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Improved B_1 Homogeneity of 3 Tesla Breast MRI Using Dual-Source Parallel Radiofrequency Excitation

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Abstract

Purpose—To compare breast MRI B_1 homogeneity at 3 Tesla with and without dual-source parallel radiofrequency (RF) excitation.

Materials and Methods—After institutional review board approval, we evaluated 14 consecutive breast MR examinations performed at 3 Tesla that included 3D B_1 maps created separately with conventional single-source and dual-source parallel RF excitation techniques. We measured B_1 values (expressed as % of intended B_1) on each B_1 map at nipple level in multiple bilateral locations: anterior, lateral, central, medial, and posterior. Mean whole breast and location specific B_1 values were calculated and compared between right and left breasts using paired t-test.

Results—Mean whole breast B_1 values differed significantly between right and left breasts with standard single-source RF excitation (difference L-R, Δ=9.2%; $p<0.001$) but not with dual-source parallel RF excitation (Δ=2.3%; $p=0.085$). Location specific B_1 values differed significantly between right and left on single-source in the lateral ($p=0.014$), central ($p=0.0001$), medial ($p=0.0013$), and posterior ($p<0.0001$) locations. Conversely, mean B_1 values differed significantly on dual-source parallel RF excitation for only the anterior ($p=0.030$) and lateral ($p=0.0003$) locations.

Conclusion—B_1 homogeneity is improved with dual-source parallel RF excitation on 3T breast MRI when compared to standard single-source RF excitation technique.

Introduction

The use of magnetic resonance imaging (MRI) at 3 Tesla (T) has increased substantially in recent years. This increase in field strength over the more commonly used 1.5T scanners provides higher signal to noise (SNR), leading to potential benefits including greater spatial resolution and decreased scan times. Despite these advantages, MRI at 3T also creates significant technical challenges. Chief among these, particularly in breast imaging, is tissue signal variability or "shading" due to B_1 transmit field inhomogeneity resulting from dielectric resonance effects.

First reported in breast MRI by Kuhl et al (1) and further quantitatively described by Azlan et al (2), these adverse B_1 effects are due to the higher frequency B_1 transmit fields that are used at greater field strengths. This results in non-uniform flip angles and measured signal, most pronounced from right-to-left for bilateral axial breast imaging (3),. The non-uniformity can lead to significant variations in T1 contrast that in turn cause significant

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spatial variations in signal intensity and contrast-enhancement or variations in fat saturation uniformity for non-adiabatic radiofrequency (RF) pulses. This resulting tissue contrast and signal enhancement inhomogeneity is particularly problematic in dynamic contrast-enhanced (DCE) breast MRI.

Proposed solutions to address the issue of tissue shading effects include techniques to maximize T1 contrast, including 3D imaging and increased flip angles (3,4). Recently, dual-source parallel excitation techniques have been developed to address the challenge of dielectric shading by increasing uniformity of the applied RF field. The use of independent transmit channels also allows for optimization of the local and whole-body specific energy absorption rate (SAR) using patient adaptive techniques, leading to reduced SAR deposition levels and decreased scan times (5). This technique has been shown to be useful in body and musculoskeletal imaging (5,6), but to date there are no published studies examining its effectiveness in reducing B_1 inhomogeneities in breast MRI at 3T. We thus sought to evaluate MRI B_1 homogeneity in breast imaging at 3T with and without dual-source parallel RF excitation.

Methods

Patient Population

The protocol for this study was approved by our institutional review board and was compliant with the Health Insurance Portability and Accountability Act. Our institutional review board waived informed consent. We included 15 consecutive patients who underwent a clinical breast MRI from February 18, 2010 to March 8, 2010. Several patient body composition factors were assessed. Patient height, weight, and body-mass-index were obtained from the medical records. Breast size was visually assessed for each patient by examining the B_1 maps at the level of the nipple and categorized as small, medium, or large while also noting any asymmetry.

B_1 Maps Acquisition

All MR examinations were performed on a Philips Achieva Tx 3T scanner using a dedicated 16-channel bilateral breast coil (Philips Healthcare, Best, the Netherlands). Patients were scanned axially in the prone position with feet first. After the standard clinical breast MRI sequences were obtained (including a T2-weighted fast spin echo sequence, T1-weighted non-fat suppressed sequence, and a T1-weighted fat-suppressed dynamic contrast-enhanced MRI sequence), B_1 transmission field mapping was performed separately with conventional single-source RF excitation and dual-source parallel RF excitation (MultiTransmit, Philips Healthcare, Best, the Netherlands) techniques (7).

