

1 Comparison of conventional (left) with TrueForm (right) magnet design.

TrueForm™ Technology

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TrueForm is a technological innovation introduced to enable full utilization of the 3T power without the usual limitations and compromises. TrueForm design has been employed in all the field generating hardware units of the system (magnet, gradient, RF) as well as in the operating software (acquisition, processing).

TrueForm magnet and gradient design

TrueForm magnet design is an innovation that produces a cylindrically optimized homogeneity volume instead of the conventional elliptical volume. A cylinder corresponds better to the true form of the human body. TrueForm gradient design also creates a cylindrical

shape for the gradient linearity volume. The two combined result in better image quality by reducing the unusable edges in the images as well as better fat saturation for the whole area covered in a scan. TrueForm reduces the overlap needed between steps for large virtual field-of-view (FOV) exams and thus reduces the number of steps needed for a given scanning range compared to a conventional elliptical design. By modifying the relative diameter, the relative distance, the thickness as well as the density of the windings, a cylindrically optimized homogeneous volume can be achieved (Fig. 1). Cylindrically optimized magnets have a larger homogeneity volume compared to conven-

tional with identical “nominal” specifications – ideally, a cylinder has a 1.5 times larger volume than an ellipsoid with identical dimensions $x/y/z$. Figure 2 shows a schematic representation of the different parameters optimized in order to realize the TrueForm magnet design. The magnet of MAGNETOM Verio consists of 6 coils where the Niobium Titanium superconducting wire is being wound. For MAGNETOM Verio, TrueForm magnet and gradient design provide the ability to use efficiently a large FOV of up to 50 cm x 50 cm x 45 cm for several applications. Clinical examples are shown in Figures 3 and 4.

TrueForm RF Design

Shading effects in MRI at higher field strength are a common issue. Several techniques and applications have been proposed to solve this problem. Especially for clinical systems it is important to have a solution to improve image quality. Approaches to reduce B1-shading suggested previously involved the use of B1 saturation pads, which were cumbersome and not easy to use for both the patient and the technologist.

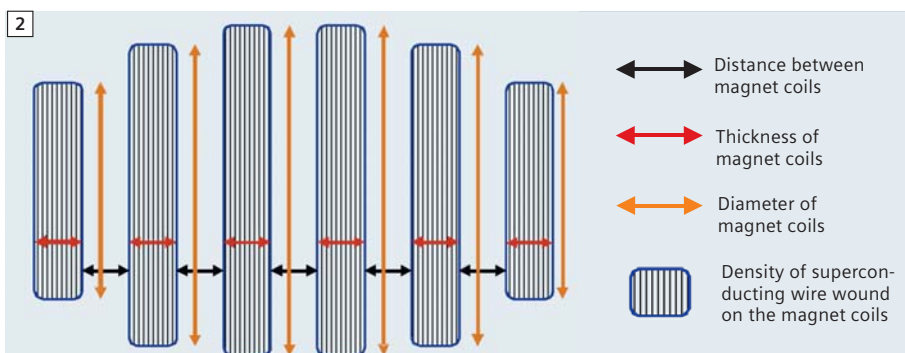
TrueForm RF provides an intelligent solution using the standard transmit setup of a clinical 3T scanner.

TrueForm RF design includes innovative hardware technology as well as new application and processing features, which ensure uniform RF distribution in all body regions. In particular, TrueForm RF for MAGNETOM Verio consists of:

