Targeted Rapid MRI Exams and Reconstructions using T_2 Shuffling

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Target Audience: MRI researchers and clinicians interested in clinical integration of advanced sequence and reconstruction methods.

Introduction: Advanced MRI pulse sequence and reconstruction methods based on parallel imaging[1], compressed sensing[2], and pattern recognition[3] have shown great promise at reducing overall exam times while providing high-value diagnostic information in several clinical applications. Nonetheless, their widespread use has been hindered by sequence complexity, inadequate performance across diverse populations and operating conditions, and prohibitively long reconstruction times. Here we aim to address some of these issues to create abbreviated exams that can enable same-day MRI access. We base our protocols on T2 Shuffling (T2Sh)[4], a four-dimensional acquisition that permits volumetric reconstruction of images with variable T2 contrast. We reduce end-to-end reconstruction times to 85 seconds by leveraging high-performance computing without compromising reconstruction quality. We integrate the protocols and reconstructions into a clinical workflow for pediatric knee MRI and adult prostate MRI at our institutions.

Methods: A four-dimensional fast spin-echo (FSE) acquisition that encodes the anatomy in volumetric fashion and permits reconstruction of images with variable T2-contrast was implemented, termed T2Sh[4]. A protocol for fast pediatric knee MRI[5] consisting of a localizer (1 minute), T2Sh (7 minute), and a coronal 2D FSE T1 (3 minute) was fully integrated into a clinical workflow. Additionally, an abbreviated adult prostate protocol consisting of a localizer (1 minute), T2Sh (6.5 minute), and an axial 2D diffusion (7 minute) is in development and evaluation. Table 1 lists the main T2Sh scan parameters for the two targeted exam applications. In addition to the abbreviated exams, T2Sh scans have been added to the conventional pediatric knee[6] and adult prostate MRI protocols to aid in clinical evaluation. The iterative T2Sh reconstruction was redesigned to scale across multiple multi-core CPU machines, optimally tuned for an eight-node cluster, and deployed at Lucille Packard Children's Hospital. Each node consisted of a dual socket Xeon E5-2699 v4 (44 cores), 128 GB of RAM, and a 100 Gb/s network switch. The end-to-end reconstruction was implemented using the GE Healthcare Orchestra toolkit and the open-source BART library[7,8].

Results: In a previous IRB-approved study[5], ten pediatric subjects had targeted knee MRI orders over a three-month period, with eight exams completed on the same day as requested. Over a one-year period, 44 patients have completed targeted knee MRIs. The targeted approach reduced typical exam times to 15 minutes from the conventional pediatric knee protocol's 30 minutes while providing isotropic volumetric images with less technologist planning. Figure 1 shows T2Sh images from a representative knee MRI case. Clinical evaluation of T2Sh for prostate lesion detection is ongoing; over a two-month period, 90 subjects have undergone a conventional prostate MRI protocol followed by T2Sh with IRB approval and informed consent, with 118 total lesions detected. Among them, 28 were transition-zone lesions. Figure 2 shows T2Sh images from a representative prostate MRI case. Using the optimized compute cluster, the end-to-end (raw data to DICOM images) reconstruction times for T2Sh were reduced to 85 seconds for the knee scans and 40 seconds for the prostate scans.

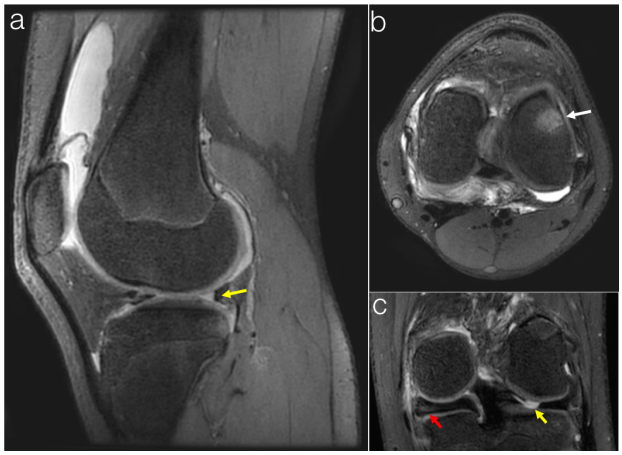

Fig 1. T2Sh knee MRI of pediatric patient showing discoid meniscus (red arrow), bone marrow edema (white arrow), and torn meniscus (yellow arrow) at effective echo times of (a) 21 ms (sagittal), (b) 50 ms (axial), and (c) 90 ms (coronal).

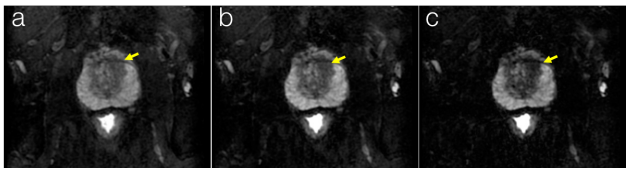

Fig 2. Axial T2Sh prostate MRI of adult patient showing PIRADS 5 Gleason 8 transition zone lesion (yellow arrow) at effective echo times of (a) 20 ms, (b) 100 ms, and (c) 200 ms.

Discussion and Conclusion: Shorter overall exam times have enabled same-day access for pediatric knee MRI[5], and a similar trend may also hold in the future for adult prostate MRI. The short T2Sh reconstruction times enable the technologist to check image quality before the patient leaves the table and perform volumetric reformats following a typical clinical workflow. We believe a similar approach can be used to optimize and reduce other iterative reconstruction methods, thus eliminating the offline reconstruction bottleneck. Ongoing clinical studies show promise at replicating the abbreviated exam approach in a broader range of applications, with a clear path toward full clinical integration.

References: **[1]** Pruessman, MRM 42(5):952-62, 1999. **[2]** Lustig, MRM 58(6):1182-95, 2007. **[3]** Ma, Nature 495:187-92, 2013. **[4]** Tamir, MRM 77(1):180-95, 2016. **[5]** Tamir, ISMRM 0231, 2017. **[6]** Bao, JMRI 45(6):1700-11, 2017. **[7]** Uecker, BART: 10.5281/zenodo.1066014. **[8]** Tamir, Sedona Workshop, 2017.

Table 1. T2Sh scan parameters for pediatric knee and adult prostate MRI exams. The reconstruction provides images at multiple T2-weighted contrasts.

Parameter	T2Sh FS Knee	T2Sh FS Prostate
Excitation Mode	Non-selective	Outer Volume Suppression
TR (ms)	1200	2000
Fat Sat Efficiency	90 %	90 %
Echo train length	83	83
Echo spacing (ms)	5.93	6.06
Partial Fourier	65 %	-

Bandwidth (kHz)	62.5	41.67
Field of view (cm^2)	16 x 14.4	22 x 13.2
Slice thickness (mm)	0.6	1.6
Matrix size	288 x 288	256 x 256
Number of slices	240	104
Scan time (min:sec)	7:04	6:27
Recon time (sec)	100	46