As previously described (6), the dual-source parallel RF excitation technique employed in our study distributes RF power to the ports of the system body coil using two independent RF transmit channels under full software control. The resulting applied B_1 field is effectively a linear combination of the B_1 fields generated by each source. Using patient-adaptive RF shimming, the power, amplitude, phase and waveform of the two RF sources are automatically adjusted for optimal uniformity in each patient's unique anatomy. In practice, the process involves first acquiring a short B_1 calibration scan on a per-patient basis to map the B_1 field produced in the subject by each of the independent RF sources and determine the expected RF energy deposition in the patient. For breast imaging, parallel RF excitation can be used during particular acquisitions (by selecting it in the protocol) to improve B_1 homogeneity, without requiring changes to other sequence parameters.

For our study, B_1 maps were calculated using both standard single-source and parallel dual-source RF excitation. In each case, optimal B_0 homogeneity was first achieved using a

patient-adaptive image-based B_0 shimming technique (SmartExam Breast, Philips Healthcare, Best, The Netherlands). Next, B_1 transmission field maps were created using a previously described actual flip-angle imaging (AFI) approach (2,7), which enables accurate and rapid 3D in vivo measurement of the B_1 field. This method employs a 3D gradient echo pulse sequence incorporating two identical RF pulses but with different TRs, and imaging parameters were defined based on previous recommendations (2,7): TR_1/TR_2 = 30/150 msec, TE = 2.2 msec, flip angle = 60°, matrix size = 128 × 128, FOV = 40 × 40 cm, slice thickness = 12 mm, and number of slices = 7. The same imaging parameters were used for standard single-source and dual-source RF excitation acquisitions. A B_1 calibration scan was run prior to the dual-source RF excitation acquisition, as described above.

Image Measurements

B_1 maps were calculated by measuring the actual flip angles generated in the subject relative to the intended flip angle, expressed as a percentage, using the relationship:

$$\alpha \approx \cos^{-1}\frac{rn-1}{n-r} \quad (1)$$

where α is the actual flip angle, r is the signal ratio S_1/S_2 with S_1 and S_2 the signals measured after the corresponding TRs (TR_1=30msec, TR_2=150msec), n = TR_2/TR_1. Profile plots were defined on B_1 maps to quantify right to left variation across the field of view using ImageJ (National Institute of Health, Bethesda, MD). B_1 values were measured by defining five circular regions of interest (ROIs) of equal area (1.2 cm^2) in each breast on each B_1 map at the level of the nipple. ROIs were drawn for each subject in the following bilateral locations: anterior, lateral, central, medial, and posterior (figure 1). Mean whole breast B_1 values were also calculated for each subject by averaging the five ROI values for each breast.

Statistical Analysis

Intra-patient differences between right and left whole breast and location-specific B_1 values for both dual-source parallel RF and single-source RF excitation techniques were evaluated using paired t-test. All computations were performed using JMP version 9.0.2 (SAS Institute Inc, Cary, NC).

Results

We scanned 15 patients with both single-source and dual-source parallel RF excitation techniques. A single patient who had undergone left mastectomy with silicone breast implant reconstruction was excluded (n=1) due to inability to draw ROIs of left breast tissue. Thus, the final cohort included 14 patients. Indications for the clinical breast MRI in the study patients were high risk screening (n=7), evaluation of extent of disease in patients with known breast cancer (n=6), and short-interval 6 month follow-up for a prior MRI finding in a high risk screening patient (n=1). The mean patient age was 55 years.

The patient cohort exhibited varied body compositions, with a relatively even distribution of breast sizes (small n=5 patients, medium n=6 patients, large n=3 patients). Only one patient demonstrated visually perceptible breast size asymmetry (right breast was larger than the left). Mean patient height was 164.6 ± 6.8 cm, mean patient weight was 69.9 ± 9.2 kg, and mean patient body-mass-index was 25.4 ± 2.8 cm/kg.