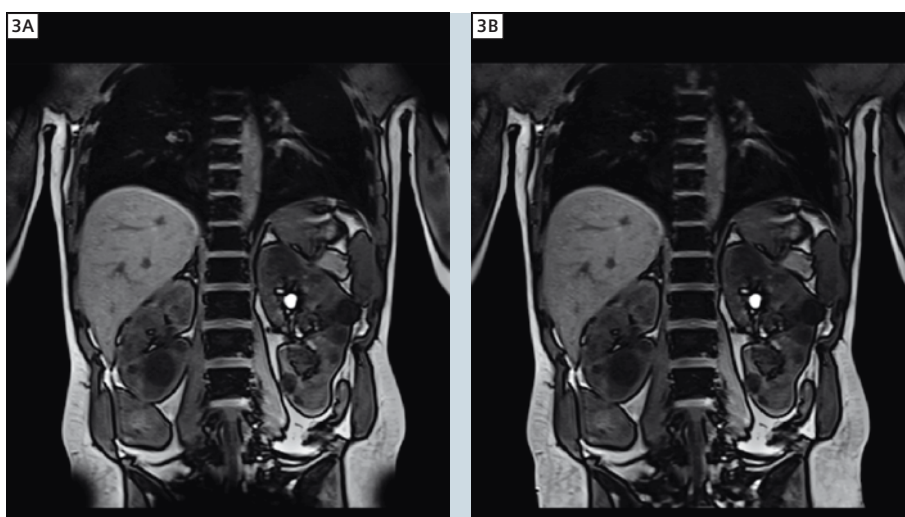
- *TrueForm Excitation*, which uses optimized amplitude and phase transmission settings. TrueForm RF Excitation has the functionality of a 2-channel Transmit Array.
- *α-SPACE* which is a version of the SPACE sequence using composite adiabatic excitation pulses which are insensitive to B1 spatial variations.
- *B1 Filter* which is an adaptive Inline image filter that reduces any remnant B1 effects without affecting image contrast.

TrueForm Excitation

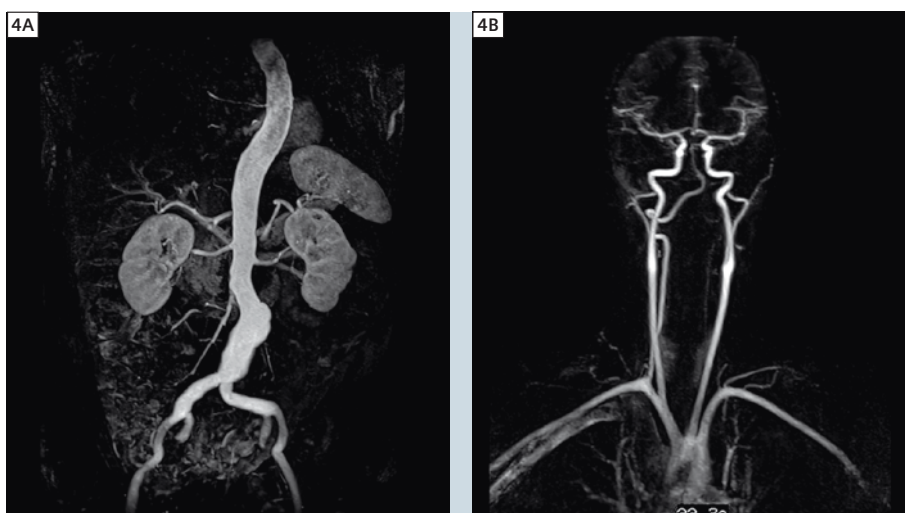
In most scanners the two ports of the body coil are fed with equal amplitude and a 90-degree phase shift to produce a circularly polarized field. At low frequencies, this yields a homogenous field distribution in most cases. But at higher frequencies (3 Tesla and more), the interaction of the fields with the patient could make use of a different feeding approach. Nistler et al. [1] suggested that in several cases there is a better phase difference and amplitude weighting capable of delivering better results than simply using a 90 degree feeding. A 16-rung high-pass birdcage for whole-body imaging was modeled in a simu-



2 Graphical explanation of the different parameters optimized in order to realize TrueForm magnet design.



3 Comparison of gradient echo coronal images of the torso without (left) and with (right) TrueForm magnet design. Distortions along the edges of the imaging field are minimized.



