, or incomplete image degradation due to pulsation artifacts with a low visual SNR.
3. Acceptable image quality, in which there was only subtle inhomogeneity of signal intensity across the whole field of view

and/or moderate pulsation artifacts with a high visual SNR.
4. Good image quality, in which there were only mild inhomogeneities of signal intensity, with no dielectric resonance effects, subtle pulsation artifacts and a high visual SNR.
5. Excellent image quality, in which there were no or only a slight signal intensity inhomogeneity, with no or subtle pulsation artifacts and a high visual SNR.

Quantitative assessment of enhancement rates

The enhancement rates of the lesions were calculated for the second postcontrast acquisition using the following equation:

$$[(SI_{post}-SI_{pre})/SI_{pre}]$$

where SI_{pre} is the signal intensity before the bolus administration of the contrast agent and SI_{post} is the signal intensity after the injection of the contrast agent. Following completion of these calculations, contrast enhancement rates of each lesion at 1.5T and 3.0T were compared.

Statistical analysis

The Wilcoxon matched-pairs signed rank test was used to test the statistical significance of the difference in the image quality scores of the dynamic contrast-enhancement series between images obtained at 1.5T and 3.0T. Student's t-test was used to test the statistical significance of the difference between enhancement rates of the same lesion observed on 1.5T and 3.0T.

Interobserver reliability of the subscribed BI-RADS type of the lesions was determined by calculating a two rater unweighted Kappa statistics. Kappa (κ) is defined as $\kappa=(P_o-P_e)/(1-P_e)$, where P_o is the actual probability of agreement and P_e is the expected agreement by chance. Kappa score above 0.81 is considered "almost perfect" interobserver reliability, between 0.61 and 0.8 is "substantial", 0.41-0.6 is "moderate", 0.21-0.4 is "fair" and below 0.2 is "slight" interobserver reliability [18]. McNemar's test was used to test whether the lesion margins were homogeneous. In addition, interobserver reliability analysis using Kappa statistics was performed to determine consistency between 2 different field strengths, evaluating the 3 main morphologic features including border architecture, rim enhancement and homogeneity of the lesions.

Results

A total of 102/105 cancer lesions were identified in 31 women (102 lesions detected at 1.5T, 105 lesions at 3.0T). Since the major indication for breast MRI in this study was suspected multicentricity, this unusually high number of malignant lesions was expected. Nine benign lesions were also detected. A total of 105 histologically-proven invasive cancers, DCIS and LCIS were detected in 31 patients, 24 had unilateral breast cancer (4 patients with single lesions, 20 patients with multicentric/multifocal lesions) and 7 patients had bilateral breast cancer (Table 1). One patient had a solitary ductal carcinoma *in situ*, 8 patients had a combination of a ductal carcinoma *in situ* and an invasive lesion, 2 had a combination of multicentric carcinoma and an invasive lesion contralaterally, and one patient had a combination of an invasive cancer and a fibroadenoma contralaterally (Table 2). The size of the detected lesions ranged from 3 to 70 mm.

Table 1. Distribution of malignant breast lesions

Breast lesions	*Number*	*%*
Unilaterally localized		
Single	4	12.9
Multicentric	20	64.52
Total	24	77.42
Bilaterally localized	7	22.58

Cancer detection

The two readers detected 102 and 103 cancers at 1.5T, and 103 and 105 cancers at 3.0T, which was not significantly different ($p<0.01$). One cancer was observed at 1.5T which was missed at 3.0T (Figure 1), and 4 cancers and high risk lesions were detected at 3.0T that were missed at 1.5T (Figure 2).

The one case in which a tumor was missed at 3.0T, a ductal carcinoma *in situ* was observed at 1.5T, while there were no detectable lesions at 3.0T due to a technical failure in which i.v. contrast signal suppression instead of fat suppression occurred (using VIEWS sequence). In 2 women, ductal carcinoma *in situ* was more clearly delineated as two parallel hyperintense stripes on 3.0T, whereas a single linear lesion at 1.5T was apparent (Figure 3). In 2 cases of recidivant multicentric lobular carcinoma *in situ* and lobular invasive carcinoma, the lesions were not detectable at 1.5T, while at 3.0T imaging "wash-out" dynamics and morphologic characteristics were apparent.

In a patient with a histologic diagnosis of a fibroadenoma, benign characteristics of the lesion were clearly depicted on the images obtained at 3.0T, while it was highly suspicious for malignancy on the 1.5T images.

