MR/White Paper

The Role of 3T MRI for Prostate Imaging

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Background

According to the National Cancer Institute, there will be 288,300 new cases of prostate cancer in 2023 and about 34,700 related deaths. Prostate cancer represents 14.7% of all new cancer cases in the U.S. The prostate cancer death rate declined by about half from 1993 to 2013, most likely due to earlier detection and advances in treatment. Since then, however, the pace of decline has slowed, likely reflecting the rise in cancers being found at an advanced stage. The five-year survival rate is 97.1% when the cancer is regional but drops to 32% with distant metastases. Prostate cancer is the second leading cause of cancer death in American men.[1] Recent advancements in imaging technology have improved the sensitivity and specificity of screening, providing vital information for the diagnosis and treatment of prostate cancer.[2] The role of MRI has progressed over the years with the development of powerful software and hardware. Multi-Parametric (MP) MR protocols include Diffusion-Weighted Imaging (DWI), Dynamic Contrast Enhancement (DCE) Imaging, and Magnetic Resonance Spectroscopy (MRS).

Essentials

MRI has been a promising technique to image the prostate since the 1980s, but its maturity came after newer techniques to obtain functional information with a higher signal-to-noise ratio (SNR) changed the way radiologists perceived MR prostate imaging. MP MR provides not just anatomical T1W and T2W images, but also functional information through DWI, DCE, and MRS. In MP imaging, the anatomical and functional information is integrated, MP MR is useful and proven to be a successful technique in the detection, monitoring, and treatment planning of prostate cancer.[3]

MRI Multi-Parametric Protocol

Anatomical Imaging

Conventional MRI protocols, used for prostate cancer imaging involve T1W and T2W imaging. In high-resolution T2W images, the peripheral, central, and transition zones can be clearly differentiated, and it is generally used to depict prostate anatomy (see Figure 1). Since T1W contrast in the prostate is very low, the different anatomic zones cannot be appreciated as clearly. Therefore, T1W sequences are mainly used for the detection of post-biopsy hemorrhage, evaluation of prostate contour, and as a baseline pre-contrast sequence. However, on T2W images, prostate cancer is often seen as an area of low signal intensity surrounded by the high-intensity signal normally seen in the peripheral zone (example in Figure 1). The variation in signal intensity decrease seen in cancer can depend on the cancer grade, known as the Gleason score (for example, the higher the Gleason score, the lower the signal intensity on the T2W image cancer), as well as the density of cancer.[4]

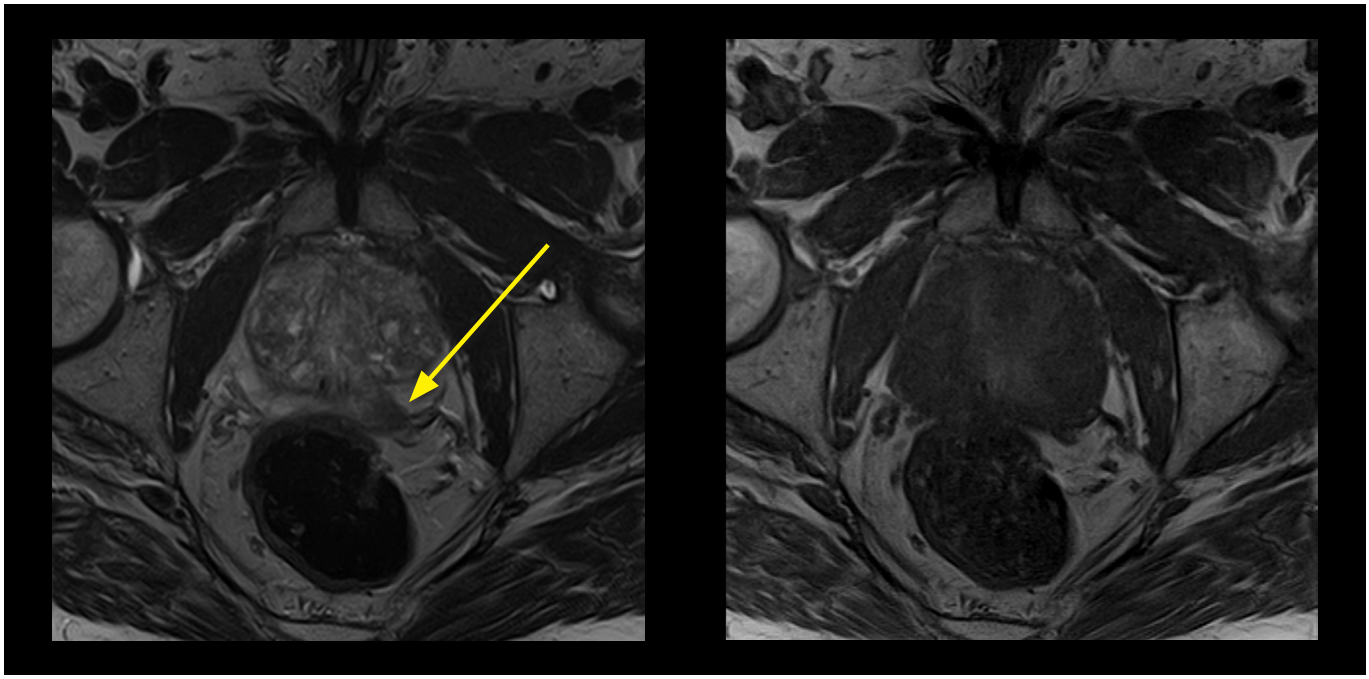

Figure 1: Shows an axial T2W on the left and an axial T1W of the prostate on the right. The arrow indicates a tumor in the peripheral zone, which is visible on the T2W image, but not clear on the T1W image.

