Award Number: W81XWH-11-1-0253

TITLE: Prostate Cancer Detection Using High-Spatial Resolution MRI at 7.0 Tesla: Correlation with Histopathologic Findings at Radical Prostatectomy

PRINCIPAL INVESTIGATOR: Andrew Rosenkrantz, M.D.

CONTRACTING ORGANIZATION: New York University
New York, NY 10016

REPORT DATE: October 2012

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE
1 October 2012

2. REPORT TYPE
Annual

3. DATES COVERED
6 Sep 2011 - 5 Sep 2012

4. TITLE AND SUBTITLE
Prostate Cancer Detection Using High-Spatial Resolution MRI at 7.0 Tesla: Correlation with Histopathologic Findings At Radical Prostatectomy

5a. CONTRACT NUMBER

5b. GRANT NUMBER
W81XWH-11-1-0253

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Andrew B. Rosenkrantz, M.D.

E-Mail: Andrew.Rosenkrantz@nyumc.org

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
New York University

New York NY 10016

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This study aims to develop high spatial-resolution prostate MRI at 7.0T. During this first phase of our study, we aimed to perform technical development and optimization of the necessary hardware and software to be able to perform 7.0T prostate MRI in a clinical setting. Specifically, we aimed to develop a novel surface coil array in conjunction with optimization of turbo-spin echo T2-weighted sequences to achieve high spatial-resolution high SNR images. Our ultimate system employed two transmit-receive elements and six receive-only elements, avoiding parallel transmission and RF shimming, thereby achieving a much simpler design than has been explored by other groups for 7T prostate MRI. This coil design was supplemented by investigation of sequence modifications to overcome challenges related to RF power availability at 7T. In combination, these hardware and software changes led to substantial improvements in image quality. It is hoped that the SNR gain compared to 3T will provide comparable results to 3T endorectal coils, avoiding the need for this comparatively invasive devise. These initial steps are now being followed with testing in prostate cancer patients prior to radial prostatectomy, allowing for pathologic confirmation of our findings.

15. SUBJECT TERMS
prostate cancer; MRI; 7.0 Tesla

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					USAMRMC
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
U	U	U	UU	17	

Table of Contents

Introduction

This study aims to develop high spatial-resolution MRI of the prostate at a field strength of 7.0T. Central to this project is development and optimization of the necessary hardware and software to be able to perform 7.0T prostate MRI in a clinical setting. Specifically, we aim to develop a novel surface coil array in conjunction with optimization of turbo-spin echo T2-weighted MRI sequences for such a coil, in order to achieve high spatial-resolution high signal-to-noise images of the prostate. This goal will allow for imaging patients with solely an external surface coil, yet attain images of similar if not better image quality than previously attained using an endorectal coil at lower field strengths. Following initial technical development, 7.0T prostate MRI will be performed in a cohort of men with prostate cancer awaiting prostatectomy, and the imaging findings will be compared with findings from their standard clinical 3.0T MRI as well as with histopathologic findings from prostatectomy. If successful, this project will facilitate the role of prostate MRI in influencing prognosis and treatment selection for men newly diagnosed with prostate cancer.

Body

During this first phase of our study, we aimed to perform technical optimization of the coil and accompanying sequences, in order to achieve maximal image quality during subsequent patient scans. The descriptions provided in this report of the first phase of our study are based on a previous presentation of our initial work [Zhang B, Rosenkrantz A, Sodickson D, Taneja S, Stefanescu C, Wiggins G. 7T External Prostate Array with Single Channel Transmit: Simulation and Experiment. Proceedings of the 20th annual meeting of the ISMRM, Melbourne, 2012 (2782)].

Imaging of deep torso structures, such as the prostate, is challenging at 7.0T due to extreme RF inhomogeneity. Other groups have used 8- or 16-channel transmit-receive (TxRx) arrays for prostate imaging at 7T, although these have relied on parallel transmit and RF shimming, which bring additional complexity to the equipment required and the acquisition of data. Given that prostate imaging entails coverage of just a small region of interest, we aimed to achieve excitation in the prostate through the use of only two transmitter elements, one anterior and one posterior, with fixed power split and phase relationship. When positioned appropriately, these elements should interfere constructively in the prostate. In initial testing, two different transmitter element designs were evaluated through simulation: traditional loops and radiative dipole antennas. The strong interaction between the human tissue and the electromagnetic field requires full wave EM stimulation to predict the coil behavior. We used the simulations to help design and build a two-element transmit-receive plus six-channel receive-only array for prostate imaging at 7.0T and tested initially in human volunteers. Such a system does not require parallel transmission.