Whole Breast B_1 Values and Comparisons

B_1 measures are reported in Table 1. Mean whole breast B_1 values per patient ranged from 72 – 108% (median, 90%) for single-source RF excitation technique and 90 – 116% (median, 102%) for dual-source parallel RF excitation technique. Mean right whole breast B_1 values differed significantly from mean left whole breast B_1 values with single-source RF excitation (mean difference L-R, Δ=9.2%; $p<0.001$) but not with dual-source parallel RF excitation (mean difference L-R, Δ=2.3%; $p=0.085$) (figure 2). An example comparing the variations in B_1 values between the right and left breast with conventional single-source and dual-source parallel RF excitation techniques in a single patient is provided in figure 3.

Regional B_1 Values and Comparisons

Intra-patient regional B_1 values significantly differed between right and left on single-source RF excitation in the lateral ($p=0.014$), central ($p=0.0001$), medial ($p=0.0013$), and posterior ($p<0.0001$) locations, with posterior regions demonstrating the greatest B_1 inhomogeneities ($\Delta=-14\%$). Conversely, mean B_1 values differed significantly on dual-source parallel RF excitation for only the anterior ($p=0.030$) and lateral ($p=0.0003$) locations, Table 1.

Discussion

Single-source RF transmission attempts to generate a circularly polarized RF field by utilizing a single RF source that is split between two ports 90° apart. This design, termed quadrature drive or mode, was adequate at 1.5T and lower magnetic (B_0) field strengths. However, at 3T field strength, standing wave effects are more problematic, particularly in larger patients, resulting in non-uniform RF excitation across the field of view. Recently, several studies have demonstrated that the use of multiple channels with parallel RF excitation can substantially improve image homogeneity in both body and musculoskeletal imaging applications (5,6,8–10). However, there are currently no published studies that specifically examine the use of this novel technique for the breast imaging application, where B_1 inhomogeneities are particularly problematic due to off-center positioning of patients' breasts in the whole-body RF coil (2).

The system utilized in our study enables the use of both single-source RF excitation and dual-source excitation within the body coil, allowing for our intra-examination comparisons. We demonstrated that there is improvement in B_1 homogeneity with dual-source parallel RF excitation techniques on 3D breast MRI when compared to the conventional single-source technique. For whole breast averaged B_1 measures, there were significant right-to-left differences on single-source RF excitation maps, but not on dual-source RF excitation maps. When evaluating location specific B_1 values, we noted that improvements in B_1 homogeneity were greatest in the central, medial, and posterior aspects of the breasts.

However, we did note that there was significant right-to-left B_1 inhomogeneity on dual-source RF excitation B_1 maps at the anterior location that was not significant on the single-source maps. The reason for this is unclear but could demonstrate that the dual-source method is only able to correct low-order spatial variations in B_1. Higher channel parallel RF excitation techniques may further improve B_1 homogeneity for breast imaging. Additional investigation into this phenomenon is warranted.

Our results confirm quantitatively the B_1 inhomogeneity challenges that have been previously described (1,2). Prior authors have reported that tissue signal variability due to reduced B_1 occurred most prominently in the right breast while we observed this phenomenon affecting the left breast. This difference is readily explained by patient positioning; the 16-channel coil used for our study enables us to scan patients oriented feet first rather than head first (as was utilized by Azlan et al and Kuhl et al).

Our study has several limitations. We evaluated a small number of patients (n=14), and future larger studies would be useful to confirm our results. However, our results agree with those of previous reports for body MR applications demonstrating improved B_1 homogeneity with dual-source parallel RF excitation (6). Additionally, we sought only to evaluate quantitative differences in B_1 homogeneity; we did not qualitatively assess the appearance of corresponding T1-weighted and T2-weighted images or the effect of B_1 inhomogeneity on clinical interpretation. Finally, as our study was performed on a single 3T Philips MR scanner, our results of improved B_1 homogeneity using dual-source parallel excitation may be vendor specific.

In conclusion, our study confirms that dual-source parallel excitation can significantly improve B_1 homogeneity over conventional single-source excitation techniques in breast MRI at 3T. This technique has the potential to substantially reduce a major challenge of breast MRI at higher field strength and improve tissue contrast and lesion conspicuity.

