REFOCUS FLIP ANGLE MODULATION ON THE PD TSE SEQUENCES IN THE MAGNETIC RESONANCE IMAGING OF THE KNEE, FOR THE EVALUATION OF MENISCAL INJURIES

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KEYWORDS: Pseudo-Steady State (PSS), Refocus Flip Angle, PD TSE sequences, SAR, meniscal lesions, signal to noise ratio, Magnetic Resonance of the Knee

ABSTRACT

The Radiofrequency Refocused Echo Spin-Echo Echo-Train Rapid-Acquisition sequences, known as Turbo Spin Echo (TSE) or Fast Spin Echo (FSE) are the most commonly used sequences in Magnetic Resonance as they provide a notable contribution in morphological and anatomical terms, thanks to their high spatial and contrast resolution. Furthermore, they allow a higher signal noise ratio than the other families of sequences thanks to the numerous refocusing pulses and thanks to a TR so long as to allow sampling as many K-space phase encodings as possible and with a complete recovery of the Longitudinal Magnetization. Finally, the multiple 180 ° pulses of these sequences reduce the inhomogeneities of the Magnetic Field by minimizing the phenomena of magnetic susceptibility. However, their application, especially in scanners with a high intensity of static magnetic field B0 (1.5T and/or 3T) is prevented by the deposition of RF due to the long echo trains, which sometimes involve exceeding the limits of the specific absorption rate (SAR) for patient safety. Over time, a common solution to the SAR problem has been the use of refocusing angles smaller than 180 ° (160 °-140 °-120 °), which lead to its reduction at the cost, however, of an obvious penalty in terms of signal-to-noise ratio (SNR). In this study we present a modulation method of the Refocus Flip Angle applied to the DP-TSE sequences in the evaluation of meniscal lesions in the study protocol of the Magnetic Resonance of the Knee, which exploits the phenomenon of the Pseudo-Steady-State (PSS), leading to a noticeable SAR reduction without loss of SNR and also providing excellent contrast resolution.

INTRODUCTION

Magnetic Resonance is currently the method of choice in the study of joint pathology, as it is a non-invasive, multiplanar and multiparametric method. The high contrast resolution associated with a high sensitivity for pathological areas and excellent tissue characterization allows extreme diagnostic precision, assuming a role of primary importance in the diagnosis of numerous pathologies. The knee is one of the most studied joints in MRI. It is estimated that about 80-90% of meniscal tears are of a traumatic nature following sports activity and 10-20% of a degenerative nature following degradation due to dehydration with increasing age. The FSE/TSE sequences, in particular those weighted in proton density, are the most used sequences in MRI for joint study, as they allow excellent tissue discrimination (tendons, ligaments and menisci). However, one of the main limitations of these sequences is the excessive heating of the tissues, a direct consequence of a large number of 180 ° iRF echo trains (ETL 15-40). It is known that the energy deposition of an RF pulse is proportional to the square of the inversion angle (α2): this means that a 180 ° pulse deposits a SAR 4 times higher than one pulse at 90 °. To overcome this problem, various strategies have been applied over time with the aim of limiting the SAR, among these the reduction of the refocusing angle with fixed Flip Angles, has allowed lower SAR levels but with an evident reduction of the MR signal. In our study we have implemented various strategies to optimize the contribution of the signals coming from the components of the Mx and My magnetizations, in particular by modulating the Refocus Flip Angle at variable angles with the aim of exploiting the Pseudo -Steady-State (PSS) phenomenon. This strategy allowed to obtain a better visualization (contrast resolution and higher SNR) of the meniscal lesions in the TSE PD sequences of the knee MRI, thus obtaining, with a low SAR and within the expected limits, a more sensitive and specific imaging.

OBJECTIVES

The aim of our study was to modulate the Refocus Flip Angle parameter, exploiting the phenomenon of PSS, applied to the TSE PD sequences, in the MRI of the knee, to obtain a better visualization of the meniscal lesions, achieving a more sensitive and more specific imaging, compared to TSE PD sequences with constant refocusing angles and less than 180°.

MATERIALS AND METHODS

MRI examinations of the knee were performed at the Department of Radiology of the University hospital "Paolo Giaccone" of Palermo, using a Philips Achieva 1.5 T Philips Healthcare MRI scanner.

The receiving coil used is the Knee-Coil SENSE 8ch, within which the knee under examination is allocated. Ten volunteer patients underwent MRI of the knee. The examinations were performed after the volunteer patients were properly and adequately informed about the study in progress, and duly signed the informed consent. The various sets of sequences for a single patient were performed in several sessions with an interval of approximately 7 days.

