APPLICATION OF RADIAL ACQUISITION MULTISHOT SEQUENCE IN MULTIPARAMETRIC *MRI OF PROSTATE*

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ABSTRACT

The purpose of our study is to evaluate the T2 weighted sequence with multishot radial sampling (Radial Acquisition Multi-shot) also known as Multivane sequence in Philips Healthcare, introduced by J.Pipe with the aim to minimize motion artifacts in Magnetic Resonance Imaging (MRI).
In the field of prostate MRI the Multivane sequence is useful in non-cooperating patients and/or patients who, due to their clinical conditions (such as glaucoma, arrhythmia, and severe benign prostatic hypertrophy), have not been receiving intravenous antispasmodic agents, administered for limiting the motility of intestinal loops, particularly rectum.
The Multivane sequence is based on the collection of data throughout parallel multiple lines in periodic rotation around the center of k-space and advanced mathematical reconstruction. As the data at the center of k-space (low frequency) containing signals with maximum amplitude will be continuously sampled, this trajectory will provide an excellent contrast-noise ratio (CNR) and spatial resolution, without motion artifacts responsible of "blurring" in the final image. Specifically, each given point of the periphery of the k-space will be sampled by a certain line and the next one and so on, and for the final image reconstruction, once multiple data will be estimated, different algorithms will be used to compensate for motion artifacts.
In this study we compared the Radial Acquisition Multishot TSE Multivane (Philips Healthcare) with the classic T2W TSE sequences with linear Cartesian sampling. Multivane sequences have proven to be superior and therefore of greater utility compared to sequences with linear Cartesian data sampling, in patients who can not receiving spasmolytic agents.

INTRODUCTION

The Multiparametric MRI (mpMRI) of the prostate has become the main imaging modality for the detection, localization and local staging of prostate cancer (PCa). The term "multiparametric" means essentially the combination of different information: morphological information through the T2 weighted sequences, information on the diffusiveness of molecules through diffusion weighted sequences (Diffusion Weighted Imaging, DWI), information on dynamism and contrast enhancement through perfusion sequences (Dynamic Contrast Enhanced Magnetic Resonance Imaging, DCE-MRI) and, although still under study, information on metabolic alteration through spectroscopy sequences (Magnetic Resonance Spectroscopy Imaging, MRSI).
Each of these sequences provides different information and their combination gives this method a considerable degree of performance in the definition of Adenocarcinoma of the prostate. In particular, T2W sequences play a key role in a primary detection of PCa. T2W Magnetic Resonance Imaging (MRI) of the Prostate is a challenge for several reasons: most of the anatomical structures in this area are rather small and adjacent to a variety of "mobile" structures. In addition, a wide spectrum of artifacts including pulsations and artifacts related to rectum motility may occur also in collaborating patients. The detection of lesions and the assessment of their extent is the main goal of modern imaging and therefore requires high standards. The subject of our study is the Multivane sequence, recently proposed for MR imaging of the prostate, which allows for excellent correction of minimal movements related to the patient and/or to the involuntary motility of the various adjacent anatomical structures, an excellent contrast resolution and adequate spatial resolution, fundamental prerequisites for an adequate diagnosis and for applying an adequate therapeutic management.
The aim of our study was to apply and assess the MULTIVANE sequence (Philips Healthcare) in the mpMRI of the prostate, in not cooperating patients and/or in patients who, due to their clinical conditions (such as glaucoma, arrhythmia, and severe benign prostatic hypertrophy), have not been receiving intravenous antispasmodic agents, administered for limiting the motility of intestinal loops, particularly rectum.