In 2 cases the propagation of infiltrative cancer

Table 2. Final pathologic diagnosis of the lesions

Pathologic diagnosis	*Number*	*%*
Malignant and high-risk lesions		
Invasive Ca	55	48.25
DFSP	1	0.88
DCIS	37	32.46
LCIS	11	9.65
Total	105	92.11
Benign lesions		
Trichofolliculoma	1	0.88
Fibroadenoma	3	2.63
Papilloma	1	0.88
Lymph nodes	4	3.51
Total	9	7.89

DFSP: dermatomyosarcoma protuberans, DCIS: ductal carcinoma *in situ*, LCIS: lobular carcinoma *in situ*

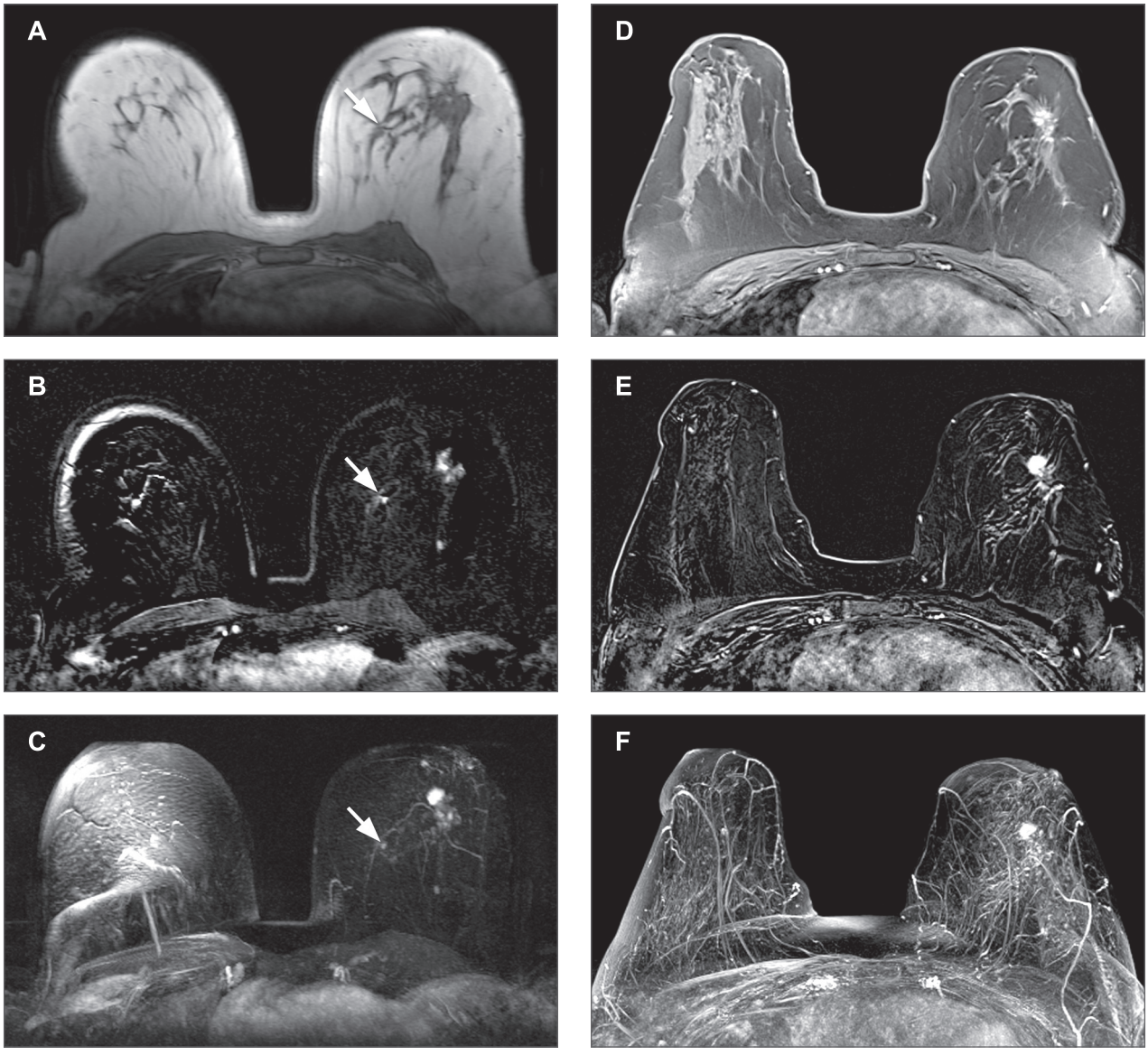

Figure 1. DCIS 4 mm. At 1.5T one focal lesion < 5 mm in the inner medial quadrant (arrow) can be visualized at FLASH (**A**), subtracted (**B**) (arrow), and maximum intensity projection (MIP) images (**C**) (arrow). It could not be detected at 3.0T VIEWS (**D**), subtracted (**E**) and MIP (**F**) images.