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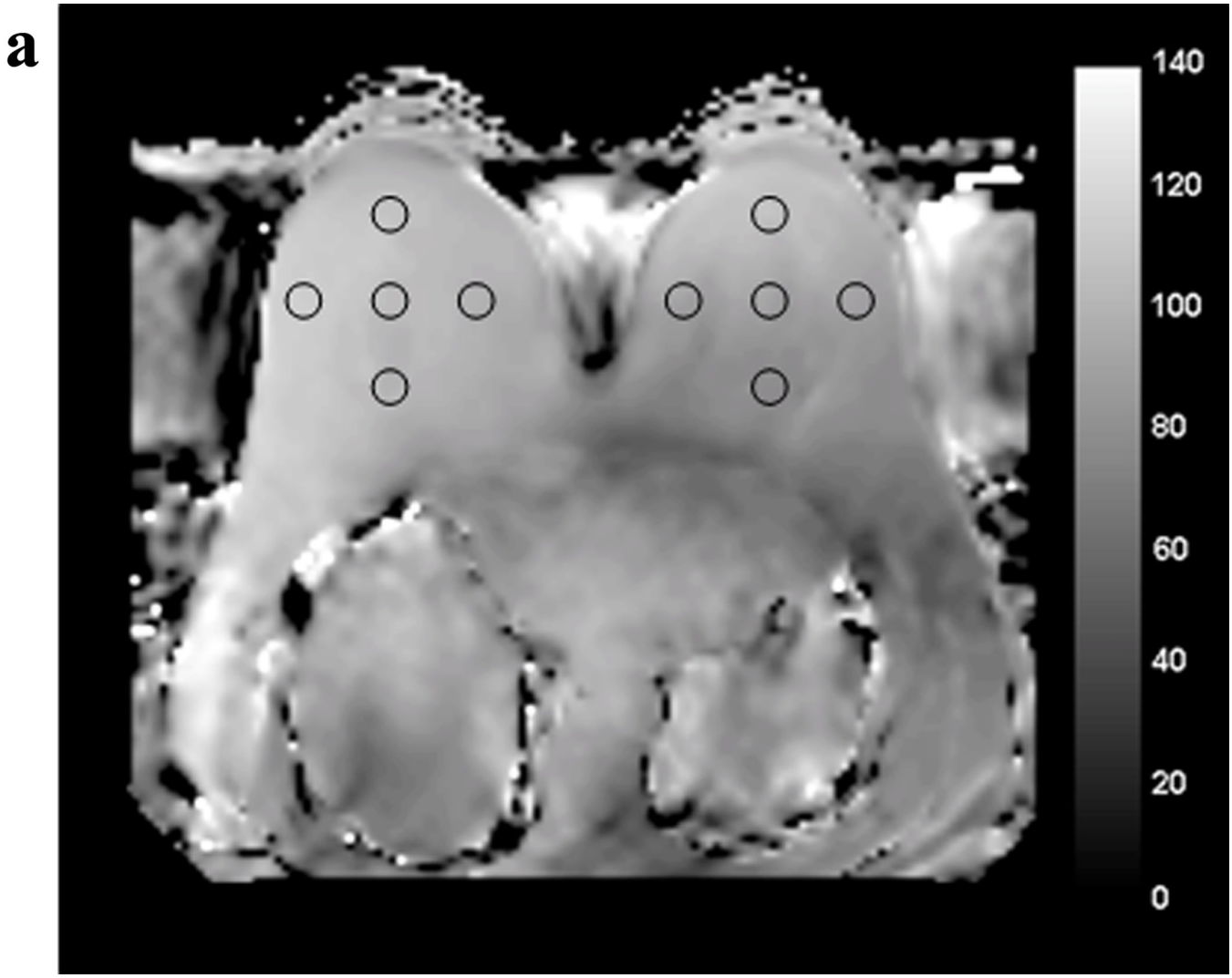