A system with two surface coil loops and a system with two radiative antennas were simulated with the FDTD method (Microwave Studio, CST, Germany). The simulated loop diameter is 16 cm, corresponding to the approximate depth of the ROI in the HUGO body model. As shown in Figure 1a, one loop is placed anterior and the other is placed posterior, with both loops shifted 5.5 cm away from the center in opposite directions to compensate for B1+ twisting, to create maximum B1+ in the ROI. The two radiative antennas were designed with a copper strip 0.7 cm wide and 11 cm long, split in the center and placed on a block of high dielectric substrate (relative epsilon = 37) 6.7 cm x 4.2 cm x 14.3 cm in size. These were placed in the center in shown in Figure 1b, since the radiative antenna shows little B1+ twisting.

Based on the simulation results, the 2 loop structure that was chosen for transmitting RF power in our 7T prostate coil design was incorporated into an 8 channel receive array. The array was constructed using loop elements, with a raw of 4 overlapped elements anterior and another row of 4 posterior elements (Figure 2). The loop diameter was reduced to 12 cm based on phantom experiments. In each row of four, one coil was used both to transmit and receive, while the remaining coils were receive-only; thus, all 8 loops were used to receive, potentially enabling increased sensitivity and parallel imaging. A quarter lamda lattice balun was constructed at the output of each loop to balance current flowing in the coil. Each receive-only element was connected to a pre-amplifier (Siemens Healthcare, Erlangen, Germany) and preamp decoupling was implemented with a phase shifter to transform the input impedance of the preamp appropriately. Bridging the lattice balun with a diode provided active detuning, and additional detuning is provided by a passive detuning circuit located on the opposite side of the loop. For the two transmit-receive elements, equal power is provided to each through a Wilkinson power divider, with cable lengths chosen to provide 180 degree phase difference between the two coils. A T/R switch is placed in each transmit path routing the coils either to the RF transmitter or to two preamps. To allow conformation of the anterior array to different subjects it was constructed of a single piece of etched Pyraflux flexible circuit board material (Dupont, Wilmmington DE). In volunteer measurements, flip angle maps were obtained with a turboFLASH sequence with preparation pulses (R/TE/BW=5000ms/2.2ms/490Hz/pixel, TA=0:35,FOV=350x350mm). After careful calibration of the flip angle in the prostate, SNR maps were calculated from GRE measurements, both with and without RF excitation (TR/TE/BW=200ms/r.1ms/300.0Hzz/pixel, TA=0:53, FOV=220mmx220mm, 256 matrix). SNR was also measured at 3T in a clinical patient with a 16 element body array (Siemens Healthcare, Erlangen, Germany). T2-weighted TSE images of the prostate were acquired with resolution 0.6 mm * 0.6 mm * 3 mm, TR/TE/BW=10,300ms/81ms//255 Hz/pixel, TA=4:08 min.

Simulation of the two coil systems showed that with proper offsetting of the loop transmit elements, a B1+ field of slightly greater magnitude and uniformity could be achieved in the target ROI than with the radiative antennas (Figure 3). Close examination of the B1 vectors through the RF cycle showed that the two loops create a region of circular polarization in the prostate, enhancing the B1+ efficiency. The radiative antennas, while they beam their energy directly towards the ROI, create only linear polarization with this two coil arrangement. Although more radiative antennas could be used to wrap around the body and create circular polarized B1+ in the center, this would involve a more complex splitting and control of the RF transmit signal.