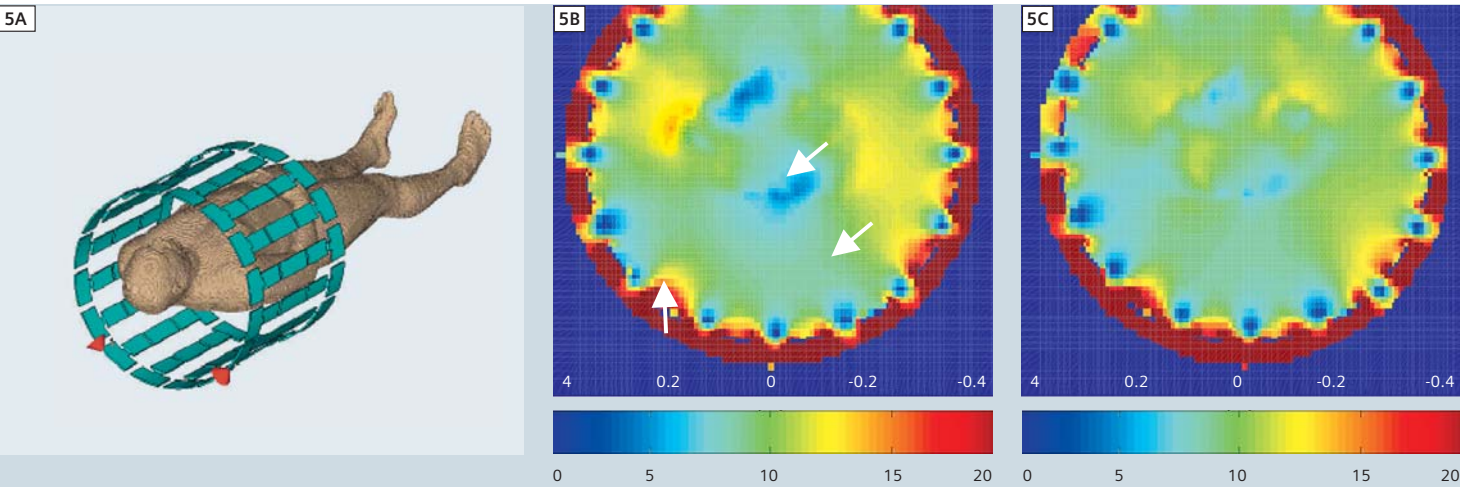
4 MR Angiographies (MRA) with 45 cm FOV in the z-direction acquired in one step with MAGNETOM Verio using 24 Matrix coil elements (left) and 28 Matrix coil elements (right).

lation program. Each of the two ports could be excited separately; the resulting fields were combined and analyzed in the post processing. While this setup produces a homogenous circularly polarized field in the empty coil using the conventional CP feeding (90 degrees / equal amplitude), this is different with human models inside the coil. The results were evaluated using a male and a female human model, both in different positions of the models relative to the coil isocenter. Nistler et al. found that the position of the human model in head-first or feet-first orientation has virtually no influence on the results. Simulations performed by Nistler et al. show that in most cases if you improve

homogeneity also the power deposition in reduced. They also investigated the influence on local SAR hot spots or on the relation of SAR-Local/SAR-whole body (wb) for all model setups. They concluded that if the amplitude and phase settings are varied there are only a very limited number of positions in the human model, where the SAR hot spots arise. The solution they suggested further reduces this possibility. Figure 5 shows the B1 distribution in the human model, when the conventional CP feeding is used. The areas with inaccurate flip angles (lower or higher then the value determined by the sequence) are obvious. Now the phase difference for the feeding ports was

varied between 0 and 360 degree and also the amplitude relation P2/P1 was modified between -21 dB and +21dB. The resulting field distributions were analyzed concerning B1 homogeneity (standard deviation). Additionally, the necessary input power for all combinations was calculated to generate an average field of 11.7 μ T. As a result it could be seen that an improvement in homogeneity is possible and the power deposition into the patient can also be reduced. This is also shown in Table 1. In summary, the results by Nistler et al. show that the field homogeneity and the power deposition in a patient can be optimized by using a conventional birdcage with two feeding ports.