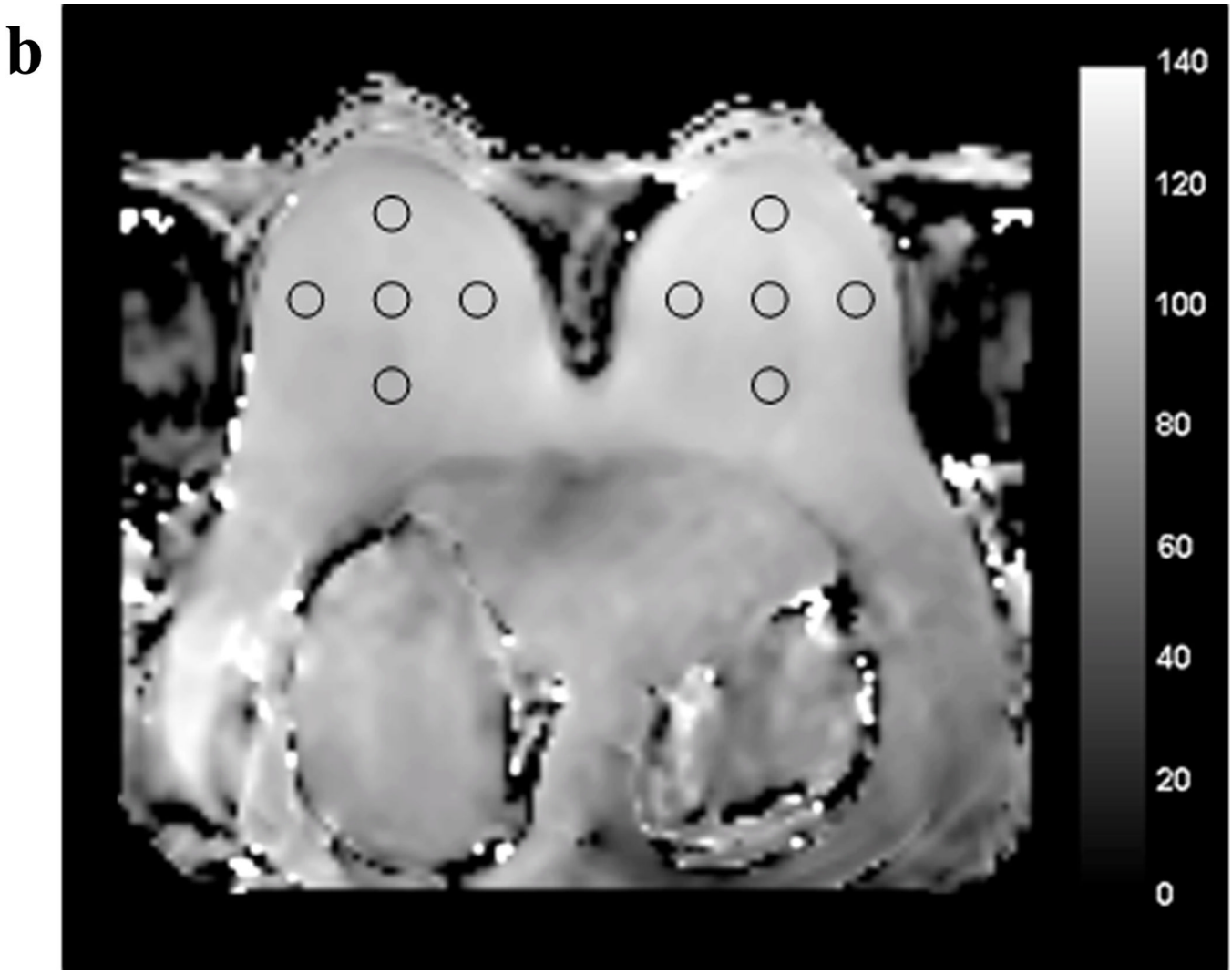


Figure 1.
Example of regions of interest (ROIs) drawn at the level of the nipple on the B_1 maps acquired with standard single-source RF excitation (A) and with dual-source parallel RF excitation (B).