However, the sensitivity and specificity of decreased signal intensity on T2W images are limited because tumors can be isointense, or other factors may contribute to the low signal intensity, such as hemorrhage and scarring.[5] The combination of T1W and T2W imaging is the standard protocol for evaluating prostate anatomy. However, several studies reported low specificity, low sensitivity, and high intra-observer variability even when high-resolution imaging with an endorectal coil was used.[6] Morphologic criteria evaluating anatomic features have been established to detect tumor invasion, extracapsular extension, and seminal vesicle invasion.[7] However, a wide range of sensitivities and specificities still limit the diagnostic value of morphological imaging alone and highlight the need for a combined anatomical and functional protocol.

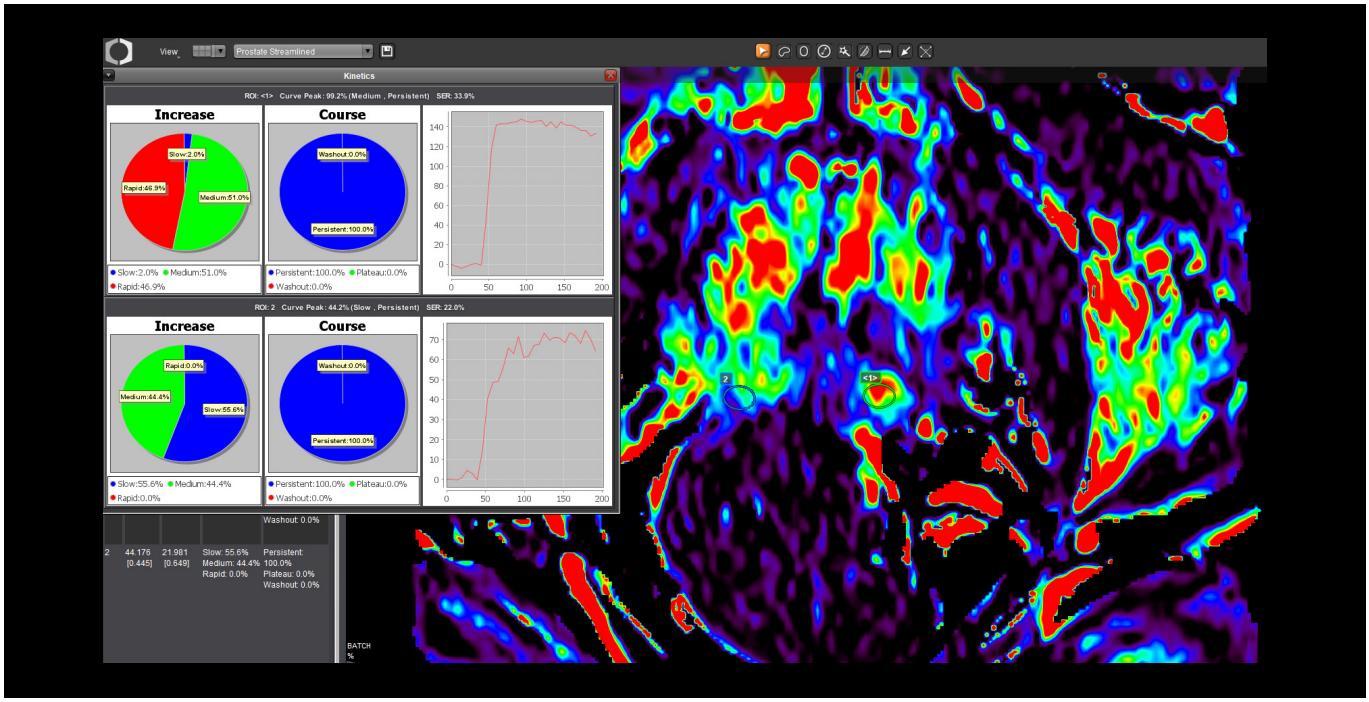

Figure 2: OLEA prostate Peak Enhancement map with a color overlay on this dynamic contrast image. The green arrow points out the tumor which correlates to the top graphs and curve, and the blue arrow indicates contralateral normal tissue with the bottom graphs and curve. The Peak Enhancement map represents the percentage of increase of the initial up-slope of the concentration-time curve.

Dynamic Contrast-Enhanced Imaging

Dynamic Contrast-Enhanced MRI (DCE) is an advanced technique that yields information highly related to angiogenesis and vascularity. Since tumor neovascularity is generally more permeable than normal vessels, more heterogeneous in size, and more disorganized, enhancement patterns can be readily compared to normal tissue. These changes in vascularity due to angiogenesis are well characterized by DCE.[8]

Increased tumor vascularity in prostate cancer leads to earlier and higher peak enhancement compared to normal tissue, followed by rapid washout of the contrast agent. Strong and rapid enhancement is observed when many tumor vessels exist. In addition, with highly permeable tumor vessel walls, fast exchange between the intravascular space and the extracellular-extravascular space will occur, which will be seen as a fast washout. Thus, the dynamic uptake and washout of the contrast agent reveal the pharmacokinetics of cancer tissue.[9] Due to the high vascularity of the prostate in general, discernment of prostate cancer can be made by comparing the pre and post-gadolinium images (Figure 2).

