DYNAMICALLY APPLIED MULTIPLE B1+ SHIMMING SCHEME FOR ARTERIAL SPIN LABELING OF THE PROSTATE AT 7T

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Introduction: The increased longitudinal relaxation time of the blood at ultrahigh field (UHF) can improve non-contrast enhanced perfusion imaging using arterial spin labeling (ASL), especially for targeted tissues with long arterial transit times and/or intrinsic low perfusion, such as the prostate. One well-known challenge for UHF imaging is the destructive interference of RF pulses (1), which can dramatically decrease B1+ field homogeneity and RF efficiency, making B1+ shimming (2-4) an indispensable technique for satisfactory UHF imaging. However, B1+ shimming for the target anatomy alone (3,4) is not sufficient for ASL. RF pulses within the ASL sequence have varying requirements with respect to B1+ amplitude, homogeneity, location and spatial coverage. Therefore, to optimally use the RF power available and simultaneously manage the RF deposition in the body, different RF optimization solutions can be applied dynamically during an ASL sequence. Such a dynamic shimming strategy is demonstrated in this paper along with initial results demonstrating improved quantitative perfusion results compared with a single shim solution optimized on the prostate. To our knowledge, these are the first attempts at performing ASL perfusion studies in the human prostate at 7T.

Materials and Methods: All healthy adult males recruited for ASL prostate perfusion were imaged under an IRB approved protocol. This study was performed on a Magnex 7T magnet, a Siemens console, whole body gradients, and an external 16-channel transceiver TEM stripline array driven by a series of 16, 1 kW amplifiers (CPC, Pittsburgh, PA). Modified FAIR (5) with Q2TIPS (6) was used for prostate perfusion with the saturation pulse train of Q2TIPS applied in the superior side of the prostate region (Figure 1). Separate B1+ shimming solutions based on a multi-slice small flip angle calibration scan (2) were performed for different ASL components within specific user defined regions (Figure 2). Each B1+ shim solution consisted of a table of phases and gains which could be loaded onto the amplifier's controller within ~5 µs. In order to accurately switch from one shim solution to the next, the acquisition sequence was programmed to send TTL triggers to the RF amplifier, each of which initiates the loading of the appropriate table. For comparison purposes, perfusion scans with a single fixed B1+ shimming solution, scheme 1, were also performed.

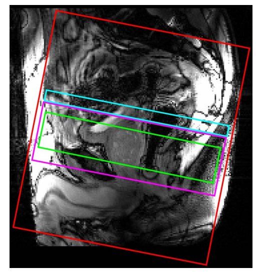

Figure 1 Imaging (green), selective inversion (pink), spatially confined inversion (red) and superior saturation (cyan) slabs used in prostate perfusion studies using FAIR with Q2TIPS. The anatomic image was acquired with trueFISP.

ASL prostate perfusion studies used the following imaging parameters: TR/TE = 3000/8.7 ms, FOV = 240 x 240 mm^2, matrix size = 80 x 80, in-plane resolution = 3 x 3 mm^2, slice thickness/gap = 5/1 mm, number of slices = 5, left-right phase encoding direction with 50% oversampling, acquisition order = descending, GRAPPA iPAT factor = 4 with 24 reference lines, partial Fourier = 6/8, number of measurements = 200, selective/spatially-confined inversion slab = 50/230 mm, labeling time (TI_1)/post-bolus delay (TI_2) = 0.8/1.6 s. The superior saturation pulse train lasted during the entire delay period by using 40 mm saturation slab with 50 ms pulse interval, and proton density (PD) images (M_0) were acquired with the same EPI imaging parameters but with a 10 s TR. RF power was manually set to the permitted maximum for adiabatic inversion. Local B0 shimming was performed in the prostate region by using volumetric phase maps (7). Motion correction and co-registration were performed within SPM. Prostate blood flow (PBF) was estimated with a single blood compartment model (8) (see the formula in Figure 3).