5A



5 (left) Simulation model with a two-port high-pass birdcage coil, with a human male model positioned head first inside the coil. B1 Field Plots for conventional (middle) and TrueForm RF design (right). Arrows show areas of B1 inhomogeneity that is corrected with TrueForm Excitation technology.

Table 1: Abdomen in center of the coil

Excitation scheme	Homogeneity	Power in Patient	Power relation Port 2 / Port 1(dB)	Phase difference Port 2 – Port 1
Symmetric (conventional)	19.3	3639	0	90
Best homogeneity	11,9	3418	6	120

Change in homogeneity (relative standard deviation in %) for possible phase and amplitude weightings, showing a significant improvement in homogeneity change in total power for possible phase and amplitude weightings, showing a power reduction compared to symmetric excitation. Reference power value is for a mean B1 of 11.7 μ T.

Therefore it is necessary to change the weighting for the two ports. In particular, B1 homogeneity can be improved by almost a factor of 2, while the SAR performance (power deposition) can also be improved / reduced by between 5–10%.

This implementation of TrueForm RF Excitation on MAGNETOM Verio has the functionality of a 2-channel Transmit Array system.

It offers a robust and effective method to reduce B1 inhomogeneities.

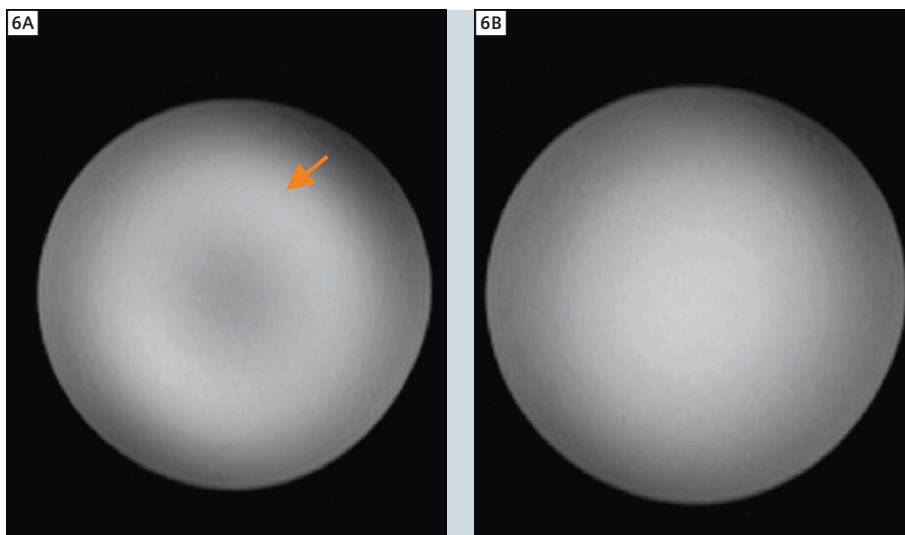
The independent setting of amplitude and phase of the two feeding ports of the RF Body coil is done in an anatomy-specific optimization. No time for patient-specific adjustments is required, saving up to 1 minute per examination. Together with accurate patient- and anatomy-specific SAR calculations, based on the Hugo model, TrueForm RF Excitation increases examination speed and image quality.