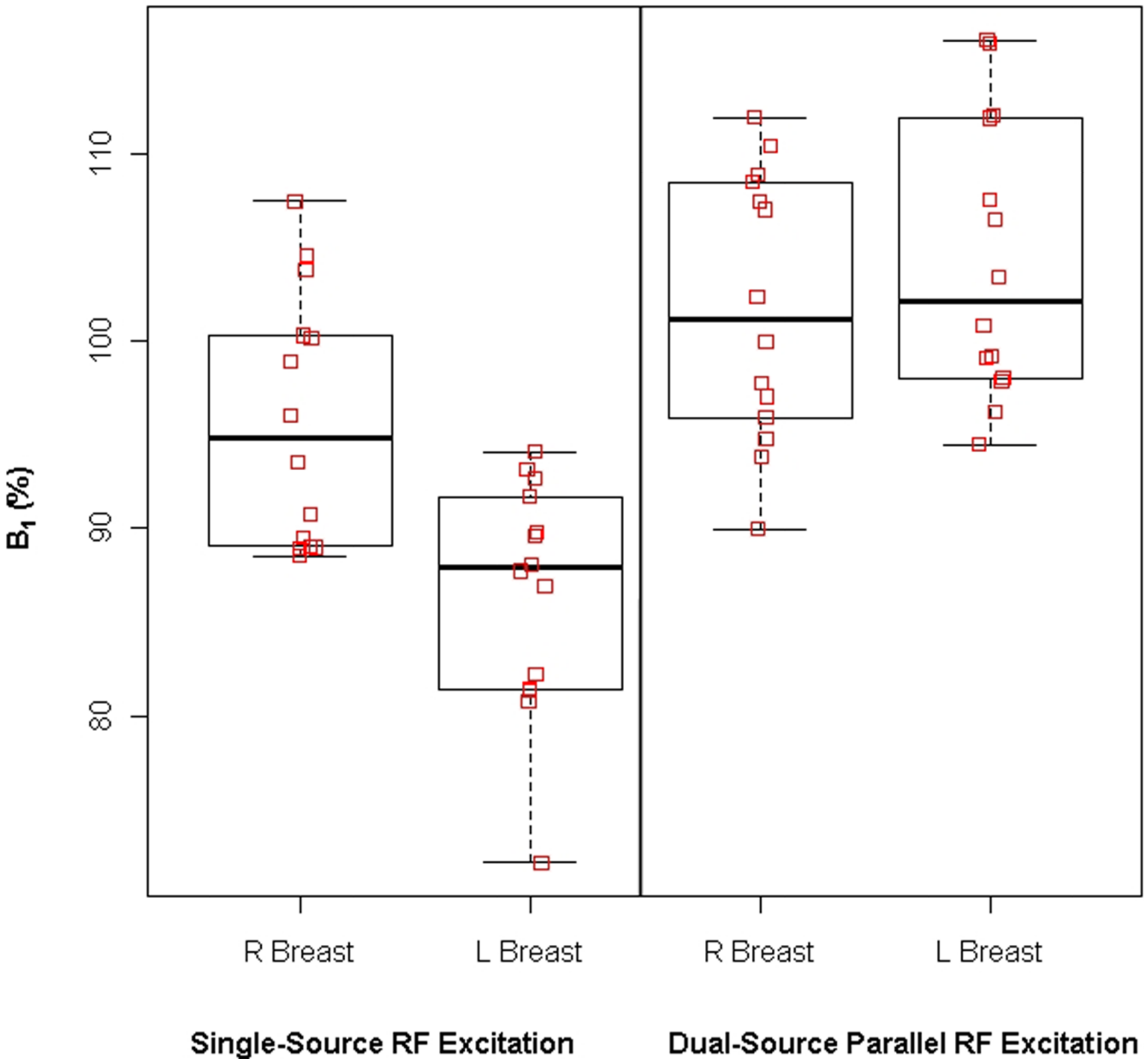