MATHERIAL AND METHODS

Radial Acquisition Multi-shot Technique

Towards the end of the 90s J.Pipe, in order to limit the patients' related motion artifacts, presented a correction method based on a new technique in k-space data collection and reconstruction. The PROPELLER method (Periodically Rotate Overlapping Parallel Lines With Enhanced Reconstruction) is based on collecting data in parallel multiple

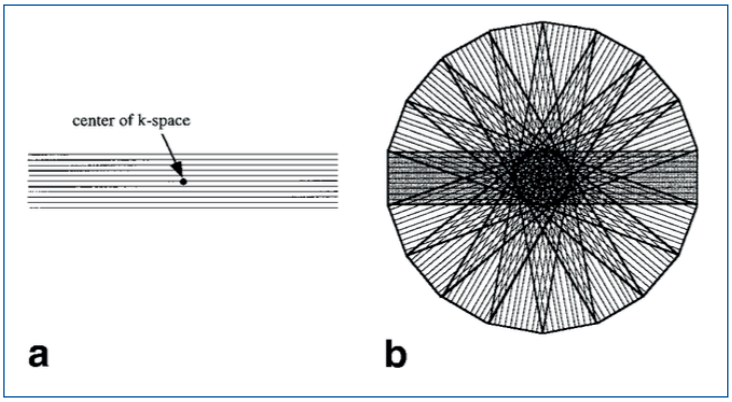

Fig. 1 - *Representation of a single strip n (a), consisting of multiple phase-coded lines l and corresponding to a set, and a complete set of n strips radially directed to the the k-space centre (b)*

lines in periodic rotation around the center of k-space and advanced mathematical reconstruction.
Patient's movement produces artifacts in MR imaging, as a result of tissue displacement during the period between each data sampling period and subsequent radiofrequency (RF) excitation, and also as a result of the spin phase induced by movement through magnetic field gradients between an excitation RF pulse and the subsequent data sampling period. Several strategies have been used over the time to mitigate these artifacts without any useful results. The sequence introduced by J.Pipe is based on the sample of the the k-space data in *n* strips in a rotating and periodic way through parallel linear trajectories *l* corresponding to l- codified phase lines.

Each strip consists of several parallel lines encoded in phase, typically ranging from 8 to 32 lines. The strips are rotated with a rotational shift that varies between 10°- 20° until all the useful data relating to the k-space have been acquired.
This trajectory provides an excellent contrast-to-noise ratio as the data at the center of k-space (low frequency), containing signals with maximum amplitude, will be continuously sampled. The data of the periphery instead will be reconstructed through mathematical processes with the final purpose to correct the least movements of the patient. Thus, each point will come and be sampled from a given line and from the next one and so on and, once multiple data are estimated, different algorithms will be used for the final image reconstruction without motion artifacts.
In particular, in *Phase Correction* there is a phase correction for each strip, then in *Rotation, Translation and Through-Plane* the data of each strip are processed by averaging and applying algorithms of the sum of least squares, allowing to solve or correct the patient's movements. Finally, in the *Final Reconstruction* a regridding of the data is performed: it is not possible to perform a Fourier Trasform because the Fourier Transform cannot operate on a non-cartesian K-space.
The sequences Radial Acquisition Multishot TSE T2W, known as Multivane (Philips), Propeller (GE), Blade (Siemens), Radar (Hitachi/Fujifilm) and Jet (Canon/Toshiba) according to various vendors, are all characterized by the following approach: after an RF pulse at 90°, which deflects the magnetization from the Longitudinal plane on the Trasversal X-Y plane, and a train of n. RF pulses at 180°, which make the MMT rotate by inverting the phase, Finally , the application of a variable phase and frequency gradient allows to have an indication of k-space start reading. To record the echo signal, the phase and frequency gradients will be simultaneously switched on with one of the n amplitudes allowed to encode the lines of the K-space in a radial, not Cartesian, mode.