a-SPACE

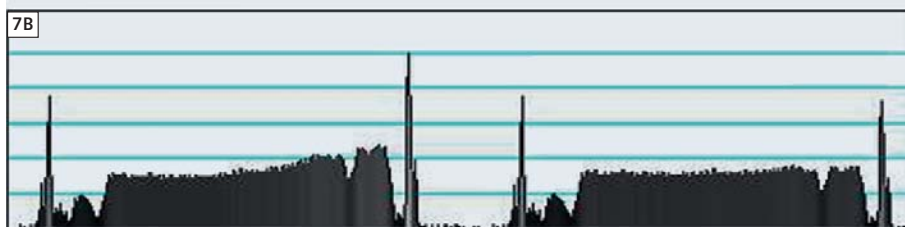
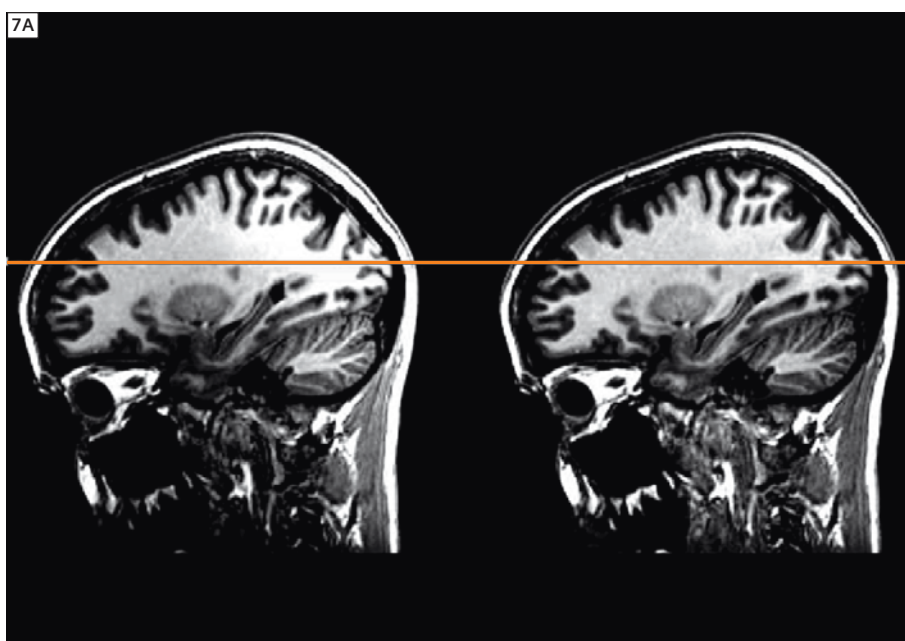
For the case that B1 inhomogeneities are still present in the images, the users have the opportunity to use the a-SPACE sequence with adiabatic instead of conventional pulses. Adiabatic pulses are insensitive to B1 distribution and, as seen in the phantom images below, improve the homogeneity in the images.

B1 Filter

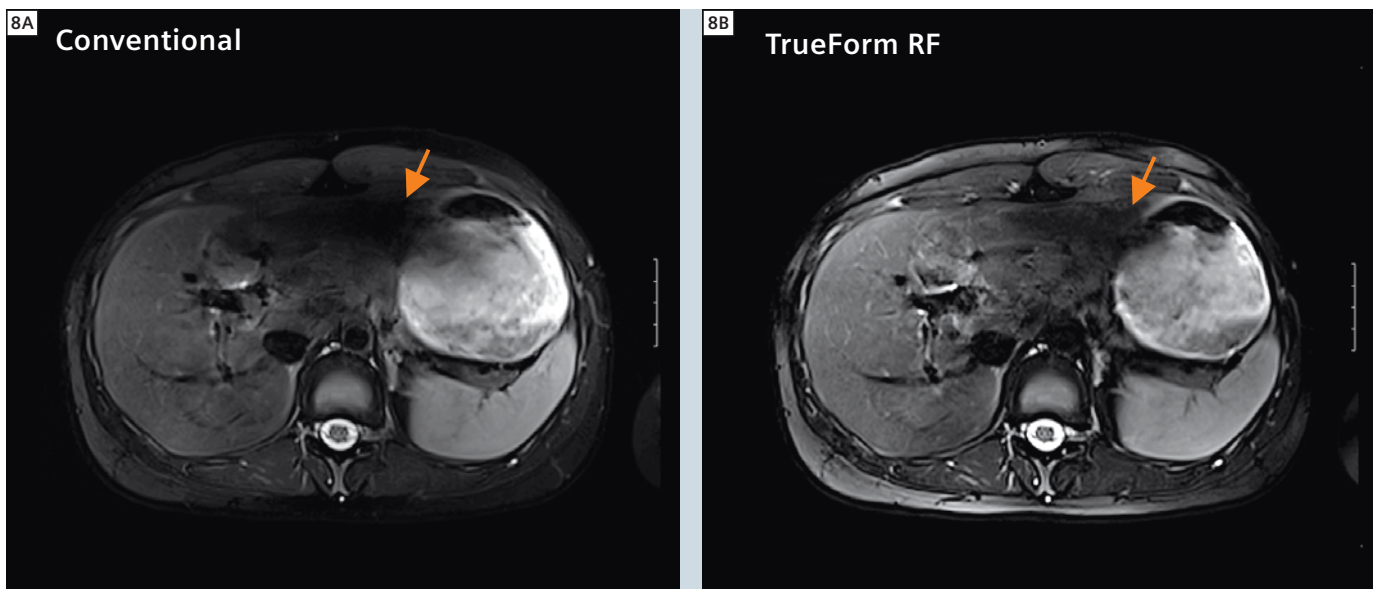
The final measure involved in TrueForm RF Technology is a postprocessing image filter. This filter improves the image intensity profile without affecting the image contrast. Such a filter will not improve the diagnostic value of the images but will enable the radiologists to provide perfect-looking images in their reports to the referring physicians.



