Magnetization Prepared ZTE to address Multiple Diagnostic Contrasts

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Target audience MR methodologist, neuro-radiologists and musculoskeletal

Introduction

Conventional clinical MRI is blind to fast T_2 relaxing species due to the finite echo times used. Ultra-short (UTE) and/or Zero echo time (ZTE) approaches (1,2) can overcome this drawback offering clinical potential, visualizing highly ordered or mineralized tissues, fibrosis, myelin architecture, pulmonary tissue, teeth and much more. Those sequences can easily be designed to perform 3D sampling with isotropic spatial resolution simplifying work flow. Compared with UTE, ZTE allows performing MRI almost silently which is anticipated to significantly improve patient comfort and acceptance. The availability of a silent imaging module could also be beneficial for other clinical applications far beyond the mapping of fast T_2 relaxing species. However, all short TE approaches have poor image contrast, because all species contribute to the detected MR signal and there is actually no time for most of the contrast mechanisms to substantially evolve. Furthermore, in ZTE often the flip angle is limited due to maximum B_1^+ constraints which can make conventional T_1 contrast difficult to be achieved. Thus, contrast manipulation using magnetization preparation (MP) is an appropriate approach for ZTE to address contrast issues (3,4). In this study, three different magnetization-prepared contrast manipulation schemes (fat suppressed, T_1-, T_2-weighted) have been applied to ZTE, UTE and conventional Cartesian sampling to compare contrast behavior.

Methods

The three 3D sequence candidates (ZTE, UTE, Cartesian) have been integrated into magnetization-prepared gradient echo imaging for comparison, using chemical shift selective pre-saturation (SPIR) for fat suppression, adiabatic inversion-recovery (IR) for T_1-weighting and a T_2-prep preparation for T_2-weighting. A proton density scan (PD), without MP was added. In this study, SPIR was applied to all MP-MRI scans before sequence train read-out. In-vivo experiments were performed on 6 healthy volunteers, written consent obtained, using a clinical 3T MRI system (Philips Ingenia) equipped with a 15-element head coil employing identical FOV $(250mm)^3$, spatial resolution $(1.4mm)^3$ and low tip angle (3°) for comparison. ZTE imaging were performed with a short block excitation RF pulse (12.8µs duration) in presence of a "constant" read gradient that changed in direction from FID to FID at a TR of 2.3ms resulting in a total scanning time of roughly 2 minutes for a native ZTE at 66% angular sampling. Due to the finite switching time from transmit to receive on this clinical system a TE of 60µs was realized and extra data sampling was used to fill the missing samples at k-space center (5). UTE sampling was performed at the same TE in two different flavors using the same excitation RF pulse and tip angle but different read-out bandwidth, one comparable with the ZTE and one with the highest bandwidth resulting in slightly shorter TR (TR ~2.0ms). 3D Cartesian gradient echo imaging was performed at the same spatial resolution (TE/TR: 1.2/3.8ms, similar readout bandwidth like ZTE and flip angle) and linear profile order using comparable scan segmentation (T_{shot} length of the MP-train, $T_{acq.train}$ actual train length for sampling) to maintain steady state properties. Additionally SENSE was applied to achieve comparable total scanning times to the 3D radial scans.

Results and Discussion

Figure 1 shows selected transversal reformats for all the different MP-prepared scans. The image contrast is comparable for all sequences. The contrast for ZTE and UTE is almost identical as expected. Minor differences are visible because of lacking RF-pulse bandwidth bias correction in ZTE. Due to the little higher TE, the Cartesian already showed a slightly changed contrast compared with the ZTE / UTE scans. T_2- and T_1-weighting are of excellent quality and comparable in all scans. Although all MP scans were performed with fat pre-saturation, which was not optimized timing-wise, fat suppression appears to be best in the Cartesian. This could be a misperception due to the lack of short T_2 signal (from the cerebral membranes, etc.) picked up in ZTE and UTE. On the other hand, the Cartesian sequence has a better defined contrast point than the radial sequences which always update the center of k-space (6). An interesting finding of this study is summarized in Fig.2. Fat suppression has significant impact on contrast, because magnetization transfer effects cannot be neglected; meaning RF pre-saturation-based fat suppression does not only suppress fat! Figure 3 shows sagittal reformats of the volumetric multi-contrast ZTE scan from one volunteer supporting very good image quality at isotropic resolution. Although carrying almost the same MR information the ZTE was running on acoustic whisper level while the UTE sequence is seriously loud.