Image acquisition and evaluation

Image quality, the contrast of the relevant anatomical structures and the presence and extension of various artifacts were evaluated and compared with the classic Turbo Spin Echo (TSE) sequence T2W on the axial, sagittal and coronal plane respectively.
The MRI examinations were performed with a high-field RM Scanner, 1.5T Philips Achieva (Philips Heathcare) with gradients combined with 30mt/m

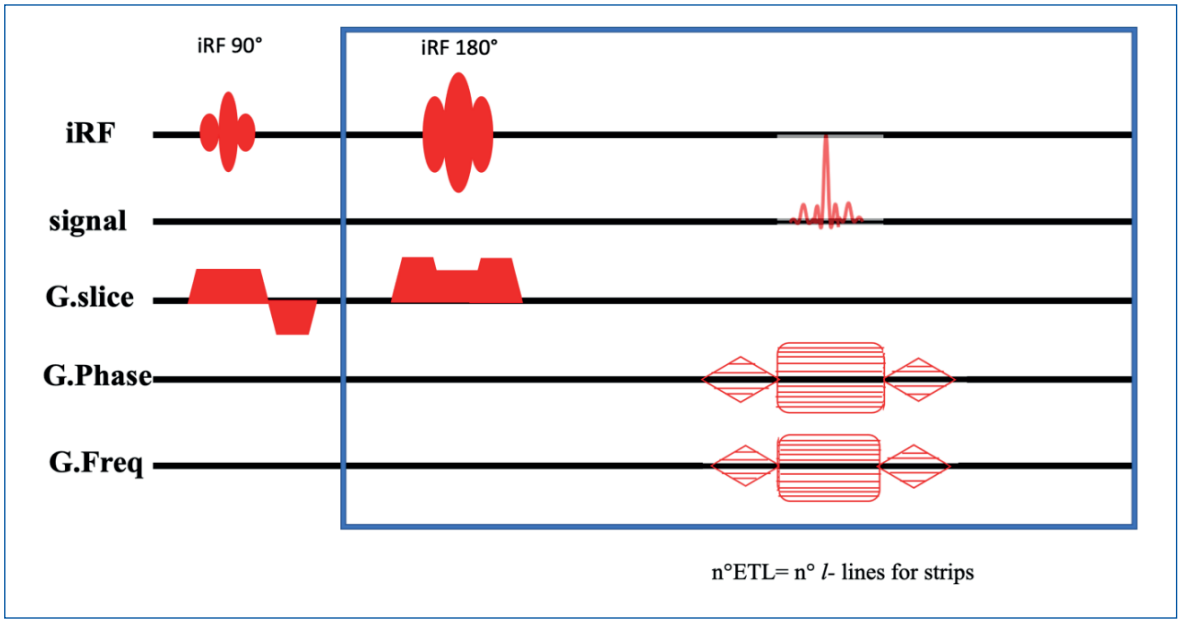

Fig. 2 - *Temporal diagram of Radial Multishot Turbo Spin-Echo sequence*

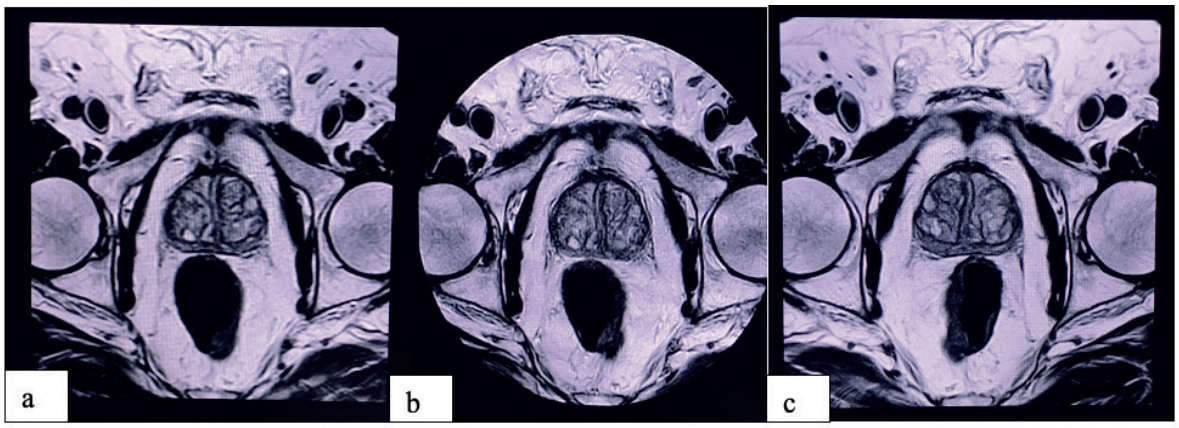

Fig. 3 - *Representation of three T2 -weighted images in axial plane in a 68 years-old patient with benign prostatic hypertrophia and with suspect PCa. Respectively, a T2w image with Cartesian sampling without spasmolytic agents administrated (a), an image with radial multi-shot sampling for compensation of movements (b) and finally the same acquisition with Cartesian sampling but with spasmolytic agents administration . It can be noted that radial sampling (b) can efficiently limit motion artifacts and the undesirable effect of blurring (seen in a) with results similar to Cartesian acquisition after administration of spasmolytic agents (c).*

Amplitude and Slew-Rate of 80/120 mt/m/ms. A surface coil is positioned directly on the area of interest, allowing to fully exploit the CNR/coil distance. This surface coil is only a receiving coil, while the RF pulse is transmitted by the Q-Body coil. Image quality evaluation was carried out by one radiologist, with experience in interpreting prostate MR imaging ,who didn't know the imaging technique performed, as well as patient data, medical history and without additional MR images.
Image quality has been evaluated on a scale of 1 to 5 (1: excellent, without any impairment of image quality 2: good, with only minimal impairment of image quality 3: moderate, showing artifacts that reduce image quality but still diagnostic 4: poor , with severe impairment of image quality and limited diagnostic reliability 5: non-diagnostic, artifacts/alterations too severe to make a diagnosis) for the following criteria: contrast resolution, spatial resolution and overall motion artifacts.