The joint study protocol (standard), carried out at our Institute, provides for the acquisition of Ax T2 TSE, Ax PD TSE SPAIR, Sag DP TSE, Sag T1W, Sag TSE STIR, Cor PD TSE and PD TSE SPAIR sequences.

In the PD-weighted sequences acquired in the coronal and sagittal planes we modulated the Refocus Flip Angle parameter, with the aim of obtaining a better visualization of meniscal lesions. In particular, we started with a set of images with classic 180 ° refocusing iRF, comparing it with a further 3 fixed angle sets at 160 °, 140 ° and 120 ° in terms of SAR and SNR ratio. Finally, we acquired a series in which we modulated the Refocus Flip Angle, by linearly varying the tilting angles from low values of 60 °, then intermediate values of 90 °, to high values of 110 ° along the echo train.

Classically, with the 180 ° iRF pulses the transverse magnetization (TM) is completely and entirely refocused without any contribution from the longitudinal magnetization (LM), instead reducing the RF flip angles below 180 °, there will be a situation in which we will have both the TM and the LM. This implies that at each subsequent cycle of pulses there will be a refocusing contribution of the deflected TM, but also of the "stored" LM, which together with the TM will contribute to the generation of the echo signal. Each subsequent pulse other than 180 ° in the train of echoes will continue to divide the magnetization into longitudinal and transverse components. With this strategy we ensure that the echoes stimulated by the longitudinal component are stored and sampled in the phase encodings with low amplitude (more useful data) thus obtaining a generation of MR signal with more essential information.

In particular, the three parameters, which play a fundamental role in the PSS phenomenon, are the values attributed to the overturning angles along the train of echoes. We will pass in a linear way from a minimum α value, which allows to reduce blood vessel flow artifacts, which would deteriorate the quality of the images and we will then proceed with an intermediate α value, which allows to maintain the relaxation time T2 constant when the signal of the central portion of the k space is sampled, thus obtaining a better resolution of contrast of the image. Finally, we will move on to the maximum α value, thanks to which we will have a higher SNR and, therefore, greater image sharpness.