Experimental measurements with a body sized tissue equivalent phantom allowed further optimization of the 2 loop transmit structure. Highest transmit efficiency was achieved with the coils offset 4.25cm from the center, less than was found in simulation, and with smaller 12 cm loops. The unloaded to loaded Q ratios were 10.3 or better for all coils. Temperature test were conducted with meat to determinate safe SAR limits. In volunteer measurements, a 90 degree flip angle could be achieved in the prostate with a 550v 1ms hard pulse, 40% above the scanner's usual reference calibration range. Flip angle maps show good correspondence to the simulated B1+ fields, with constructive interference creating a reasonable uniform excitation across the ROI (Figure 3). SNR comparison to 3T shows a gain of 3.3 (Figure 4). T2-weighted TSE images show good depiction of prostate anatomy and clinically relevant details (Figure 5).

Full wave simulations allowed us to explore various design options for constructing a 7T coil for prostate imaging. This allowed us to construct a coil which does not rely on parallel transmit or RF shimming, considering simplifying the equipments and making 7T prostate imaging possible on standard single transmitter 7T systems. Raw SNR appeared much high compared to external body arrays at 3T. It is hoped that the SNR gain compared to 3T will provide comparable results to 3T endorectal coils, avoiding the need for this comparatively invasive devise.

Given the challenge in creating sufficient excitation in the prostate with the RF power available from this initial coil design, further sequence optimization was performed to improve 7T image quality. These sequence modifications were aimed toward increasing the RF penetration in the prostate while staying within

SAR limits. Sequence modifications comprised: (1) extending the 180 degree RF pulse duration in order to reduce pulse amplitude for a given flip-angle and allow more power into the coil for a given SAR (Figure 6); this modification generated significantly higher SNR within the prostate (2) extending the 90 degree RF pulse duration; and (3) employing RF pulses with lower time-bandwidth-product; this change trades the slice profile for lower pulse power, enabling further power for a given SAR.

In summary, extensive work was performed toward optimization of the 7T coil arrangement, supplemented by investigation of sequence modifications to overcome challenges related to RF power availability at 7T. In combination, these hardware and software changes led to substantial improvements in image quality. These initial steps are now being followed with testing in prostate cancer patients prior to radial prostatectomy, allowing for pathologic confirmation of our findings.

Key Research Accomplishments

•Various design options for construction of a 7T prostate coil compared via full wave simulations

•7T coil that does not rely on parallel transmission or RF shimming constructed; uses simple two-coil transmit system

•Coil design allowed significant SNR gain compared with 3T imaging

•Additional 7T sequence modifications performed to further improve image quality

Reportable Outcomes

Zhang B, Rosenkrantz A, Sodickson D, Taneja S, Stefanescu C, Wiggins G. 7T External Prostate Array with Single Channel Transmit: Simulation and Experiment. Proceedings of the 20th annual meeting of the ISMRM, Melbourne, 2012 (2782).

Conclusions

In summary, extensive work was done toward optimization of a 7T coil arrangement for prostate MRI at this ultra-high field strength. This system employed two transmit-receive elements and six receive-only elements, avoiding parallel transmission and RF shimming, thereby achieving a much simpler design than has been explored by other groups for prostate MRI at 7.0T. This coil design was supplemented by investigation of sequence modifications to overcome challenges related to RF power availability at 7T. In combination, these hardware and software changes led to substantial improvements in image quality. It is hoped that the SNR gain compared to 3T will provide comparable results to 3T endorectal coils, avoiding the need for this comparatively invasive devise. These initial steps are now being followed with testing in prostate cancer patients prior to radial prostatectomy, allowing for pathologic confirmation of our findings.

References

1. Metzger GJ, Snyder C, Akgun C, Vaughan T, Ugurbil K, Van de Moortele PF. Local B1+ shimming for prostate imaging with transceiver arrays at 7T based on subject-dependent transmit phase measurements. *Magn Reson Med* 2008; 59:396-409
2. Metzger GJ, van de Moortele PF, Akgun C, et al. Performance of external and internal coil configurations for prostate investigations at 7 T. *Magn Reson Med* 2010; 64:1625-1639
3. Snyder CJ, Delabarre L, Moeller S, et al. Comparison between eight- and sixteen-channel TEM transceive arrays for body imaging at 7 T. *Magn Reson Med* 2012; 67:954-964

Appendices

None.