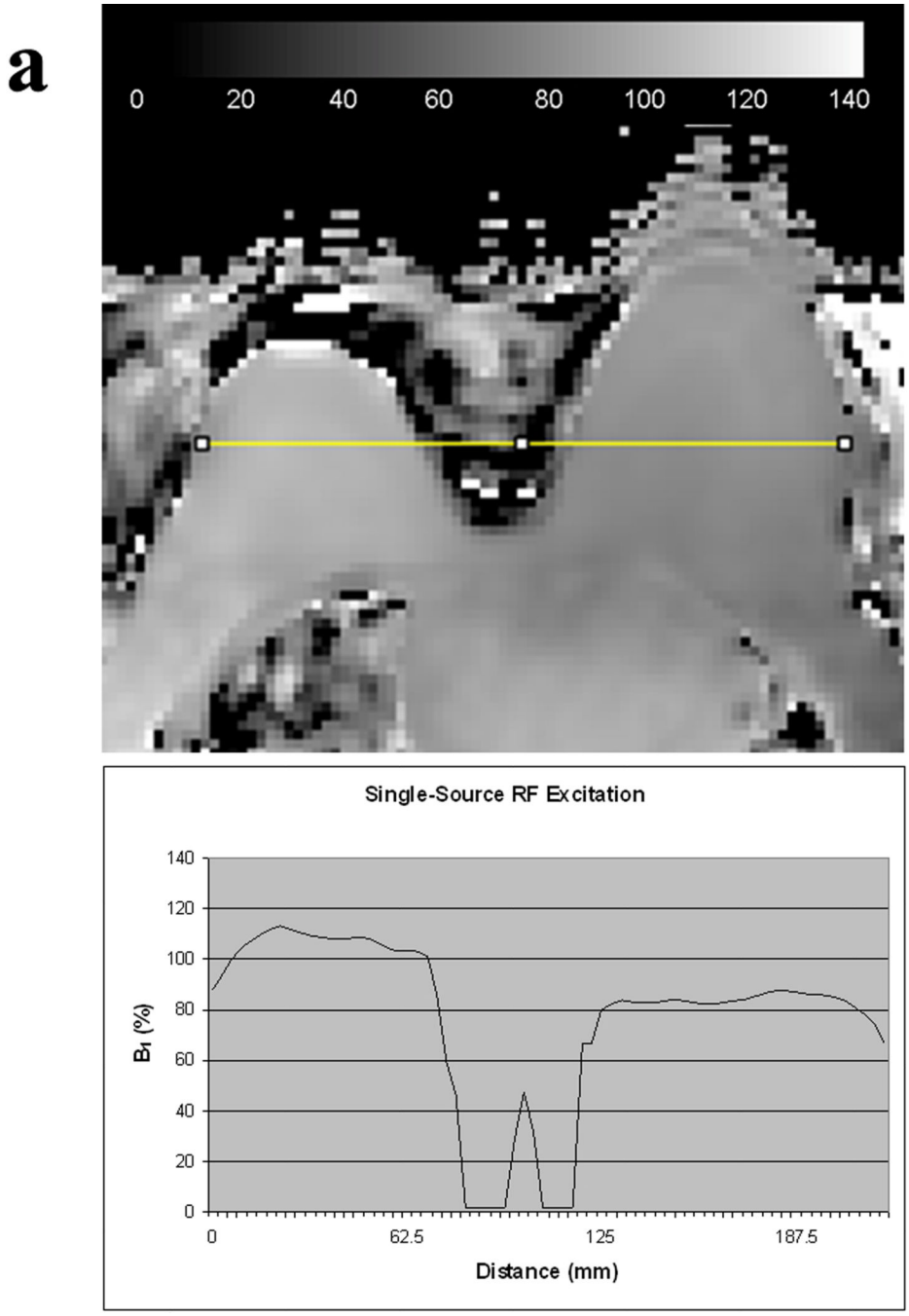