K^{trans}, the influx transfer constant, is thought to be one of the most useful parameters in DCE MR, as it represents the blood flow or permeability into a tissue. Since these factors are usually higher in tumors than in normal tissue as a result of increased flow and permeability due to angiogenesis, K^{trans} elevates correspondingly.

For high temporal resolution DCE imaging, the series consists of several fast T1W sequences covering the entire prostate before and after bolus injection of the contrast agent. Depending on timing constraints and needs, the maximum spatial resolution and temporal resolution are balanced. At Southwoods Imaging, the high-performing 3T gradients allow for spatial and temporal resolution of 0.7 mm x 0.7 mm and 1.3 ms, respectively. DCE is beneficial to prostate cancer localization.[10] When utilized in an MP MR protocol, its benefit for the initial evaluation of tumor locations can be combined with other functional imaging techniques.

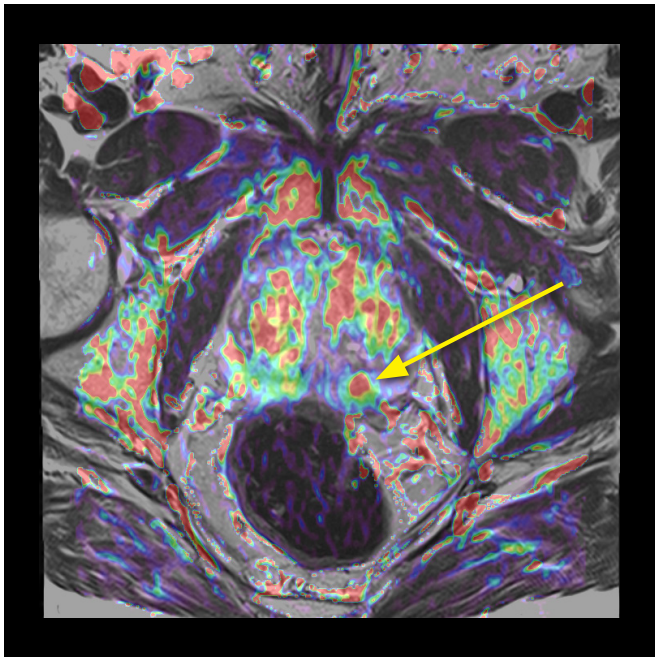

Figure 3: OLEA prostate color maps/quantitative overlay shows tumor enhancement from the DCE acquisition. This is an example of the OLEA prostate K^{trans} map overlayed on an axial T2W image. The yellow arrow indicates the tumor in the left peripheral zone.

Diffusion-Weighted Imaging

Diffusion-weighted imaging adds valuable information about tissues by exploiting the natural diffusion properties of water in living tissue to generate image contrast. Because DWI measures the Brownian motion of water molecules, it reveals what is happening within the living environment of water in tissue. The interactions of water molecules with tissue elements, are intrinsically present in the Apparent Diffusion Coefficient (ADC), explaining its high sensitivity to pathologic or physiologic conditions encountered in tissues.[11]

Reduced diffusion of water in prostate cancer has been attributed to the increased cellularity of malignant lesions and reduction of the extracellular space causing restricted motion of water molecules to the intracellular space.[11] In this

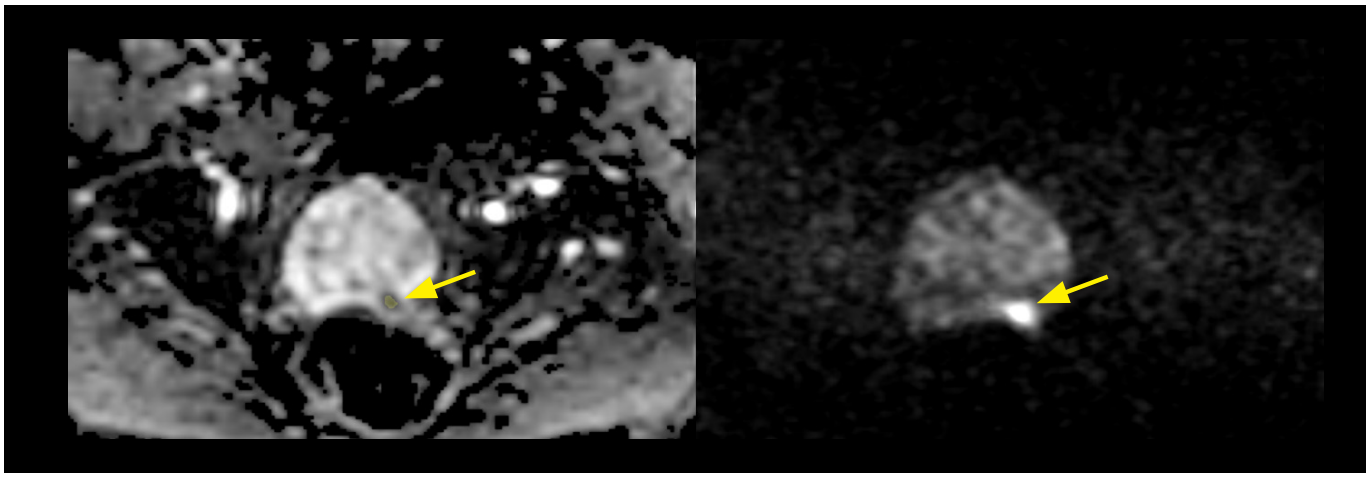

Figure 4: DWI (left) and ADC (right) maps indicate the same tumor found in the peripheral zone.