Supporting Data

Figure 1-Comparison of RF Transmit Fields for different coil arrangements. (A) Combined B1+ for two offset loop system. (B) Combined B1+ for two radiative antennas.

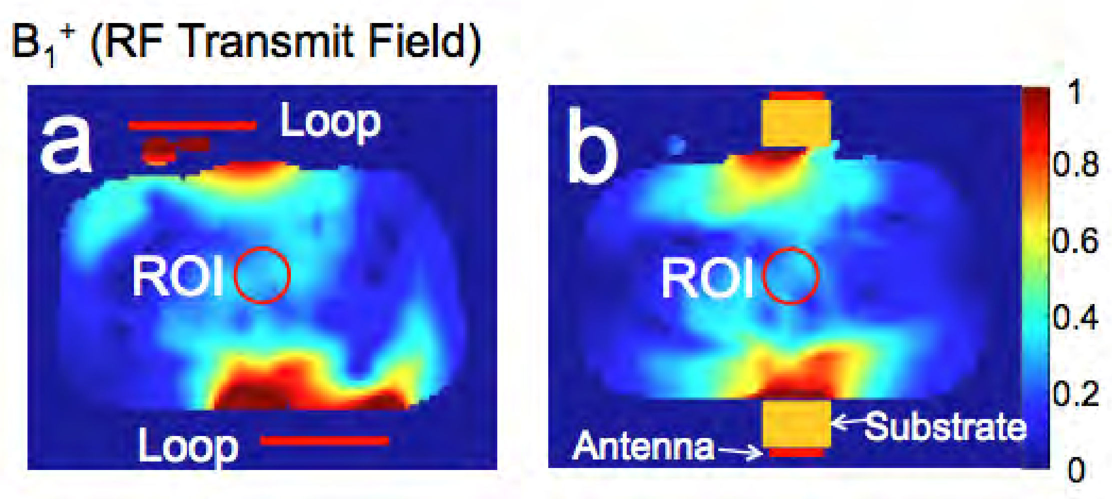

Figure 2-8-element prostate coil. (T/R: Transmit and Receive, R:Receive only)

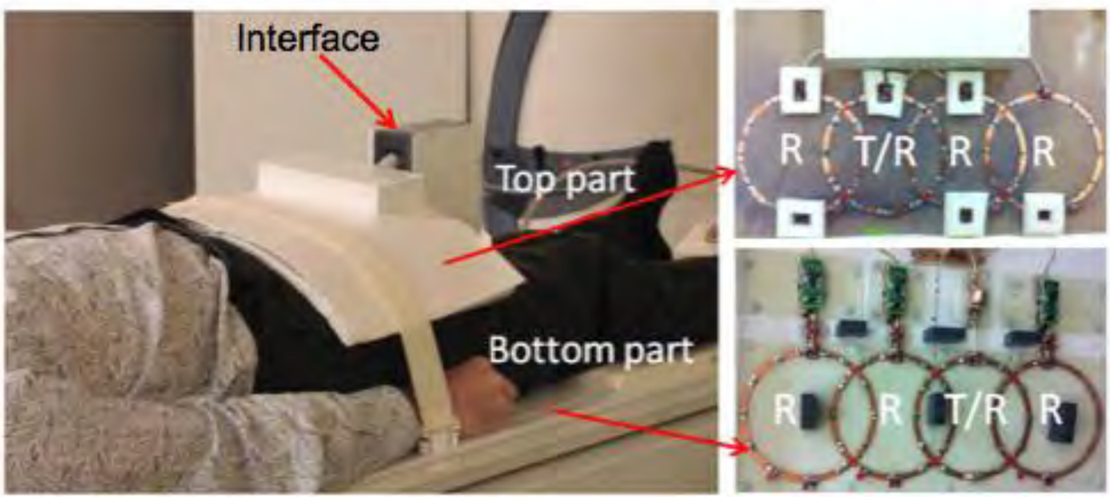

Figure 3-Flip angle maps in vivo. Left image is axial slice; right image is sagittal slice.