Figure 2.

Box plots demonstrating the mean B_1 signal (% of intended B_1) and standard deviations between the right and left breasts for all patients in the study. Whole breast B_1 signal significantly differed between right and left breast with single-source RF excitation. However, there was no statistically difference in whole breast B_1 signal with dual-source parallel RF excitation.



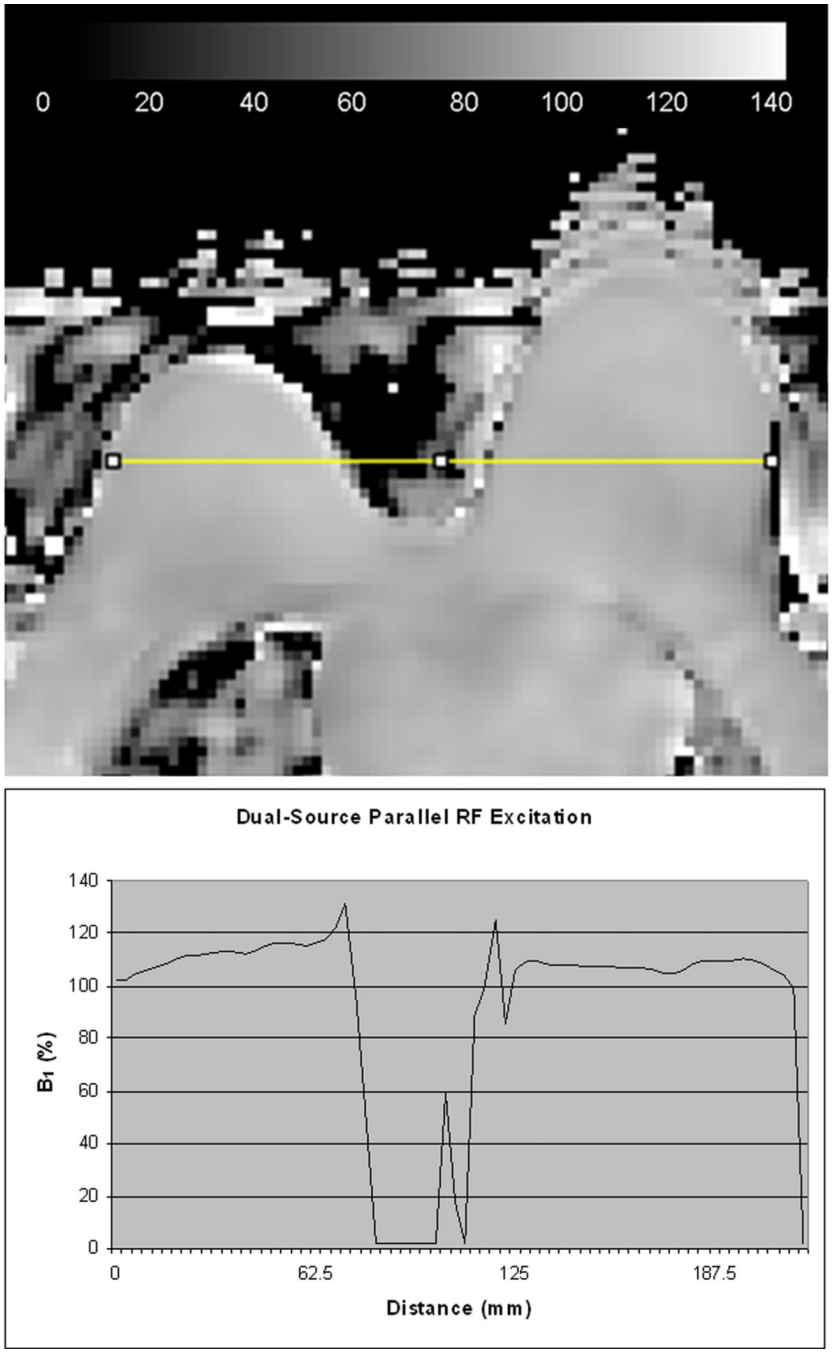


Figure 3.

B_1 homogeneity between the right and left breasts in the same patient obtained with conventional single-source RF excitation (A) and dual-source parallel RF excitation (B) techniques. Note that both visually and quantitatively, there is a significant decrease in B_1 signal intensity in the left breast with single-source RF excitation whereas a more homogeneous B_1 signal is obtained across the breasts with dual-source parallel RF excitation technique.

Table 1

Mean region-specific B_1 values (% of intended B_1) for single-source RF excitation and dual-source parallel RF excitation techniques.

ROI Location	Single-Source RF Excitation				Dual-Source Parallel RF Excitation			
	Right (%)	Left (%)	Difference (%)	P value	Right (%)	Left (%)	Difference (%)	P value
Anterior	97.99±8.50	94.15±7.15	−3.83±7.92	0.094	103.99±8.31	108.76±8.64	4.77±7.32	0.030*
Lateral	96.12±8.37	87.84±6.14	−8.28±10.86	0.014*	99.86±5.41	107.39±6.73	7.52±5.67	0.0003*
Central	96.3±7.19	85.34±7.36	−10.95±7.93	0.0001*	102.82±8.60	102.06±8.94	−0.76±6.51	0.668
Medial	96.13±7.62	87.01±7.52	−9.11±8.36	0.0013*	105.24±9.89	104.96±8.33	−0.29±8.12	0.897
Posterior	92.36±8.07	78.37±6.70	−13.99±9.02	<0.0001*	97.45±7.56	98.16±8.66	0.71±7.50	0.727
Whole Breast	95.78±6.74	86.55±6.22	−9.23±6.93	0.0002*	101.87±7.14	104.27±7.42	2.39±4.81	0.085

Abbreviations:
ROI=region of interest
Statistical analysis: two tailed, paired student t test

*Statistically significant