way, DWI provides a significant quantitative biophysical measurement that can be used to distinguish between benign and malignant prostate tissue.[12]

With the application of motion encoding gradients in the imaging sequence, moving protons accumulate phase, depending on the direction and displacement of the movement. The diffusion coefficient, D, determines the amount of diffusion in tissue. The b-value and the ADC are components of the equation describing how diffusion is expressed. The b-value describes the amount of diffusion weighting, and the ADC quantifies the distance a water molecule has moved. The b-value sets the rate of diffusion weighting to be detected and provides control over image contrast. Optimizing the correct b-value is a vital step in DWI because it is directly related to the ability to detect water diffusion. The higher the b-value, the higher the diffusion weighting. The ADC quantifies the combined effects of both diffusion and capillary perfusion, where a decreased ADC means reduced diffusion and an increased ADC indicates there is less restriction of water molecule motion. The ADC is related to the condition of tissue with tumor growth or cancer advancement. As cells increase in density, the intracellular and extracellular space decreases, limiting the diffusion of water molecules resulting in a reduction of ADC. Therefore, DWI provides a powerful measurement in terms of ADC for the characterization and differentiation of lesions.[13]

A higher Gleason score has repeatedly been associated with decreased ADC. Malignant lesions have been reported as 20%-40% lower than benign or normal prostate tissue.[14] The b-values used for detecting prostate cancer typically range between 0 and 1000 s/mm^2, and even higher b-values can be used in the transitional zone or to improve differentiation between benign findings and cancer.[13] Southwoods Imaging uses four b-values 100, 500, 1000, and 1400.

Side note:

Regional Variation in ADC Prostate Values

Differences in ADC map values have been shown based on location and tissue composition. In addition, the specifications of the sequence parameters have a strong influence on ADC. Therefore, it is important to obtain information on normal ranges of ADC for a specific system and protocol before comparisons can be made.

Clinical Interpretation of DWI

When DWI is added to the imaging protocol, it has been shown that DWI and ADC map can increase the sensitivity and specificity of detecting sensitivity ranges from 54% to 98% and specificity ranges from 58% to 100% when DWI is used in conjunction with T2W imaging.[16] However, clinical interpretation should take several limitations into account that arise from anatomic features of the prostate zones. For instance, normal tissue in the peripheral zone generally has a higher average ADC than the transition zone and base. Therefore, cancerous tissue in the peripheral zone can be more easily distinguished because there is less overlap with cancerous tissue. Furthermore, a high prevalence of benign prostatic hyperplasia (BPH) in elderly men adds to the difficulty of distinguishing prostate cancer from normal tissue, and in some cases, the ADC values of BPH mimic prostate cancer.[17] Also, ADC measurements in the central gland have been found to increase with age, limiting the sensitivity in younger patients. Despite these and other clinical complications, DWI has many advantages, including short acquisition time and good contrast between tumors and normal tissue.