6 Phantom image intensity maps acquired with conventional (left) and a-SPACE (right). Part of the TrueForm RF design, a-SPACE significantly improves the homogeneity within the sample.



7 Image Intensity Profile showing the effect of the B1 Filter (right): the signal intensity is much more uniform across the image when using the B1 Filter, part of TrueForm RF design.



8 Images showing uniform image intensity in the abdomen after application of TrueForm RF design.

Clinical Examples

In the clinical examples of the application of TrueForm RF design, one can see elimination or significant reduction of the B1 artifacts that occasionally appear when imaging different body parts at 3T. In particular, Fig. 8 shows how TrueForm recovers the signal in the anterior part of the liver of a very athletic patient. Fig. 10 shows recovery of the uniformity in the image intensity for bilateral breast imaging. Fig. 11 shows elimination of the B1 inhomogeneity in the posterior part of the right leg.

In the abdomen, the existence of B1 inhomogeneities – particularly in patients with ascites or edemas – has been the major obstacle that impeded the spread of 3T MRI in the abdominal and general radiology clinics for some time.

Recently the issue of B1 inhomogeneities has been raised for breast imaging at 3T, where apart from the basic problem of image homogeneity, severe concern was expressed regarding possible misinterpretations of contrast uptake if the actual excitation angle deviates too strongly from the nominal flip angle in gradient echo sequences used for dynamic studies [2]. Geppert et al. compared the application of TrueForm RF in breast imaging. B1 maps were acquired using the body coil in order to have a flat sensitivity pro-

file. The evaluation of the calculated B1 distribution maps was performed by applying several regions of interest (ROI) in areas that exhibited very high or low signal intensities. The maximum and minimum measured flip angles were considered for each breast and normalized to a nominal flip angle of 90 degrees to enable a direct comparison. As a final measure, for each scan the absolute of the maximum deviation from 1.0 was reported.

The last example shows the application of the adiabatic mode with a-SPACE when imaging muscle. When the adiabatic mode is switched on, the signal loss is recovered.