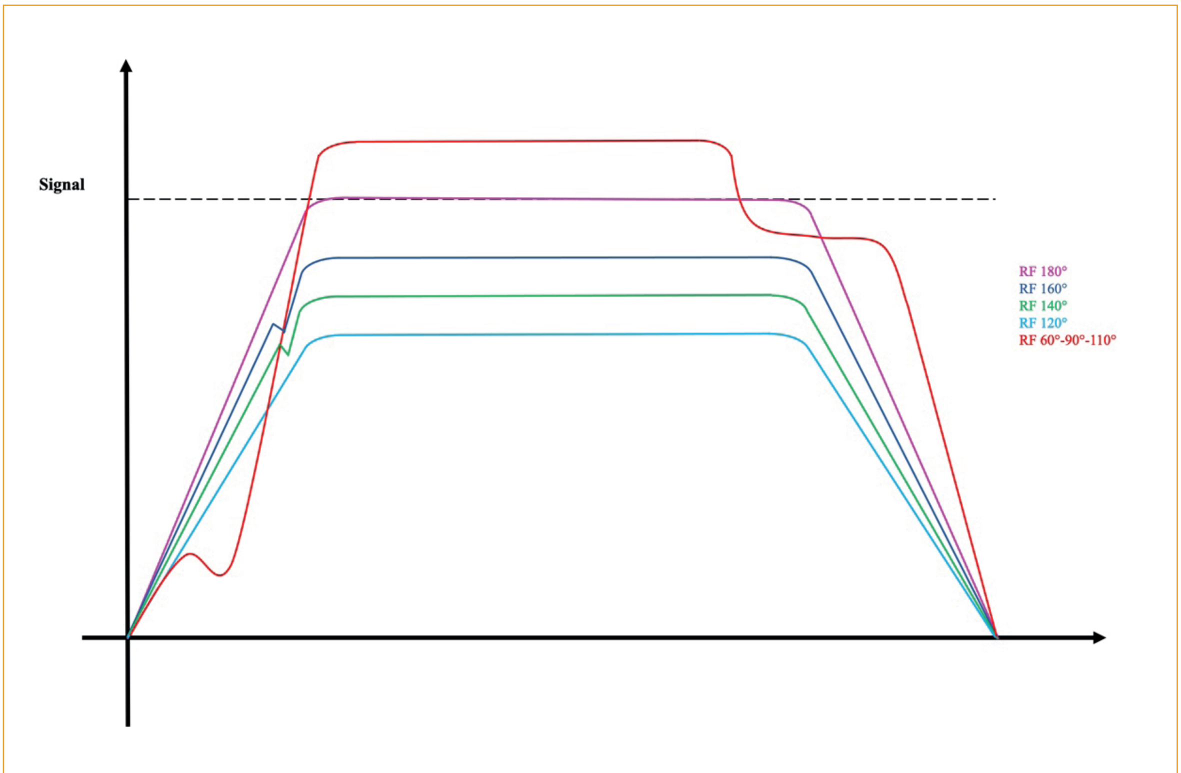

Fig. 1 - *Representative diagram of the variation of the refocusing angle in relation to the MR signal. In the first case (pink) 180 ° iRF pulses are used, in the second case (blue) 160 ° iRF constant pulses are used, in the third (green) and fourth (light blue) lines iRF pulses at 140 ° and 120 ° respectively are used. In red, on the other hand, a strategy with variable refocusing angles (60 ° / 90/110 °) is applied. Theoretical signal intensities are shown below (ignoring T1, T2 and off-resonance effects)*

AX PD TSE SPAIR			
STANDARD		**REFOCUS FLIP ANGLE MODULATION**	
N.slice	35	**N.slice**	35
TE	20ms	**TE**	20ms
TR	3763	**TR**	3763ms
FA	90°	**FA**	90°
Slice Thickness	3mm	**Slice Thickness**	3mm
FOV	160x160x125	**FOV**	160x160x125
TAcq	03:46 min	**TAcq**	03:46
NSA	2	**NSA**	2
Dimensioni voxel	0.55x0.86x3mm	**Dimensioni voxel**	0.55x0.86x3mm
SENSE	1.4	**SENSE**	1.4
Refocusing Control	1 set Costant 180° 2 set Costant 160° 3 set Costant 140° 4 set Costant 120°	**Refocusing Control**	T2-optimized→ min angle 60°, mid angle 90°, max angle 110°

Tab. 1 - *Acquisition parameters related to the Ax PD TSE SPAIR sequence of the MR study of the knee, with constant Refocus Flip Angle, and with the Refocus Flip Angle modulation technique.*

COR PD TSE			
STANDARD		**REFOCUS FLIP ANGLE MODULATION**	
N.slice	21	**N.slice**	21
TE	25ms	**TE**	25ms
TR	3317ms	**TR**	3317ms
FA	90°	**FA**	90°
Slice Thickness	3.5 mm	**Slice Thickness**	3.5 mm
FOV	149x149x80	**FOV**	149x149x80
TAcq	02:43 min	**TAcq**	02:43 min
NSA	3	**NSA**	3
Dimensioni voxel	0.417x0.452x3.5mm	**Dimensioni voxel**	0.417x0.452x3.5mm
SENSE	1.3	**SENSE**	1.3
Refocusing Control	1 set Costant 180° 2 set Costant 160° 3 set Costant 140° 4 set Costant 120°	**Refocusing Control**	T2-optimized→ min angle 60°, mid angle 90°, max angle 110°

Tab. 2 - *Acquisition parameters related to the Cor PD TSE sequence of the MR study of the knee, with constant Refocus Flip Angle, and with the Refocus Flip Angle modulation technique.*

COR PD TSE SPAIR			
STANDARD		**REFOCUS FLIP ANGLE MODULATION**	
N.slice	21	**N.slice**	21
TE	25ms	**TE**	25ms
TR	5199ms	**TR**	5199ms
FA	90°	**FA**	90°
Slice Thickness	3.5 mm	**Slice Thickness**	3.5 mm
FOV	149x149x80	**FOV**	149x149x80
TAcq	03:44	**TAcq**	03:44
NSA	3	**NSA**	3
Dimensioni voxel	0.55x0.77x3.5mm	**Dimensioni voxel**	0.55x0.77x3.5mm
SENSE	No	**SENSE**	No
Refocusing Control	1 set Costant 180° 2 set Costant 160° 3 set Costant 140° 4 set Costant 120°	**Refocusing Control**	T2-optimized→min angle 60°, mid angle 90°, max angle 110°

Tab. 3 - *Acquisition parameters related to the Cor PD TSE SPAIR sequence of the MR study of the knee, with constant Refocus Flip Angle, and with the Refocus Flip Angle modulation technique.*

SAG PD TSE			
STANDARD		**REFOCUS FLIP ANGLE MODULATION**	
N.slice	27	**N.slice**	27
TE	25ms	**TE**	25ms
TR	shortest	**TR**	shortest
FA	90°	**FA**	90°
Slice Thickness	3.5mm	**Slice Thickness**	3.5mm
FOV	180x180x95	**FOV**	180x180x95
TAcq	03.18	**TAcq**	03.18
NSA	3	**NSA**	3
Dimensioni voxel	0.55x0.78x3.5	**Dimensioni voxel**	0.55x0.78x3.5
SENSE	1.4	**SENSE**	1.4
Refocusing Control	1 set Costant 180° 2 set Costant 160° 3 set Costant 140° 4 set Costant 120°	**Refocusing Control**	T2-optimized→min angle 60°, mid angle 90°, max angle 110°