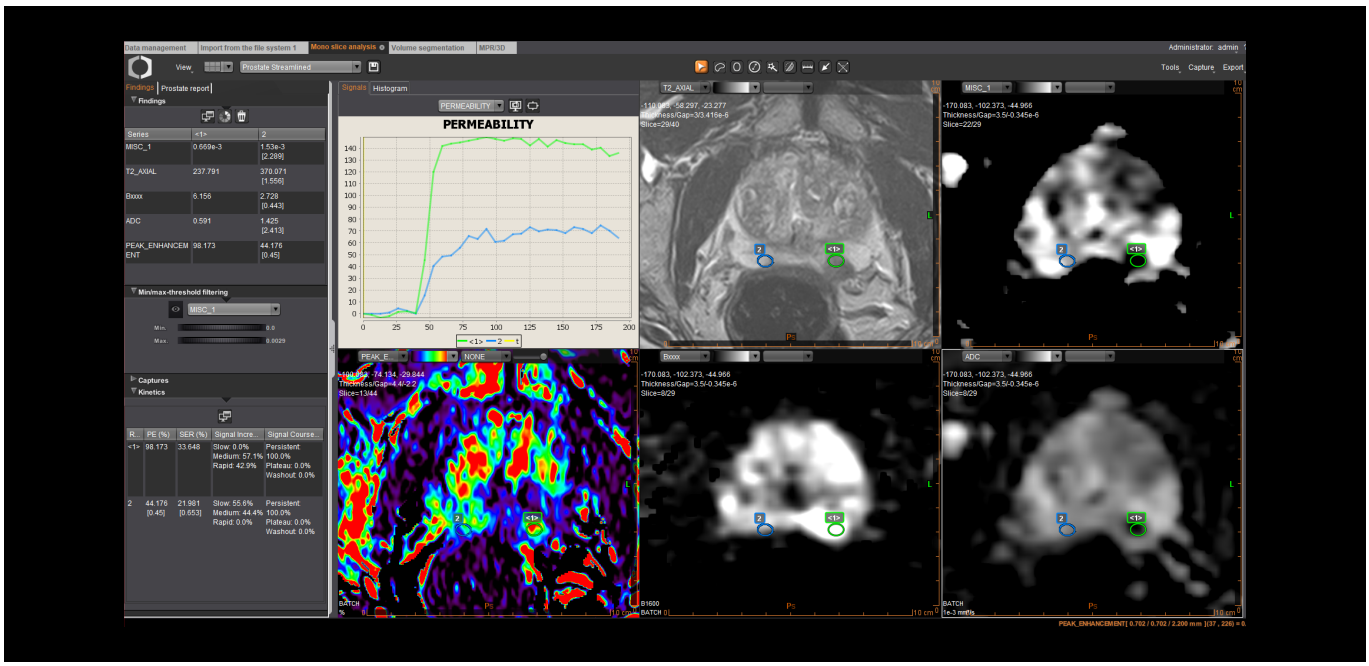

Figure 5: A screenshot of the OLEA Medical Prostate post-processing solution. The green ROI is placed in the peripheral tumor and the blue ROI is placed in normal tissue that is selected for the reference ROI to provide ratio for comparison.

Table 1: Southwoods Imaging's protocol at a glance

Parameters	T2 FS	T1	T2	DWI	DCE
Imaging Technique	FSE	FSE	FSE	EPI	3D GE
Plane	COR	Axial	Axial	Axial	Axial
TR	4300	580	3363	6963	3.6
TE	63	8	120	90	1.3
Slice Thickness	5.0 mm	3.0 mm	3.0 mm	3.0 mm	3.0 mm
Gap	1.0 mm	0 mm	0 mm	0 mm	-1.5 mm
No Wrap	Yes	Yes	Yes	Yes	Yes
Matrix	916 x 640	512 x 512	640 x 640	276 x 256	224 x 224
Resolution	2.2 x 0.9	0.4 x 0.4 mm	0.3 x 0.3 mm	0.9 x 0.9 mm	0.8 x 0.8 mm
Slices	27	30	30	29	48
b-values				100, 500, 1000, 1400	
NAQ	1	1	2	2	1
AiCE[1]	No	Yes	No	Yes	No
Acceleration[2,3]	CS 1.5	CS 1.6	CS 1.9	Exsper 2.0	

[1] AiCE: Advanced intelligent Clear-IQ Engine Canon's Deep learning reconstruction
[2] CS: Compressed Speeder
[3] Exsper: Canon's k-space acceleration technique

Multi-Parametric Imaging (MP MR)

The multi-parametric (MP) approach results in higher detection rates of cancer in the prostate.[18] The strengths of each technique are combined to aid in overcoming their individual weaknesses. Because of the possible variations and combinations of protocols and measured parameters, a scoring system (PI-RADS)[19] has been established to promote global standardization and diminish variations in the acquisition, interpretation, and reporting of prostate MR exams. Software that allows MP analysis of at least two images simultaneously is critical for the integrated interpretation of anatomic and functional images. Canon's post-processing solution powered by Olea Medical, the prostate solution application, offers an MP analysis of all available sequences on the same screen and includes access to advanced diffusion and permeability parameters. The resulting data is comprised of computed semi-quantitative and quantitative maps based on validated and documented mathematic models. To maintain high-quality reading and reporting, the PI-RADS prostate report is included in the advanced prostate application allowing the volume of interest segmentation with the extraction of derived metrics. This solution assists clinicians in their global imaging assessment workflow for the detection, characterization, and staging of prostate cancer.

Field Strength and Prostate MR: 3T or 1.5T

Prostate MR Imaging at 1.5T is a well-established, reliable diagnostic tool. However, the use of an endorectal coil is essential at 1.5T to gain enough signal for high-quality diagnostic exams, which in itself is accompanied by technical challenges. As the SNR increases linearly with field strength, increased spatial or temporal resolution can be obtained while maintaining high SNR without needing an endorectal coil. T1W/T2W imaging, as well as MP MR protocols greatly benefit from 3T imaging due to the inherent high SNR in 3T.

Accurate DCE requires high spatial resolution, high temporal resolution, and sufficient volume coverage of the prostate. It can be challenging to satisfy these needs at 1.5T but quite manageable at 3T. At 1.5T, to preserve spatial resolution for the detection of small tumors and measurement of tumor volume, the temporal resolution is limited. However, high temporal resolution is needed to accurately assess parameters such as K^{trans} and distinguish between benign and malignant tissue. 3T DCE imaging allows high spatial and temporal resolution, benefiting from the increased SNR.

As an inherently low SNR technique, DWI benefits from the SNR boost at 3T, enabling improvements in image quality and spatial resolution. Although 3T has challenges such as increased susceptibility and chemical shift, parallel imaging and protocol adjustments can be made to mitigate these effects. The ability to improve the identification of tumors is increased at 3T compared to 1.5T.[20]

Galan 3T Advantages

Imaging at 3T presents its inherent challenges, including increased power deposition, increased susceptibility, dielectric effects, and RF penetration effects.

Galan 3T was designed from the outset to help mitigate these challenges with its unique design delivering homogeneity and stability. Specifically, Multi-Phase Transmission technology automatically optimizes the phase and amplitude of each RF transmission, improving overall B1 homogeneity. Multi-phase transmission in the prostate region ensures that each RF transmission is tuned to the individual patient's anatomy and can be adjusted to deliver the optimal RF pulse.

