Fast single sequence comprehensive 4D pediatric knee MRI with T2 Shuffling

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Synopsis

Clinical application of volumetric joint MR imaging has been hampered by blurring due to T2 decay. A redesigned volumetric fast spin-echo acquisition technique termed T2 shuffling corrects for T2 decay and yields effectively a four-dimensional reconstruction with varying degrees of T2 weighting. Our work assesses the clinical application of T2 shuffling for pediatric knee MRI. Our results show that T2 shuffling has the potential to suffice as a single sequence MR examination. This is especially relevant for pediatric imaging where streamlined protocols greatly improve clinical operations and patient experience.

Purpose

Volumetric variants of fast spin-echo[1] (FSE) have been described to simplify and accelerate joint MRI, based on reformattability into multiple planes[2-4]. However in clinical practice, standard 2D imaging still predominates due largely to blurring, likely from long echo trains required for volumetric imaging[1]. This work evaluates a redesigned volumetric FSE acquisition[5] which resamples k-space positions at multiple echo times to estimate and correct for T2 decay. This acquisition supports effectively a four-dimensional reconstruction, producing images corresponding to different echo times, and thus with contrast varying from proton density to heavily T2 weighting, with scan time of roughly 7 minutes. We hypothesize that this technique, termed T2 shuffling (T2Sh), suffices as a single-sequence pediatric knee protocol.

Methods

T2Sh technique is based on randomizing the echo train view-ordering, trading off image blur with noise-like artifacts (Fig. 1). The artifacts are suppressed in a compressed sensing-based reconstruction that exploits spatio-temporal correlations in the signal relaxation curves. With IRB approval, 30 consecutive children were scanned with a routine clinical knee MRI protocol and T2Sh at 3T (GE MR750). T2Sh scan parameters were TR/TE=1400/6 ms, ETL=80, 8 channel coil array, 7.6 apparent acceleration factor (based on degrees-of-freedom), 0.6 mm isotropic resolution, and sagittal source images. Two radiologists blinded to clinical history independently interpreted each case on a multiplanar reformat capable workstation (Osirix), forming a structured diagnostic report based solely on the T2Sh images, reconstructed at 3 effective echo times (proton density, intermediate, and T2-weighted). Then, T2Sh image quality of 9 anatomic structures (Table 1) were graded on a scale of 1 non-diagnostic (cannot see structure), 2 limited (can see structure but not evaluate for pathology), 3 diagnostic (can evaluate structure with some confidence), 4 good (can evaluate structure with high confidence), and 5 outstanding (best quality of delineation). Relative quality of structure delineation of T2Sh and 2D sequences were also compared. Structured reports were compared to the official diagnostic report and judged concordant if all actionable structural derangements were identified, and confidence intervals for the proportion of concordant reports as well as the proportion of each cases with diagnostic delineation of each anatomic structure were determined. A Wilcoxon rank-sum test assessed the null hypothesis that the relative quality of T2Sh structure delineation compared to conventional 2D is unchanged. Intraclass correlation coefficients were calculated to evaluate for inter-observer agreement.

Results

Figure 2 shows representative images. Reader 1 gave concordant interpretations in 77% of the cases with 95% confidence interval (CI) of 62-92% and reader 2 gave concordant interpretations in 87% of the cases with 95% CI of 75-99%. Of the major discrepancies, the most frequent missed finding was joint bodies. Of note, findings were easily perceptible on T2Sh in retrospect, suggesting the value of clinical history when interpreting the cases. Figure 3 summarizes the image quality ratings and comparison between T2Sh and 2D. Delineation of the 9 anatomic structures on T2Sh images was at least diagnostic in all cases for both readers, except in one case where delineation of the MCL, LCL, and retinaculum was limited (95% CI is 90-100% for a diagnostic quality delineation for these three structures). The mean ratings for structure delineation was between 4.5-4.8 for reader 1 and 4.7-4.9 for reader 2. Inter-observer agreement was moderate or strong for all structures except for the PCL, medial meniscus, and cartilage, where there was fair agreement. There was no significant difference in the relative quality of structure delineation between T2Sh and 2D sequences except for the retinaculum (p<0.05), where 2D was preferred for both readers.

Discussion

Image quality with T2Sh is not inferior to conventional 2D sequences and may be clinically viable as a single sequence pediatric knee protocol. Isotropic high resolution images were especially helpful in evaluation of meniscal pathology (Fig. 4), where complex tears can be evaluated in arbitrary planes (Fig. 4). While we did not have 100% concordance between T2Sh interpretations and official diagnostic reports, review was performed without the benefit of clinical history or comparison studies, and discrepancies may be related predominantly to a learning curve in interpreting these images and lack of clinical context rather than limitations in image quality. One current limitation of using T2Sh as the sole sequence is the reconstruction time required, approximately 30 minutes, which does not permit image quality assurance prior to discharging a patient from the imaging suites. A limitation of our study is that readers could not be blinded to the sequence given its volumetric nature.

Conclusion

T2Sh yields high quality, multiplanar reformattable, 4D images with potential for application as a single sequence pediatric knee protocol.

Acknowledgements

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Figures

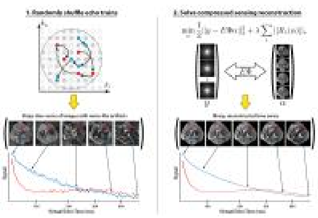

Fig 1. Overview of the T2Sh method. The echo train view ordering is randomly shuffled during the acquisition, leading to reduced image blur at the cost of noise-like artifacts. The artifacts are iteratively suppressed using a compressed-sensing based reconstruction. Full signal dynamics are recovered by constraining the signal evolutions to a small subspace during the reconstruction.

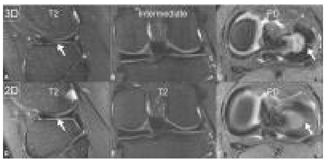

Fig 2. MRI of 16 year old female with knee pain. Top: Zoomed T2Sh images highlighting both multiplanar reformat and multi-contrast capability (A, B, and C). Bottom: Zoomed conventional 2D images in sagittal, coronal, and axial planes (D, E, and F). Note radial tear of the lateral meniscus (arrows) is particularly well seen axial reformat of T2Sh (C).

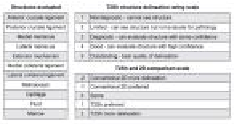

Table 1. Anatomic structures evaluated and rating criteria.

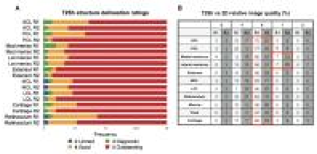

Fig 3. A. Frequency of scores of each anatomic structure with T2Sh. There were no cases with non-diagnostic structure delineation. Image quality was predominantly diagnostic or better. B. Relative image quality scores comparing T2Sh and conventional 2D sequences. T2Sh image quality was rated same or better than 2D in >70% of the cases for all structures other than retinaculum for reader 1 (63%). Evaluation of the menisci had the highest proportion of cases in which T2Sh was preferred.

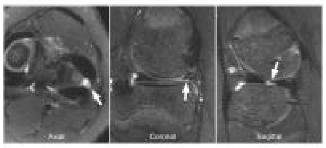

Fig 4. MRI of 15 year old male with knee pain. Zoomed T2Sh images showing complex tear of the lateral meniscus (arrows). Isotropic high resolution images permit detailed multiplanar evaluation of complex pathology.

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