Tab. 4 - *Acquisition parameters related to the Sagittal PD TSE sequence of the MR study of the knee, with constant Refocus Flip Angle, and with the Refocus Flip Angle modulation technique.*

RESULTS

With the implementation of the modulation of the Refocus Flip Angle, following the values α equal to 60 ° - 90 ° - 110 °, identified through the various tests performed at our Institute, as regards the visualization of meniscal lesions, better results were obtained in the series of images acquired in terms of both of contrast resolution and signal/noise ratio, with a considerable reduction in SAR. Tables 1-3 below show in detail, for the PD TSE sequences of the knee MRI protocol, the acquisition parameters compared between the standard sequences with the use of constant Refocus Flip Angle, and the sequences with the application of the technique of the modulation of the Refocus Flip Angle with tilting angles of 60 ° -90 ° -110 °.

In figure 2 it is demonstrated how, by reducing the FA from a classic value of 180 ° to 120°, the RM signal is progressively reduced, while applying the strategy of a Variable Flip Angle the RM signal is excellent.

DISCUSSION AND CONCLUSIONS

By analyzing the images acquired with Refocus Flip Angle kept constant with a value of α equal to 180 °, we have achieved excellent image quality: this is because all the spins are overturned and refocused by this RF pulse, obtaining a high echo signal. Subsequently, after a careful and accurate evaluation of the various series of images, which were obtained with values of α equal to 160 °, 140 ° and 120 °, it was noted that, compared to the classic iRF 180 ° pulse, both the signal and the resolution overall image contrast are slightly reduced. All these negative aspects were accentuated when reference was made to the visualization of the meniscus. Ultimately, by evaluating the series of images obtained from the Ax PD TSE SPAIR, Cor PD TSE and Cor PD TSE SPAIR and Sag PD TSE sequences with exclusive modulation of the Refocus Flip Angle parameter in variable mode, we have gained a significant reduction of the flow artifact and a significantly lower SAR than previous tests. We

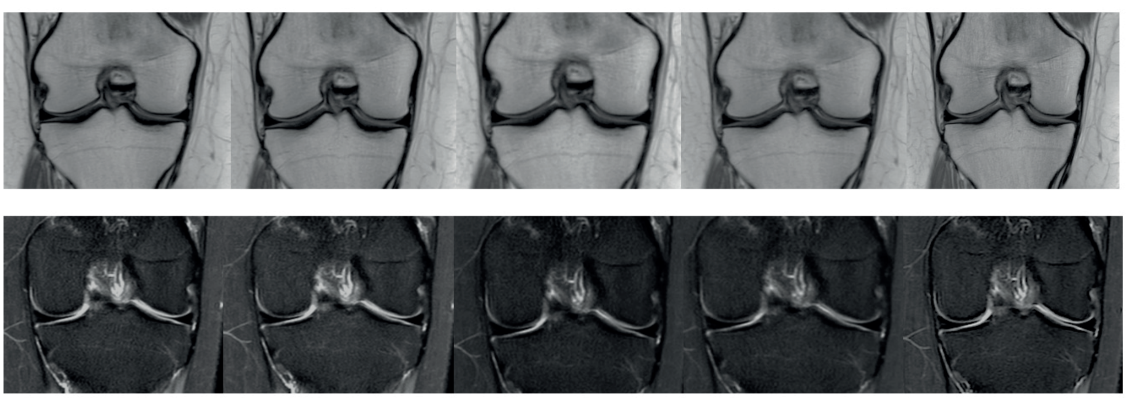

Fig. 2 - *Comparison of various refocusing angles applied to images acquired with a 1.5T scanner in Coronal PD (top) and Coronal PD SPAIR (bottom). From left to right constant FAs were applied, respectively at 180 ° 160 ° 140 ° 120 ° and finally a variable FA 60 ° / 90 ° / 110 °.*

then achieved, during the central portion of the echo train, signal amplitudes greater than those achieved with constant RF refocusing pulses at 180 °. During this increase we proceed with the signal sampling of the central portion of the k-space; it follows that the contrast resolution and the signal/noise ratio of the entire image, but with particular emphasis on the meniscal portion, will be high. In conclusion, in the MRI examination of the knee, the choice of the sequences under study must achieve the goal of obtaining the best anatomical detail and contrast between the structures under examination. The TSE PD sequences, in which the Refocus Flip Angle modulation has been performed, satisfies these needs. In fact, the images present a better quality in the visualization of meniscal lesions, thus allowing to perform a morphological study much more accurate than the one performed in the absence of this variation, with lower SAR values.

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