For patients undergoing a prostate MR exam, the Galan 3T's extra comfort features can be additionally attractive. The 71cm wide patient aperture and Pianissimo™ noise reduction technology make it possible for patients to experience a

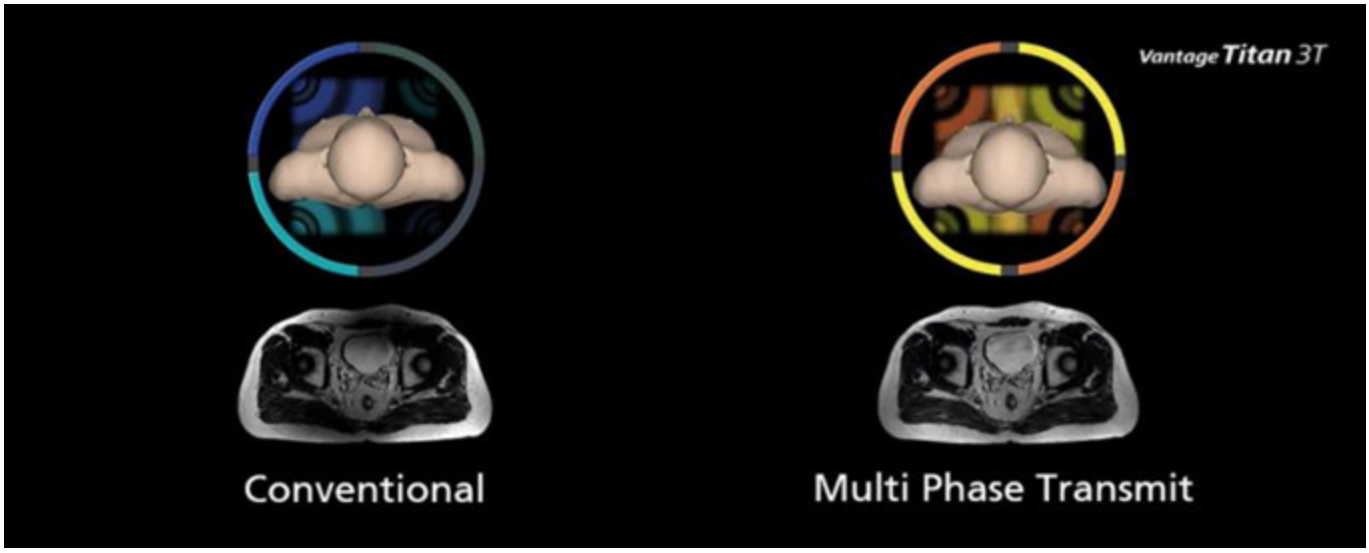

Figure 6: Graphic interpretation of a standard RF system and Canon's Multiphase RF Optimized for the patient in the magnet's bore.

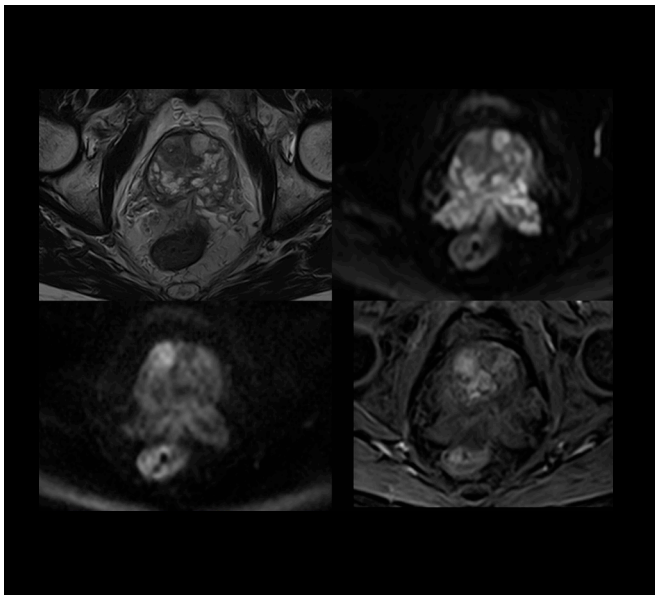

Figure 7: A 73-year-old male with Gleason 3+3=6, 60% of prostate involved in the targeted biopsy. In clockwise order starting on the top left are axial T2, b100, b1400, and post-contrast dynamic acquisitions.

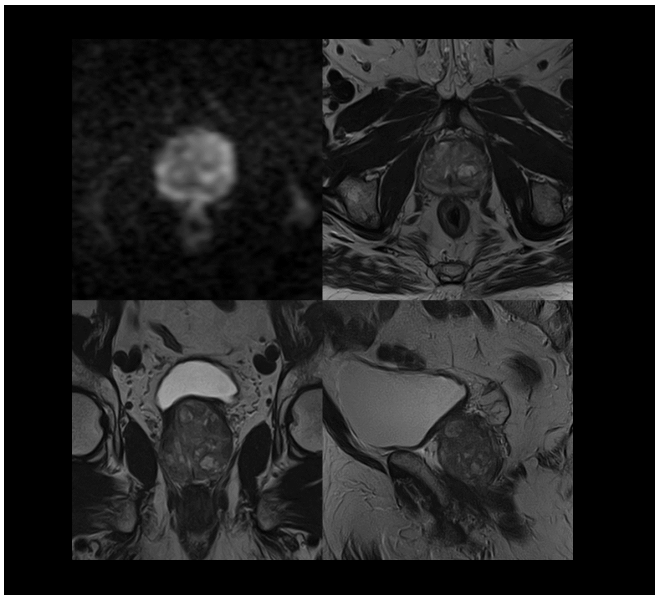

Figure 8: Images are acquired in a 72-year-old male with PSA 6.7, and two previous negative random biopsies. No PI-RADS 3 or higher lesion was identified. Therefore, the urologists continued to follow the patient instead of performing a third biopsy. The acquisitions shown in clockwise order starting on the top left are axial b1400, and T2W in axial, coronal, and sagittal planes.

much more comfortable examination. By achieving higher SNR using multi-channel surface coils and high field strength, an endorectal coil can be bypassed, increasing patient compliance, and easing anxiety.

