Gradient-modulated PETRA

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Introduction

Off-resonance blurring is a common problem for radial ultra-short echo time sequences such as ZTE[1] and SWIFT[2]. One efficient and simple way to reduce this off-resonance issue is to use higher readout bandwidth (Hz/pixel). However, to achieve higher bandwidth, those sequences require a switching time from transmit to receive (T/R) mode that is significantly shorter than what is usually possible with clinical MRI scanners. Piecewise Encoding Time reduction with Radial Acquisition (PETRA)[3] overcomes the T/R switching limitation by combining ZTE and Single Point Imaging (SPI)[4] acquisition. In ZTE, slow T/R switching results in missing k-space center points. Thus, PETRA acquires the missing center points with additional SPI acquisitions. However, while PETRA alleviates the requirement on fast T/R switching, use of higher bandwidth increases the number of missing k-space center points proportionally with the cube of the readout bandwidth. Therefore, higher bandwidth with slow T/R switching results in long additional SPI acquisition time. Here, we introduce a novel PETRA technique with gradient modulation which enables higher readout bandwidth while keeping the missing center k-space region small. Tolerance to off-resonance blurring is evaluated by comparing PETRA techniques with and without gradient modulation (GM) for an equine knee sample in a human 7T scanner.

Method

In PETRA, signal acquisition starts immediately after hard pulse excitation and the following T/R switching delay t_s, while the gradient remains constant (Fig.1). k-space center points are not sampled during the first $t_k = pw/2 + t_s$ period. In GM-PETRA, after the receiver gate is turned on, the gradient amplitude starts rising up following an inserted short delay time t_d; this delay period with flat gradient is used for acquiring missing k-space points with SPI. Under the same excitation bandwidth condition, PETRA and GM-PETRA are identical until the gradient starts rising up.

Ex vivo equine knee imaging was performed in a Siemens 7T MRI scanner. GM-PETRA was compared with conventional PETRA. Minimum T/R switching delay (t_s) was 20 µs under the standard Siemens setting. The extra delay, t_d, was set to 20 µs. Sequence parameters in GM-PETRA were as follows: pw=20 µs (bandwidth~60kHz), TE~45 µs, TR=4ms, flip angle=3°, FOV=16x16x16 cm^3, total acquisitions=131,072 including 123 SPI acquisitions, and scan time=8min 44sec. The same parameters were used for PETRA except for TR=4.2ms (scan time=9min10sec). Gradient modulation was applied in GM-PETRA (linear rise up from $\gamma G \cdot FOV$=60 kHz to 200 kHz); gradient rise time was 210µs. In PETRA, Gradients were kept constant (60 kHz). Time for extra SPI acquisitions (123 TRs) was ~0.5 sec for both PETRA and GM-PETRA (the SPI acquisition time is 37 times longer when using PETRA with 200 kHz bandwidth). Image reconstruction was performed offline with a home-built C program. Image matrix was 400x400x400 (0.4 mm isotropic nominal resolution).

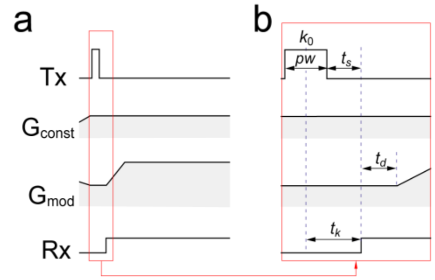

Fig.1. (a) PETRA (constant gradient G_{const}) and GM-PETRA (modulated gradient, G_{mod}), and (b) magnification of the T/R switching period (pw: pulse width, t_s: T/R switching delay, t_k: missing sampling time, t_d: extra delay before the gradient begins rising up).

Results

Equine knee images with GM-PETRA and conventional PETRA are shown in Fig.2. Sharpness of the images was visually improved for GM-PETRA, especially around the regions with strong magnetic susceptibility differences such as air tissue interfaces. Moreover, GM-PETRA clearly visualized fine structures such as small vessels, whereas those were blurry in the PETRA images.

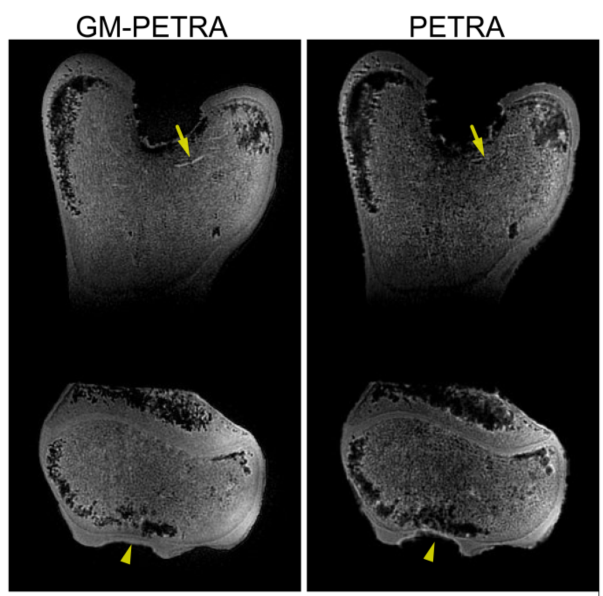

Fig.2. 3D ex vivo equine knee images acquired with GM-PETRA (200 kHz, left) and PETRA (60 kHz, right). Images from GM-PETRA are sharper overall compared to those from PETRA especially around tissue air interfaces (arrow head). Small vessels are clearly seen in the GM-PETRA images (arrow).

Discussion

GM-PETRA removed off-resonance blurring by increasing gradient amplitude (200 kHz) after excitation with lower bandwidth (60 kHz). The independence of excitation and readout bandwidth settings is another advantage of using gradient modulation in PETRA. In general, PETRA (ZTE) with higher bandwidth has a severe limitation on available flip angles due to its high RF peak power and SAR. The flexibility on excitation and readout bandwidth settings can highly mitigate the flip angle limitation. One disadvantage of using gradient modulation is increase of acoustic noise, while conventional PETRA is extremely quiet. However, GM-PETRA is still much quieter than conventional MR sequences, at least, in the current experimental setting.

Conclusion

Gradient-modulated PETRA showed significantly less off-resonance blurring compared to the conventional PETRA technique under the same excitation bandwidth condition. Gradient modulation can improve the PETRA image quality without any special hardware modification of clinical scanners.

Acknowledgements

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References

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