Conclusion

Using appropriate magnetization preparation, ZTE shows very similar contrasts as UTE. Apart from the short T_2 contributions and some radial related issues, contrast is also comparable with Cartesian scanning. MP-ZTE shows a very high flexibility, almost silent operation, isotropic 3D spatial resolution, representing and interesting alternative for conventional MRI, with the advantage of visualizing short T_2 components.

References

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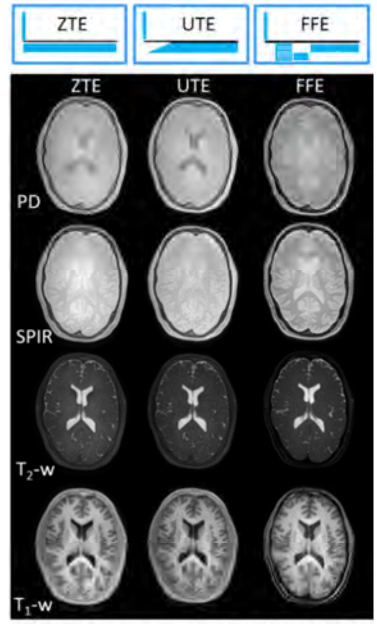

Fig.1. Image contrast comparison (ZTE, UTE, FFE). Top row: PD, SPIR row: with segmentation: T_{shot} / $T_{acq.train}$ 85(±5)/67(±7)ms, T_2-w row: 212(±20)/135(±10)ms, T_1-w row: 638(±15)/265(±20)ms.

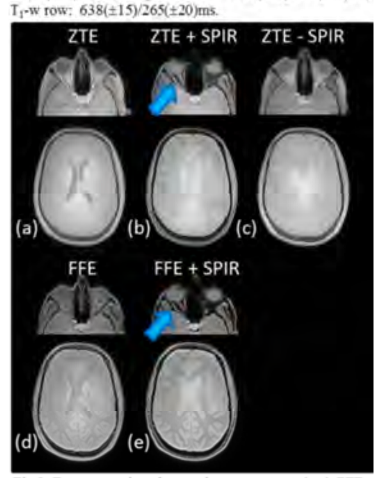

Fig.2. Fat suppression changes image contrast. (a-c) ZTE data (a) without, (b) with (c) with SPIR RF pulse but opposite saturation frequency ($-\omega_{off}$), respectively. Top slice inlet from the eye level to judge fat suppression. (b,c) show similar contrast in not fatty tissue (MTC), (d,e) confirm that this is not a short T_2-effect.

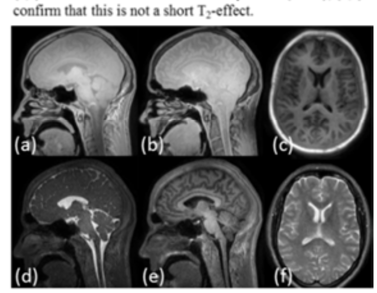

Fig.3. Selected ZTE examples. (a,b,d,e) Sagittal reformats of multi-contrast ZTE 3D data (a) PD, (b) fat- suppressed ZTE, (d) T_2-weigthed ZTE, (e) ZTE, additional no fat suppressed axial (c) T_1- and (f) T_2-weighted ZTEs using different preparation parameter settings.