Advanced Methods of Improved Image Quality

As we discussed earlier, with a 1.5T prostate MRI, it is difficult to produce images with good signal and anatomical details to meet PI-RADS Standards unless an endorectal coil is used. Due to complications and patient discomfort using an endorectal coil, 3T imaging is preferred for prostate imaging. Canon's Intelligent Deep Learning Reconstruction technique has shown promising results with increased SNR* for many body parts, including the prostate. AiCE employs a Deep Convolutional Neural Network (DCNN) to distinguish between noise and signal and intelligently remove noise while maintaining the signal. AiCE DLR has been trained to produce exceptionally high-quality images that are comparable to a high Number of Acquisitions (NAQ) Images, without the burden of long scan durations.[21] AiCE provides higher SNR compared to typical low-pass filters.

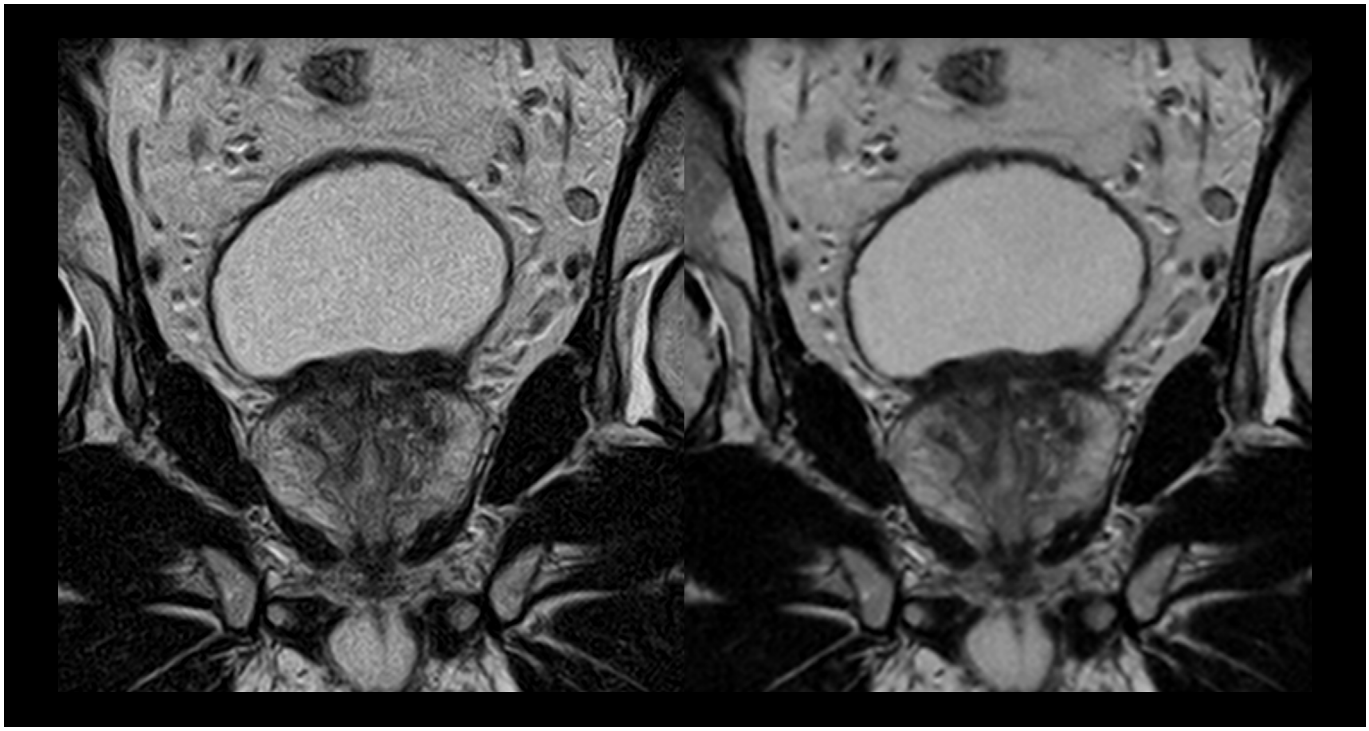

Figure 9: T2W Coronal of the prostate on the Orian 1.5T. The image on the right was reconstructed with AiCE DLR and shows an increased SNR and detail due to the noise reduction.