The Next Step: Multi-Channel Tx Array Technology

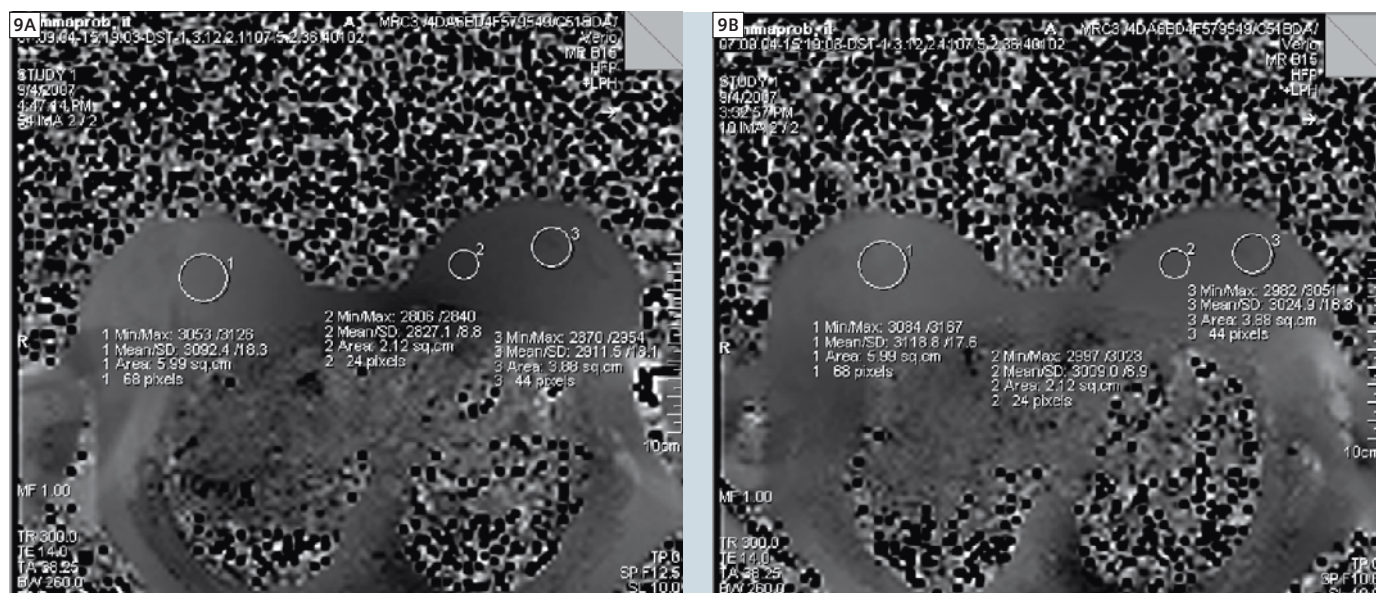
The use of parallel transmission techniques with multiple Tx channels is a possible solution to the B1 inhomogeneities that may appear at higher field strengths, but it implies costly hardware efforts. This is due to the fact that with the current technology an 8-channel transmit system would necessitate the use of 8 power amplifiers, which are rather expensive. Such a system would also hold the risk of local SAR hot spots

due to the yet-to-be-clarified consequences of the superposition of the multiple RF fields, hence there is still more research necessary to overcome this issue.