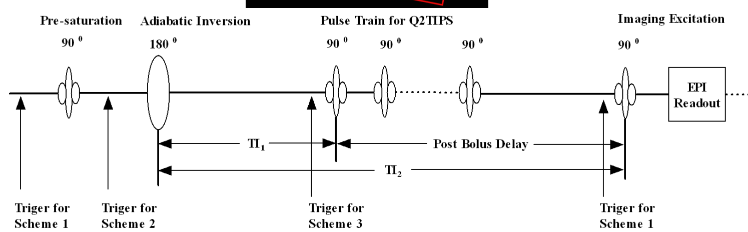

Figure 2 Diagram for multiple B1+ shimming schemes dynamically applied to FAIR with Q2TIPS for prostate perfusion imaging. External triggers (indicated by arrows) were sent out before the execution of specific sequence components to load new RF shim tables for pre-determined RF optimization settings: scheme 1 is a local B1+ shimming optimizing efficiency in the region of the prostate; schemes 2 and 3 used tradeoff solutions between efficiency and homogeneity in i) a large region covering the imaging section and a 100 mm slab superiorly and ii) in the 10 mm superior saturation slab. The tradeoff solution was accomplished by constraining our B1+ efficiency optimization algorithm with an upper limit on B1+ inhomogeneity defined as the (mean/std) ratio of |B1+|.

Results and Discussion: When using a single B1+ shim optimized for efficiency on the prostate, poor perfusion signals were observed, as well as lower estimated prostate blood flow (Figure 3). This most likely is a result of inefficient arterial blood labeling as opposed to incomplete superior saturation which would give higher perfusion signals. Perfusion-weighted images were displayed with low signal regions removed via image intensity thresholding. Parallel imaging allowed for shorter EPI echo trains resulting in shorter TEs, higher SNR and, along with local B0 shimming, reduced image distortion. Further studies evaluating the optimal dynamic B1+ shimming strategies for ASL in the prostate at UHF is under investigation.

Conclusion: Preliminary results show that optimization of B1+ for each RF pulse in a sequence and applying those solutions dynamically during imaging acquisition appear to improve ASL perfusion results in the prostate at 7T. By using a rapid, low flip angle calibration scan, RF pulses can be optimized individually to address the available B1+ amplitude as well as the homogeneity, location and spatial coverage required.

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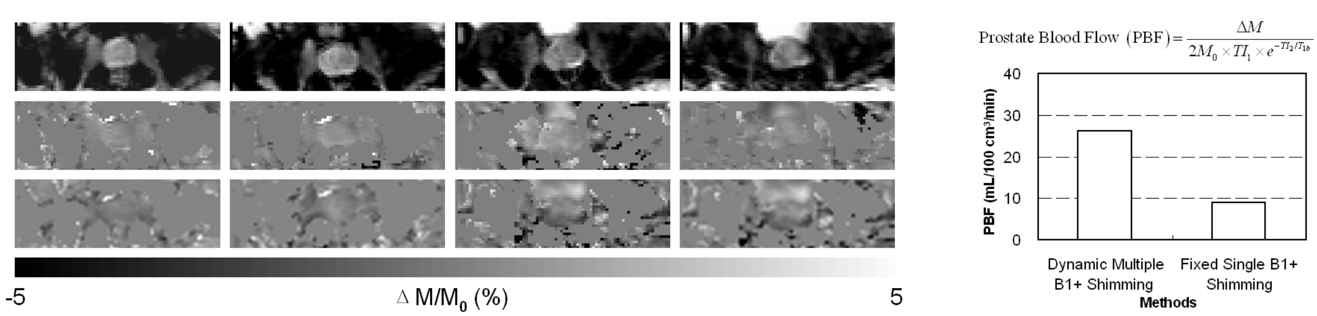

Figure 3 Prostate perfusion imaging results from one subject: on the left are proton density images (top row) and perfusion-weighted imaging maps acquired with dynamically applied multiple B1+ shimming solutions (middle row) and with fixed single B1+ shimming solution (bottom row); on the right, the estimations of prostate blood flow (PBF) are presented for prostate perfusion images using two B1+ shimming strategies.