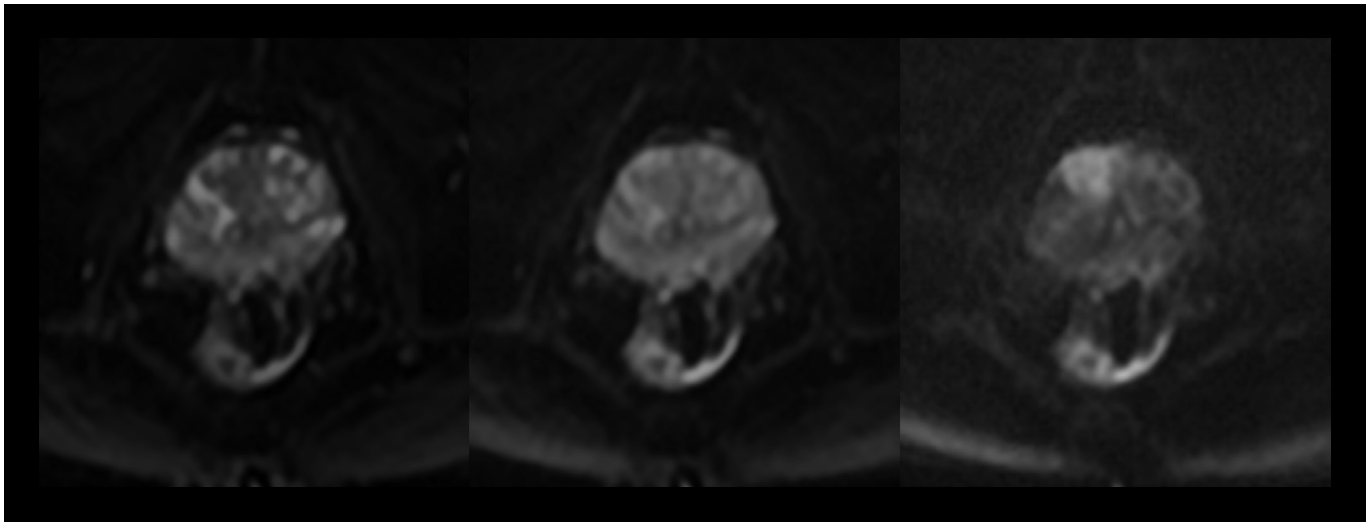

Figure 10: Shows prostate DWI images using Exsper with b0, b500, and b1400, respectively.

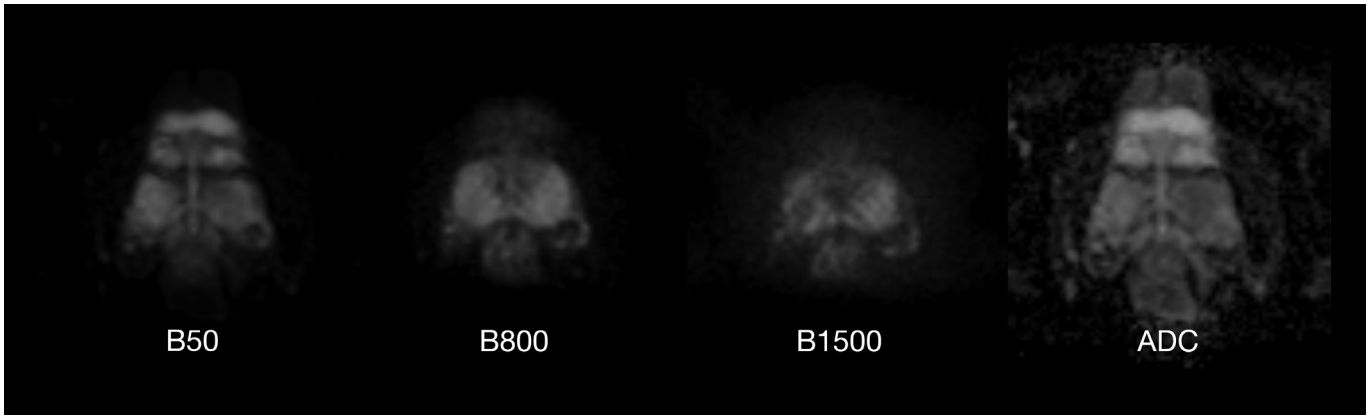

Figure 11: Example of prostate DWI with RDC and Exsper.

Exsper

Exsper is Canon's k-space based parallel imaging technique which can be applied to different sequences including DWI. Exsper reduces scan time by undersampling the k-space in the phase encoding direction while the center of the k-space is fully sampled. The fully sampled center of k-space is used as the calibration data for the unfolding calculation of the actual image in reconstruction processing. Based on the relationship between the coils in the calibration data, the composition coefficients for the folded coil image and unfolded coil image in the R-space (real space) can be calculated. Since Exsper is k-space based and not an image-based technique like SPEEDER, it is less sensitive to aliasing.

Reverse encoding Distortion Correction DWI (RDC)

RDC is intended to reduce distortion in SE EPI DWI in the phase encoding direction due to B0 field inhomogeneity or eddy current. RDC can be combined with SPEEDER or Exsper.

Summary

The use of 3T MRI and the addition of MP MR imaging techniques, such as DCE, DWI, and MRS, approach results in a higher detection rate of cancer in the prostate.[18] The PI-RADS protocol calls for at least one functional technique. In this way, a suspicious lesion found on DCE or DWI, for example, can be correlated to a finding on the T2W image. While T1W and T2W MR should be used for the evaluation of anatomy, DCE can be used for high-sensitivity imaging of potential clinically significant prostate cancers. DWI is the most simple and practical functional technique but can be prone to motion and susceptibility artifacts. MRS requires a higher level of expertise and suffers from a longer acquisition time, thus decreasing its actual clinical applicability. MP MR provides high-quality anatomic and functional images that improve the diagnosis of prostate cancer.[22] New methods of automated diagnostic maps, combining relevant parameters, are being explored. Decision support systems may assist radiologists in selecting lesions for image-guided biopsy.[18]

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