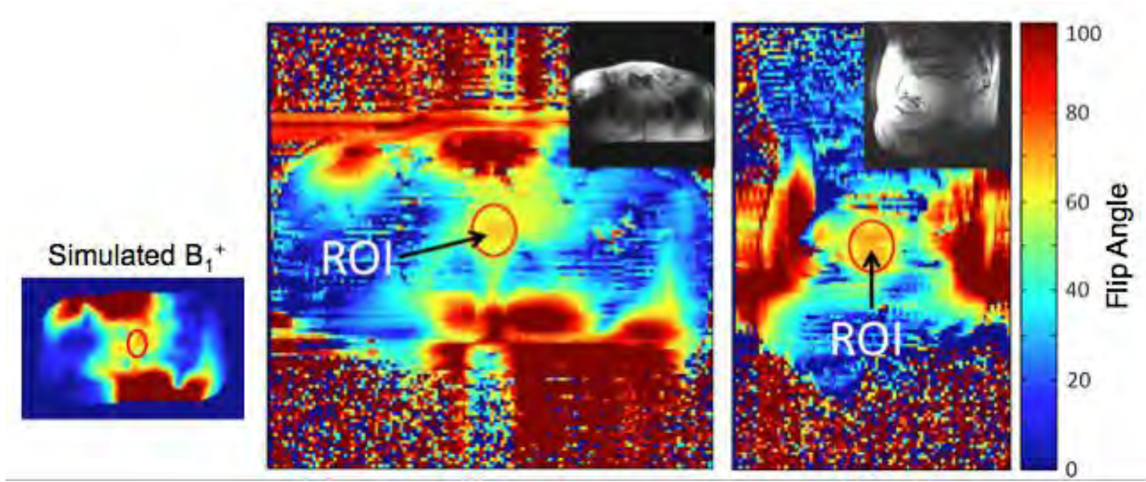

Figure 4-Comparison of 7T and 3T root sum-of-squares signal-to-noise ratios

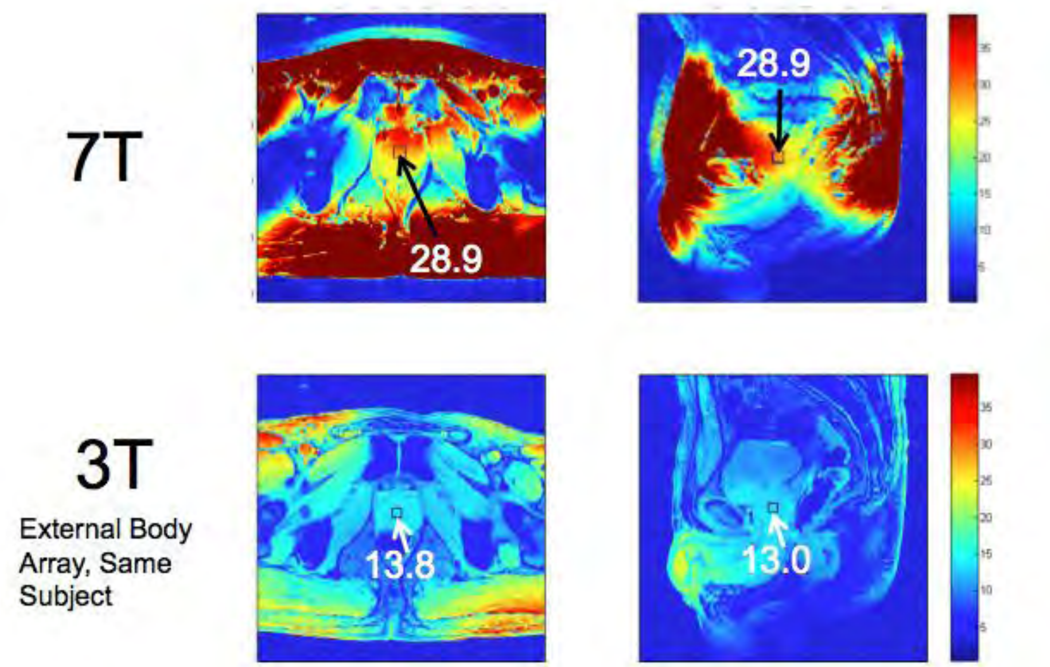

Figure 5-Depiction of prostate anatomy at 7T, including side-by-side comparison 3T and 7T in same subject, showing higher SNR at 7T.