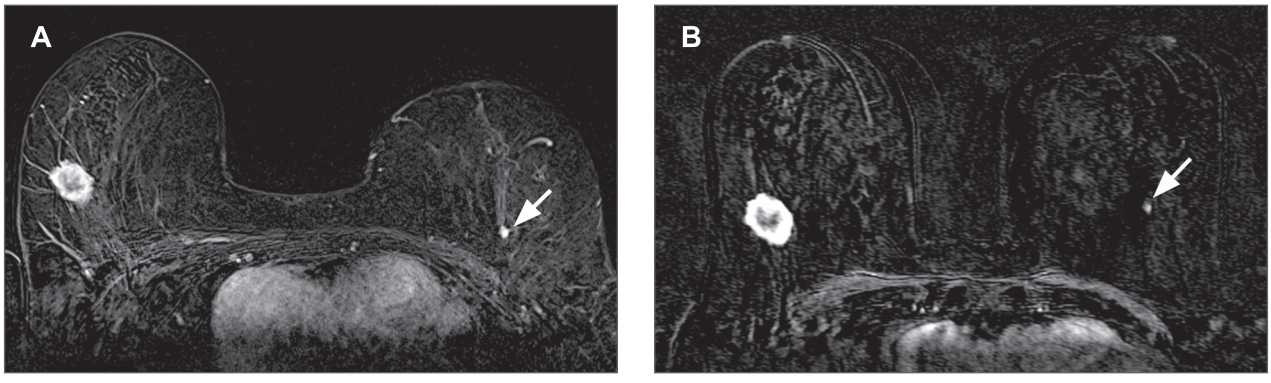

Figure 2. An incidental finding of a synchronous cancer in the left breast in a patient with invasive ductal carcinoma in the right breast. At 3.0T subtracted image (**A**), the morphology of the lesion shows spiculated margins and marginal type of postcontrast enhancement (arrow) suggestive of BI-RADS 5 category. At 1.5T subtracted image (**B**) a small focus (arrow) can easily be missed or categorized as BI-RADS 3 due to the absence of typical morphology details.