Results

The study included 10 mpMRI of the prostate examinations performed in 10 patients (aged 56-78, mean age: 65) between November 2021 and January 2022, at our Department.
In all 10 patients the sequences TSE T2w Multivane in combination with the conventional TSE T2w, with Cartesian sampling, without the administration of a spasmolytic agent, were acquired on the axial, sagittal and coronal planes, increasing the exam duration by about 6 minutes.
For the purpose of the study, in two collaborating patients and without contraindications to the administration of the spasmolytic agent, the T2w TSE sequence was also acquired after intravenous drug administration, increasing the overall duration by about 10 minutes (See Fig).

In Table 1 we reported the qualitative assessments, performed by the radiologist experienced in Prostate mpMRI, about the single Multivane sequence obtained in the 10 MR examinations included in the study, according to a 5-point qualitative scale, on the following questions: spatial resolution (Q1), contrast resolution (Q2) and total motion artifacts (Q3).

Questions	Pt. 1	Pt 2	Pt 3	Pt 4	Pt 5
Q1	0	0	0	4	6
Q2	0	0	0	3	7
Q3	0	0	0	2	8

Tab. 1 - *Qualitative assessment of 10 "Multivane" sequences in 10 Prostate mpMRI exams.*

In Table 2 the comparative evaluations between the TSE T2w sequences, with Cartesian sampling and without the administration of spasmolytic agent, and the Multivane sequences (Fig.4)

In the two patients underwent T2 TSE sequence was also after spasmolytic agent administration, in comparison with the Multivane sequence, no significant differences in contrast resolution and motion artifacts were noted, while there was a slight superiority of conventional TSE T2w over Multivane in terms of spatial resolution.