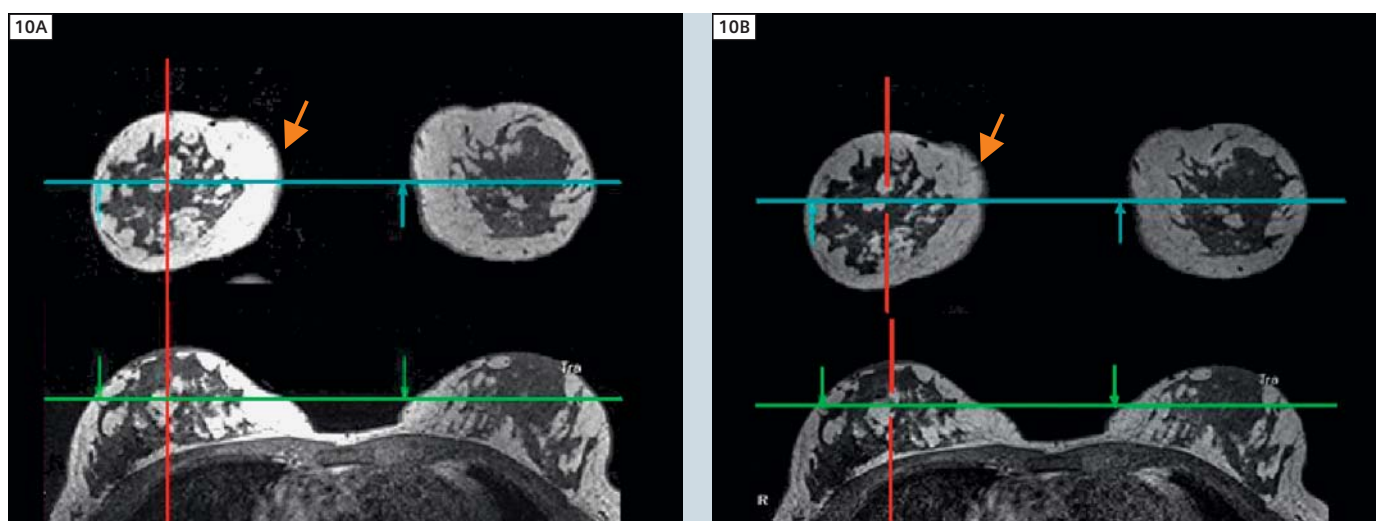
The first approach where Tx Array technology could be used is called RF shimming. RF shimming actually refers to a simplified form of parallel transmission where the multiple array elements of a coil are driven with individual amplitudes and phase shifts. Full parallel transmission on the other hand is a more complex approach. It involves in addition the use of separate pulse shapes in each array coil element. Thus, RF shimming utilizes the spatial patterns of the transmit array, but not the encoding ability of the gradient trajectory. As a consequence, the full parallel transmission (pTX) method produces superior B1 mitigation performance and in addition enables additional applications such as organ or arbitrary volume specific excitation.

References

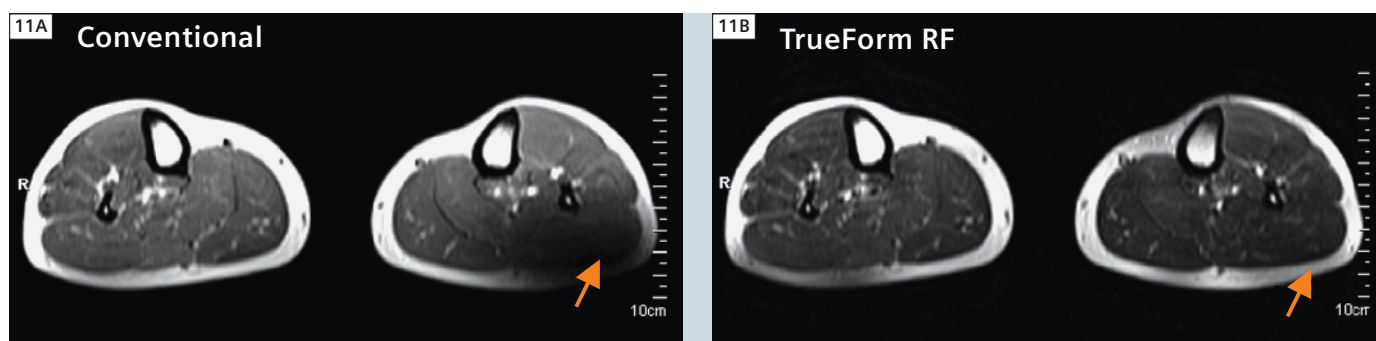
- 1 J. Nistler et al. Homogeneity Improvement Using A 2 Port Birdcage Coil, ISMRM Proceedings 2007.
- 2 C. Kuhl et al. Effect of B1 Inhomogeneity on Breast MR Imaging at 3.0 T, Radiology 2007; 244:929-930.
- 3 Geppert et al. Reduced B1-inhomogeneities in breast MRI using optimized RF excitation, ISMRM Proceedings 2008.



9 Measured flip angle distribution maps of conventional (left) and TrueForm RF Excitation (right). Regions of interest were evaluated in brightest and darkest areas of the left and right breast. Grey scale values 0-4095 represent -180 to +180 degree.



10 Images showing uniform image intensity between the left and the right breast after the application of TrueForm RF design.



11 Images showing uniform image intensity in the thighs (right) after application of TrueForm RF design.