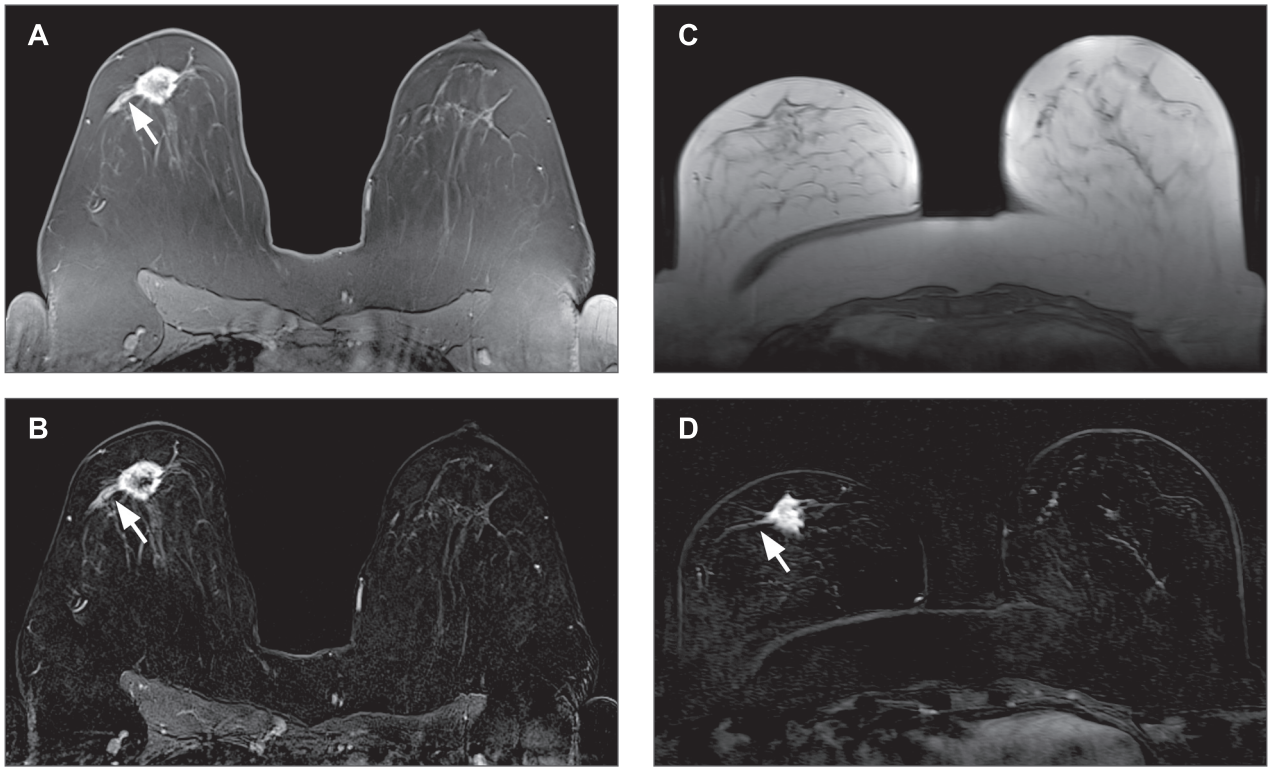

Figure 3. Overall image quality is better at 3.0T VIEWS (**A**) and subtracted (**B**) images, with a clear delineation of two parallel hyperintense stripes (arrows) indicative of DCIS. At 1.5T FLASH (**C**) and subtracted (**D**) images only a single linear lesion is detected (arrow).

spicules was tractable towards the muscle fascia at 3T (Figure 4), which not only increased the certainty and specificity of the diagnosis, but also influenced the surgical approach.