Quesito	1. TSE T2w/ Multivane	2. TSE T2w/ Multivane	3. TSE T2w/ Multivane	4. TSE T2w/ Multivane	5. TSE T2w/ Multivane	6. TSE T2w/ Multivane	7. TSE T2w/ Multivane	8. TSE T2w/ Multivane	9. TSE T2w/ Multivane	10. TSE T2w/ Multivane
Q1	4/5	4/5	3/4	4/5	4/5	4/5	4/4	3/4	3/5	4/4
Q2	5/5	4/5	4/4	4/5	4/4	5/5	5/4	5/4	4/4	5/5
Q3	3/4	2/4	3/5	2/4	3/5	3/5	4/5	3/4	2/4	3/5

Tab. 2 - *Comparison between TSE T2w sequence, with cartesian sampling, and Multivane sequence.*

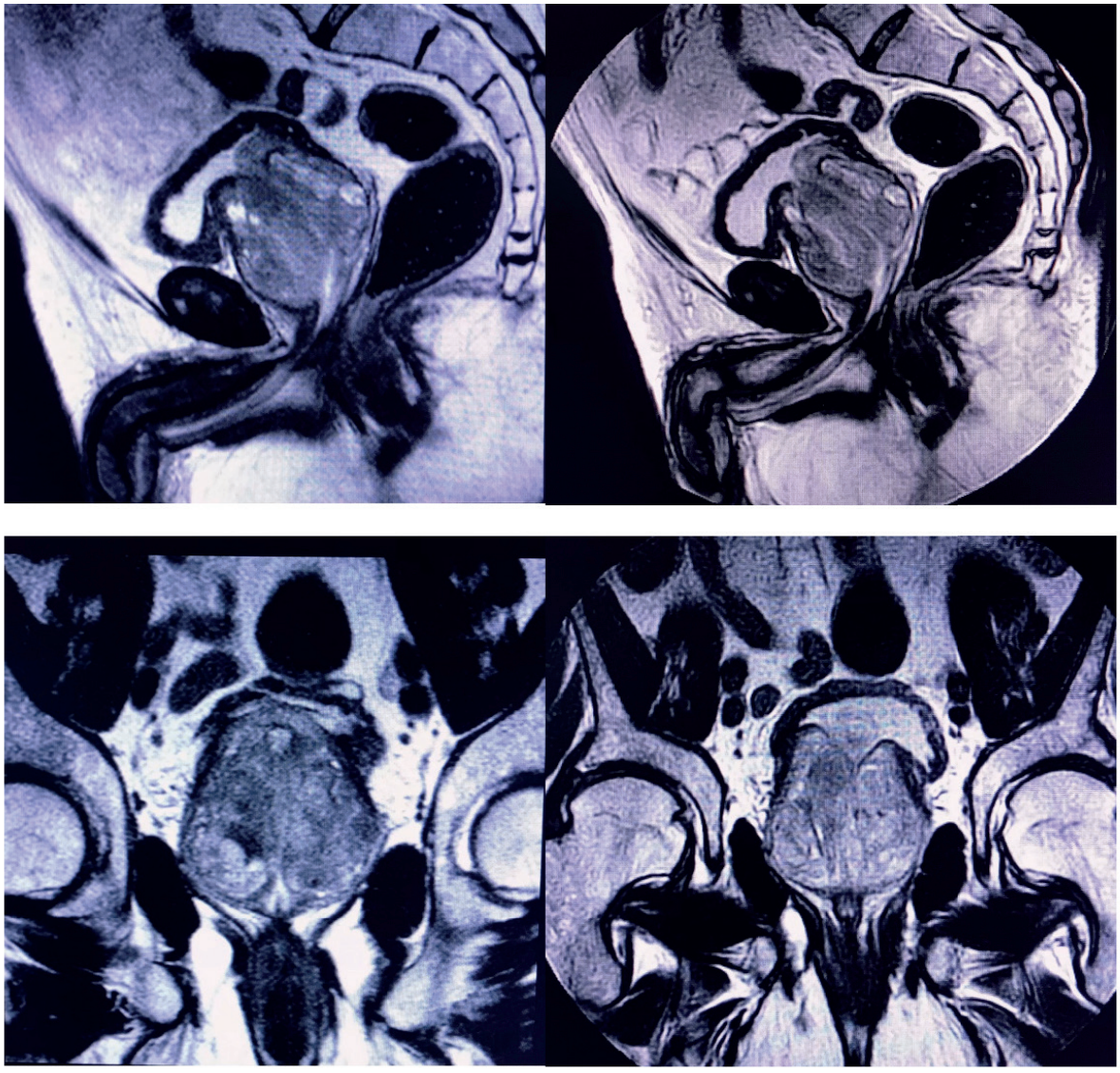

Fig. 4 - *A 69-years-old patient with suspect PC. On the left representation of T2 -weighted images with Cartesian sampling on the sagittal plane (top) and coronal plane (bottom). On the right a representation of T2-weighted images with multishot Radial sampling on the sagittal plane (top) and coronal plane (bottom).*

DISCUSSION

Prostate cancer is the most common malignant cancer in men patients, representing a significant incidence compared to all carcinomas in males and the cause 10% of cancer-related deaths.

Although of low prevalence, it is important to make an early diagnosis of these carcinomas, in order to be able to perform a correct and early therapeutic management.

MRI is a second-level examination for prostate cancer and has now gained a major role in the study of prostate cancer. It is a non-invasive method, providing high tissue contrast images as well as detailed spatial resolution of soft tissues, compared to other imaging techniques. After the introduction of advanced functional sequences, such as Diffusion Weighted Imaging (DWI) and Dynamic Contrast Enhanced (DCE) imaging, using a combined morpho-functional approach, a further improvement in tissue characterization and detection of prostatic cancer was obtained.

The sequence Radial Acquisition Multishot TSE in mpMRI of the prostate could be used in non-cooperating patients and/ or patients unable to use intravenously antispasmodic agents, with the aim of limiting the motility of intestinal loops, contributing to obtain images of good quality without motion artifacts. Sufficient