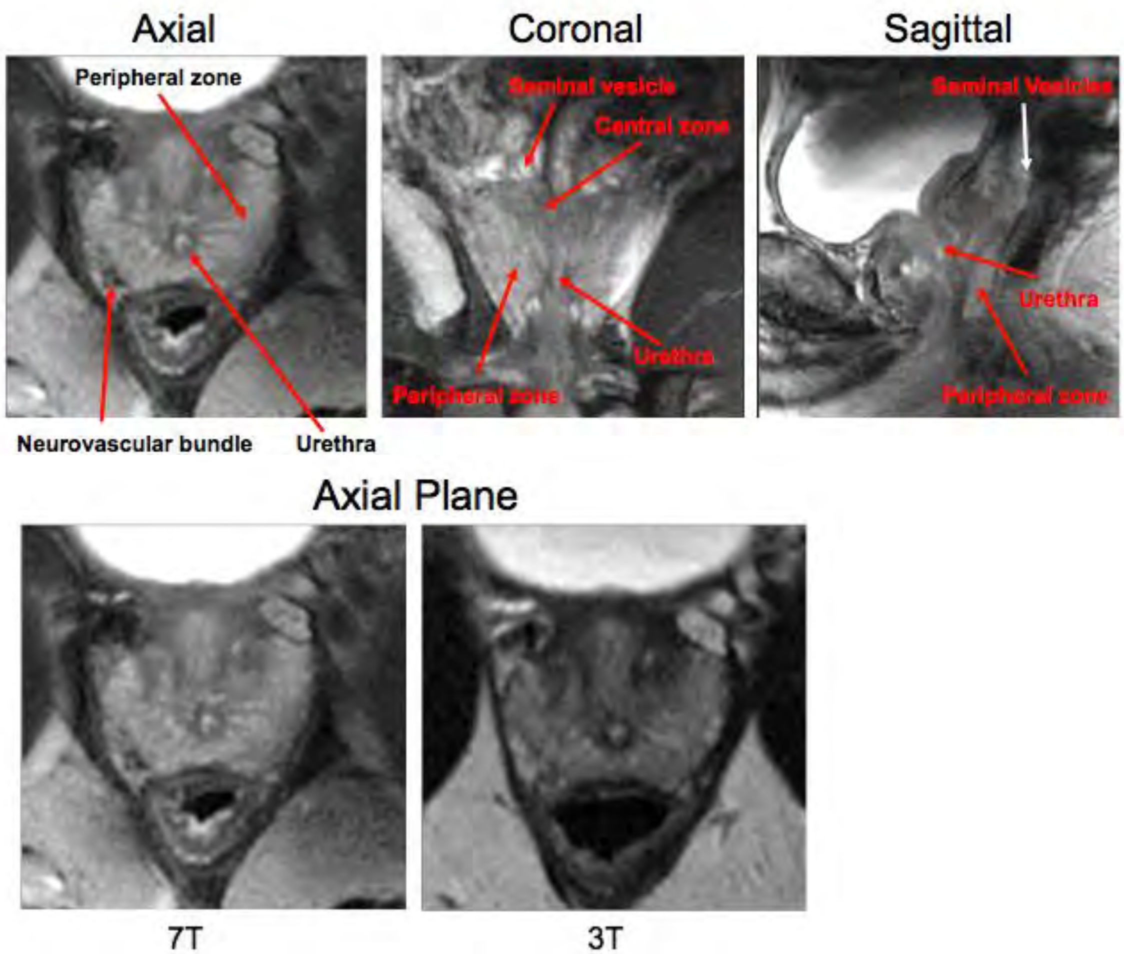

Figure 6-Pulse sequence diagram depicting parameter modifications implemented to improve performance of TSE T2-weighed sequence in conjunction with 7T prostate coil. T180 = 8000 ms; T90 = 3854 ms; turbo factor = 5. Diagram depicts a significant decrease in 180 RF power.