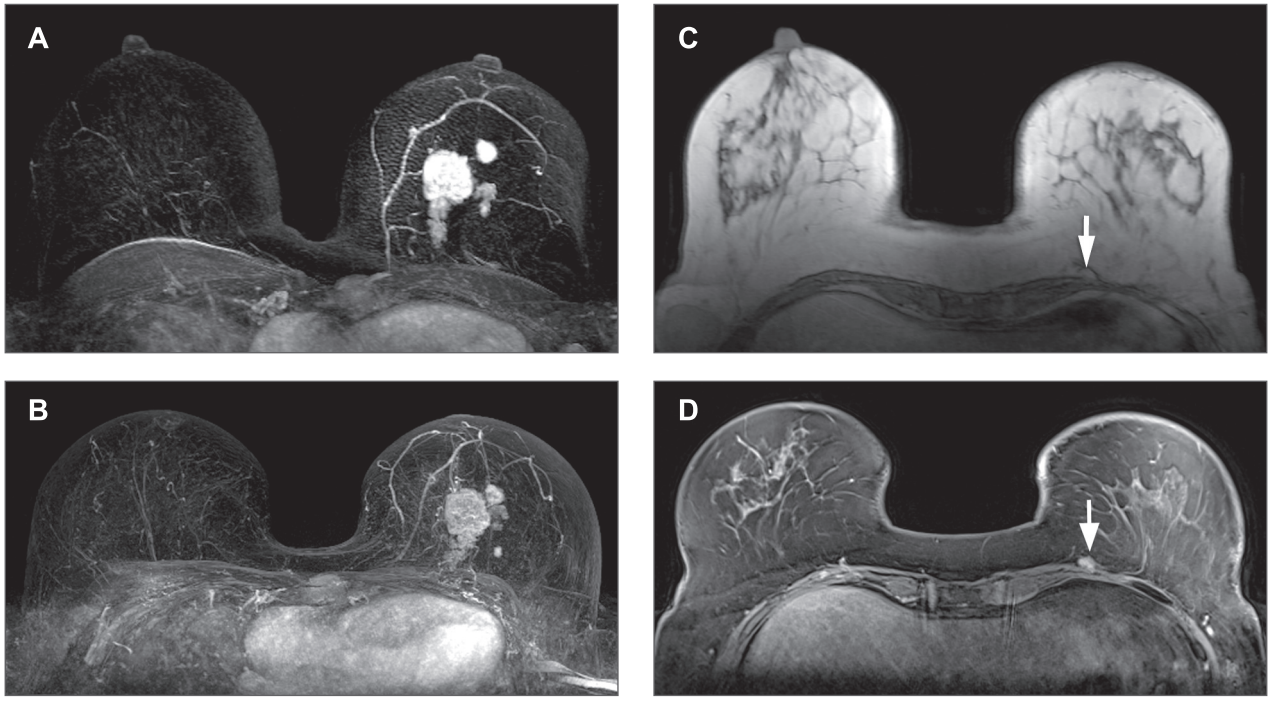

Figure 4. Maximum intensity projection images at 1.5T (**A**) and 3.0T (**B**) show multicentric invasive cancer in the left breast. An additional lesion (arrow) is detected at postcontrast VIEWS image at 3.0T with obvious invasion of the pectoral muscle (**D**), which is not clearly delineated at 1.5T FLASH postcontrast image (arrow) (**C**).

Image quality

Image quality scores for dynamic 3D gradient-echo MR breast imaging obtained on 1.5T and 3.0T prospectively, showed subtle differences. The median image quality score was 5 (excellent) for images obtained at 3.0T and 4 (very good) for images obtained at 1.5T. Lower score was assigned to images obtained at 3.0T in 6 (19%) of 31 patients, reflecting that adequate fat-saturation was not accomplished. In 3 patients fat was not saturated, while in 2 patients suppression of i.v. contrast occurred. These latter 2 patients were excluded from postcontrast morphologic and dynamic analyses.

The quality of images obtained at 1.5T was rated inferior to that of 3.0T in 17/31 cases due to an increased number of motion artifacts. On T2W sequences, images obtained at 3.0T exhibited more clearly defined morphologic characteristics of the lesion.

The feeding blood vessel was more prominent on the postcontrast images at 3.0T compared to 1.5T in 20/31 patients, which probably occurred as a result of a higher strength of a magnetic field and already observed better image quality.

Dynamic features

Mean enhancement rates for all lesions were 224.5±100.2 at 1.5T and 133.7±38.3 at 3.0T. The difference between contrast enhancement rates was shown to be significantly higher on 1.5T by using the Student's t-test for one sample ($p<0.05$) and by using the Wilcoxon matched-pairs signed rank test. Considering qualitative enhancement kinetics features, no statistically significant difference was found between two field strengths ($p>0.05$) (Table 3).

Interobserver reliability

The interobserver reliability for the raters on 3.0T was found to be substantial (κ=0.684), while at 1.5T it was fair (κ=0.351). In addition, McNemar's test showed nonsignificant asymmetry at 3.0T ($p>0.05$) and significant asymmetry at 1.5T ($p<0.05$) which indicated non-homogeneity of the reported BI-RADS types. Concordance between the two readers was absolute for rating BI-RADS 2 (benign) and 3 (probably benign) lesions. Significant non concordance occurred at 1.5T in differentiating between BI-RADS 4 and 5 types of the lesions, which was not the case at 3.0T, as a result of better lesion characterization.

Interobserver reliability between two field strengths for the rim enhancement was substantial (κ=0.643), while border architecture was moderate (κ=0.433), with nonsignificant asymmetry at both field strengths for both features tested ($p>0.05$). However, only fair consistency between 3.0T and 1.5T was shown considering the homogeneity of the lesions (κ=0.109), indicating that inhomogeneity of the lesions was significantly more often observed at 3.0T (Table 4).

Table 3. Dynamic features of enhancing breast lesions at 1.5T and 3T

Dynamic features	*1.5T*	*3T*
Type of the enhancement curve (%)		
Persistent	8	8
Plateau	36	28
Washout	56	64
Maximum enhancement rate (%)	224.5	133.7

Discussion

Previous studies showed that MR mammography offers higher sensitivity for the detection of multifocal cancer [19].

The results of our study have shown that there were small advantages of 3.0T over 1.5T imaging in MRI of the breast, as demonstrated in the same individual, evidenced by a greater number of cancers detected (105 of 105 vs. 102 of 105), better characterization, and better delineation of feeding vessels.

Our study concurs with the observation by Kuhl et al. that smaller cancers may be detected at 3.0T compared to 1.5T [7]. The smallest tumors detected at 3.0T were 3 mm and the smallest at 1.5T were 4 mm.