contrast of rather small anatomical structures and sharp images without interfering artifacts are important requirements of MRI imaging of the prostate. MRI-based detection and the diagnostic process, according to the PI-RADS, of prostate lesions depend on the distinction between the contrast of the lesion and that of adjacent tissue in T2-weighted images.

In this study we compared the Radial Acquisition Multishot TSE Multivane (Philips Healthcare) sequence with the T2W TSE , with linear Cartesian sampling for contrast resolution, spatial resolution and overall motion artifacts. Both sequences, Multivane and TSE, showed similar contrast resolution results, since in radial sampling central k-space data are sampled in equal measure or oversampled compared to cartesian TSE method.

In terms of spatial resolution, aware of the mathematical regridding process of the Multivanes, leading to a significant reduction of its own spatial resolution, however, it was moderately higher than the conventional TSE (without spasmolytic administration) due to the fact that visible movement in Cartesian sam-

pling sequences led to a "blurring" of the image by visually degrading the spatial resolution.
Regarding motion artifacts, images with the Multivane sequence have been superior compared to the classic TSE with consequent better delineation of structures and lesions.

CONCLUSION

Radial Acquisition Multishot TSE T2W Multivane sequences have been shown to be superior to standard linear Cartesian data sampling for various imaging artifacts. The k-space acquisition scheme with the so-called rotating strips, partially overlapping, is advantageous for non-cooperating patients who cause motion artifacts during data sampling. To our knowledge, only very few applications of the Radial Acquisition Multishot technique in prostate resonance in non-cooperating patients have been reported to date. Although presented results are preliminary results, the Acquisiton Radial Multishot TSE T2W Multivane sequences showed significant optimal performance in motion correction.