We observed better characterization of masses at 3.0T compared to 1.5T which we attributed to the higher signal-to-noise (S/N) and thinner sections that allowed for more clear evaluation of lesion morphology. This was especially noteworthy in one patent with a benign lesion, where at 3.0T the lesion appeared oval-shaped and exhibited minimal enhancement, whereas

Table 4. Morphologic features of enhancing breast lesions at 1.5T and 3T

Morphol. features	*1.5T (%)*	*3T (%)*
Margin		
Well-defined	61.1	66.7
Ill-defined	38.9	33.3
Rim enhancement		
Present	55.6	66.7
Absent	44.4	33.3
Homogeneity		
Homogeneous	27.8	11.1
Inhomogeneous	72.2	88.9

at 1.5T this lesion was considered suspicious for malignancy.

Significantly higher contrast enhancement rates were observed at 1.5T compared to 3.0T (225 vs. 134%). The explanation for this is uncertain at present and may reflect technical aspects of the MR systems or software, as this finding is counter-intuitive. More work is necessary to confirm or refute our observation. Since T1 relaxation times for healthy tissues at 3.0T are prolonged for about 30% [20,21], we used prolonged T1 relaxation time at 3.0T and reduced the flip angle to 10º. These two parameters are thought to be determinant of T1 contrast and certainly contribute to the lower enhancement ratios at 3.0T compared to those at 1.5T. In addition, the somewhat paradoxical lower enhancement rates observed at 3.0T has been previously subscribed to B_1 inhomogeneities by Kuhl et al. who observed a consistently reduced enhancement of lesions located in "low B_1 areas" [22]. Although we employed a 3D protocol, 8-channel coil with reduced flip angle as recommended, we also observed lower than expected enhancement at 3.0T. In 2 of our patients we noticed lack of enhancement in cancer lesions, but since fat suppression at 3.0T was inadequate in these cases, they were excluded from the study. However, one should be aware that enhancement rates in 3D breast MRI at 3.0T may be substantially reduced, implying that enhancement kinetics should be viewed with caution at present.

As shown in some comparative studies in brain imaging [23], contrast-enhancement ratio at 3.0T is higher than that at 1.5T, which allows the amount of contrast agent dose to be reduced [23,24], but those studies did not include dynamic imaging. In 3D dynamic breast imaging it seems reasonable to use the shortest possible T1 relaxation time and flip angle; consequently, it may not be recommendable to reduce the contrast agent dose. Further work and development at 3.0T is however necessary.

Also, in half of our patients we used VIEWS sequences in dynamic studies, which led to an emphasized decrease of the contrast-enhancement ratio at 3.0T compared to 1.5T obtained images. Our impression is that use of this particular sequence negatively influences the diagnostic confidence in both readers. Nevertheless, this sequence allows better perception of morphologic details, which is, however, our major basis for establishing the diagnosis.

Some difficulties and limitations are noteworthy. Attempt was made to minimize recall of studies at the time of interpreting the second study by randomly sorting the studies, but study recall bias is a limitation of this type of study design. Inadequate fat saturation remains problematic, and was observed in 6/31 (19%) patients. In some cases this resulted in only unsatisfactory suppression of fat tissue, while in others contrast enhancement was suppressed instead of fat. This reduced image quality to non-diagnostic in 2 cases. In our clinical experience, as evidenced by our study as well, we recommend that it is imperative to always check the quality of fat saturation on T2W images before starting contrast administration. We have found that if the fat suppression cannot be improved on the 3D sequences, that 2D T1 gradient echo sequences should be employed. An additional difficulty we encountered at 3.0T was that in maximum intensity projection (MIP) images in 3/31 (10%) patients the presence of the lesions was difficult to detect due to the specific localization - these poorly visualized lesions were prepectoral, and consequently obscured by contrast-enhanced pectoral muscle.

Blood vessel morphology was better appreciated at 3.0T images, which contributed to a better visualization of asymmetrically increased vascularity, facilitating the diagnostic confidence. Asymmetric increase in breast vascularity in the breast that contains a cancer was first described by Sardanelli [25]. Possible explanations include: reduced flow resistance in tumor tissue, high metabolic rate, and angiogenic stimulation of the whole breast in which a cancer is growing [25,26].

In summary, the findings in our study suggest that detection of breast cancer is better performed at 3.0T than at 1.5T. Further improvements are however necessary in order to improve tumor contrast enhancement at 3.0T.

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