REFERENCES

1. **Villeirs et al.** Magnetic resonance imaging anatomy of the prostate and periprostatic area: a guide for radiotherapists. Radiother Oncol 2005; 76:99- 106.
2. **Dickinson et al.** "Clinical Applications of Multiparametric MRI within the Prostate Cancer Diagnostic Pathway." Urologic Oncology: Seminars and Original Investigations 31, no. 3 (April 2013): 281–84.
3. **Curatolo C et al.** La Risonanza Magnetica Multiparametrica della Prostata -stato dell'arte- Volume 1, Special Issue – I Congresso FNO TSRM PSTRP 2019-10-11.
4. **Hoeks et al.** "Transition Zone Prostate Cancer: Detection and Localization with 3-T Multiparametric MR Imaging." Radiology 266, no. 1 (2013): 207–17.
5. **Haider MA et al**. Combined T2-weighted and diffusion- weighted MRI for localization of prostate cancer. Am J Roentgenol 2007; 189: 323–8.
6. **Bonekamp D et al.** Advancements in MR Imaging of the Prostate: From Diagnosis to Interventions. Radiographics. 2011 May- Jun;31(3):677-703.
7. **Mocikova, I et al.** "Prostate Cancer – the Role of Magnetic Resonance Imaging." Biomedical Papers 156, no. 2 (July 1, 2012): 103–7. doi:10.5507/bp.2012.025.
8. **Katz S et al.** MR Imaging and MR Spectroscopy in prostate cancer management. Radiol Clin North Am 2006; 44:723-734.
9. **Portalez D, Rollin G et al.** (2010) Prospective comparison of T2w-MRI and dynamic- contrast-enhanced MRI, 3D-MR spectroscopic imaging or diffusion-weighted MRI in repeat TRUS-guided biopsies. Eur Radiol; 20: 2781-2790.
10. **Ghafoori et al.** "MRI in Prostate Cancer." Iranian Red Crescent Medical Journal 15, no. 12 (December 5, 2013).
11. **McNeal JE.** Regional morphology and pathology of the prostate. Am J Clin Pathol. 1968; 49(3): 347-57.
12. **Knopp MV et al.** Dynamic contrast-enhanced magnetic resonance imaging in oncology. Top Magn Reson Imaging 2001; 12:301-8.
13. **Sciarra A, Salciccia S, Panebianco V. et al.** Proton spectroscopic and dynamic contrast- enhanced magnetic resonance: a modern approach in prostate cancer imaging. Eur Urol. 2008; 54: 485-8.
14. **DeSouza NM et al.** *"Magnetic resonace imaging in prostate cancer: the value of apparent diffusion coefficients for identifying malignant nodules"*, British Journal of Radiology, vol. 80, 2007, pp 90-95.
15. **Marcus DM et al.** The Impact of Multiparametric Pelvic Magnetic Resonance Imaging on Risk Stratification in Patients With Localized Prostate Cancer. Urology. 2014 Apr 29. pii: S0090-4295(14)00266-0.
16. **Pipe J.G. et al.** Motion correction with PROPELLER MRI: Application to head motion and free-breathing cardiac imaging. *Magn Reson Med.* 1999; 42: 963-969
17. **Pauly J.M. et al.** Projection reconstruction techniques for reduction of motion effects in MRI. *Magn Reson Med.* 1992; 28: 275-289.
18. **Rosenkrantz, AB et al.** Prostate cancer localization using multiparametric MR imaging: comparison of prostate imaging reporting and data system (PI-RADS) and Likert scales. *Radiology*269, 482–492 (2013).
19. **Zakian KL et al.** Comparison of Motion-Insensitive T2-Weighted MRI Pulse Sequences for Visualization of the Prostatic Urethra During MR Simulation. Pract Radiat Oncol. 2019 Nov;9(6):534-540. Epub 2019 Jun 25. PMID: 31252087; PMCID: PMC6832802.
20. **Sciarra A, Panebianco V , et al.** Use of 3D T2-weighted MR sequenze for the assessment of neurovascular bundle changes after nerve-sparing radical retropubic prostatectomy (RRP): a potential diagnostic tool for optimal management of erectile dysfunction after RRP. J Sex Med 2009 May; 6 (5): 1430-7.