FEMALE PELVIC FLOOR DIFFUSION TENSOR IMAGING ENABLED BY MULTI-SHOT EPI AND ADMM UNROLLED RECONSTRUCTION

Zhengguo Tan (zgtan@umich.edu)[1], John DeLancey[2], Yun Jiang[1], Vikas Gulani[1]

[1]Department of Radiology, University of Michigan, Ann Arbor, MI, USA; [2]Department of Obstetrics & Gynecology, University of Michigan, Ann Arbor, MI, USA

1. INTRODUCTION

Figure 1 depicts the anatomy of the pelvic floor. Its largest component is **levator ani**, which are composed of three paired muscles - puborectalis, pubococcygeus, and iliococcygeus. Levator ani provides the main muscular support of the female pelvic floor, such as holding pelvic organs and fostering childbirth (relax and stretch to allow fetal descent). Injuries to these muscles can lead to pelvic floor weakness and even prolapse and incontinence [1].

Although diffusion MRI is a well-established technique for mapping white matter tracts in the brain, its clinical utility in the pelvic floor remains largely unexplored due to the region's complex anatomy and the fine-scale structure of its muscles. Previous studies on perineum diffusion tensor imaging (DTI) rendered only limited resolution [2,3]. Therefore, **we aim to achieve fast high-resolution female pelvic floor DTI to understand the mechanism behind pelvic floor injuries**. This work leveraged multi-shot EPI acquisition and self-supervised alternating direction method of multipliers (ADMM) unrolling for high-resolution pelvic floor DTI at 3 T.
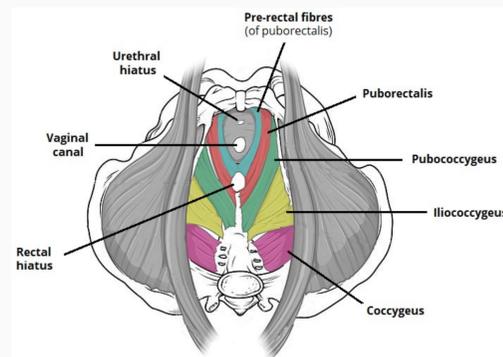

Figure 1: Superior (bird's eye) view of the pelvic floor.

2. METHODS

Data Acquisition

Table 1 lists two protocols: #1. clinical DWI based on single-shot EPI; #2. proposed high-resolution DWI with accelerated 2-shot interleaved EPI and shifted encoding among diffusion encoding directions [4].

Scans at 3 T (Vida, Siemens Healthineers, Erlangen, Germany) with body matrix coils were conducted on seven female subjects with written consent in compliance with IRB. This abstract presented the results from a 21-year-old nulliparous female subject.

Image Reconstruction

Acquired raw *k*-space data were processed in **twixtools**. Coil sensitivities were computed by ESPIRiT [5] with the **SigPy** EspiritCalib app [6]. The data from Protocol #1 was reconstructed by parallel imaging (PI) with the SigPy SenseRecon app, whereas Procotol #2 was reconstructed by multiplexed sensitivity-encoding (MUSE) [7] (github.com/ZhengguoTan/sigpy) and **self-supervised ADMM unrolling** [8] (github.com/ZhengguoTan/DeepDWI), respectively. All reconstructions were performed on A40 GPU with 40 GB memory (NVIDIA, Santa Clara, CA, USA) from the Great Lakes HPC Cluster. Diffusion-weighted images reconstructed by MUSE were denoised by the local-PCA algorithm [9] as implemented in **MRtrix3**. Reconstructed diffusion-weighted images were then fitted with the diffusion tensor model in **DiPy**.

Considering that both this poster and another poster from us (Poster #25. 0.55 T prostate diffusion-weighted imaging using multi-shot EPI and self-supervised learning reconstruction) employed the recently developed self-supervised ADMM unrolling [8], and that both posters are organized in the same presentation time slot, we encourage audiences refer to Poster #25 as well as our MRM paper [8] for methodological details.

Table 1: Acquisition protocols.

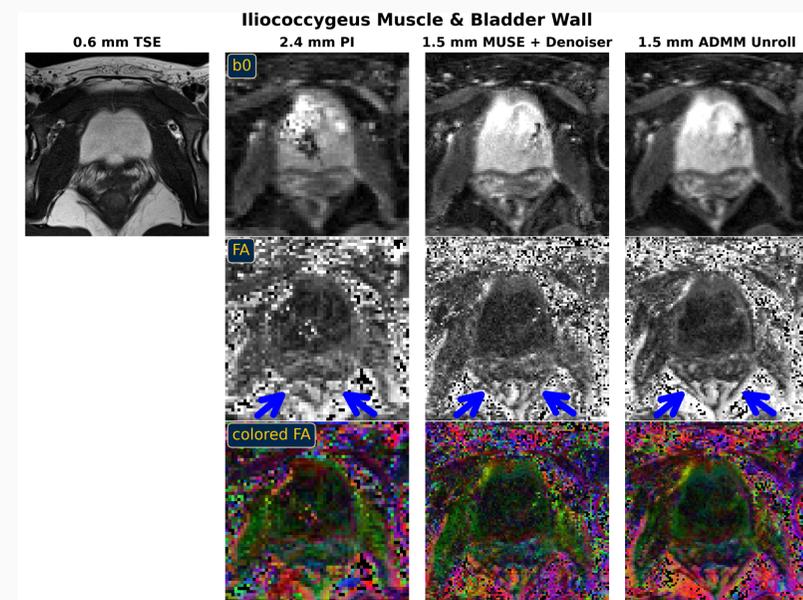| Protocol	#1 (2.4 mm)	#2 (1.6 mm)
b-value (s/mm2)	400	
diffusion directions	64	
FOV (mm)	240	
slice thickness (mm)	3	
slices	20	
reference scan	low-resolution spoiled GRE	
magnetization prep.	fat sat	
base resolution	100	160
shots	1	2
acceleration	2	2
partial Fourier	5/8	
TE/TR (ms)	43/2200	50/2300
acquisition (min)	2:35	5:06

3. RESULTS

Figure 2: Highlights of the reconstructed iliococcygeus muscle (blue arrows) in FA maps and the bladder wall (yellow arrows) in colored FA maps. Iliococcygeus is a thin muscle, inserting onto the coccyx, perineal body and anococcygeal ligament. Protocol #1 does not have sufficient resolution to resolve the iliococcygeus muscle. MUSE with the local-PCA denoiser suffers from blurring artifacts. Only the proposed ADMM unrolling illustrates sharp delineation of the iliococcygeus muscle. On the other hand, we observe that the FA maps (and diffusion-weighted images, not shown here) show good contrast of the bladder wall.
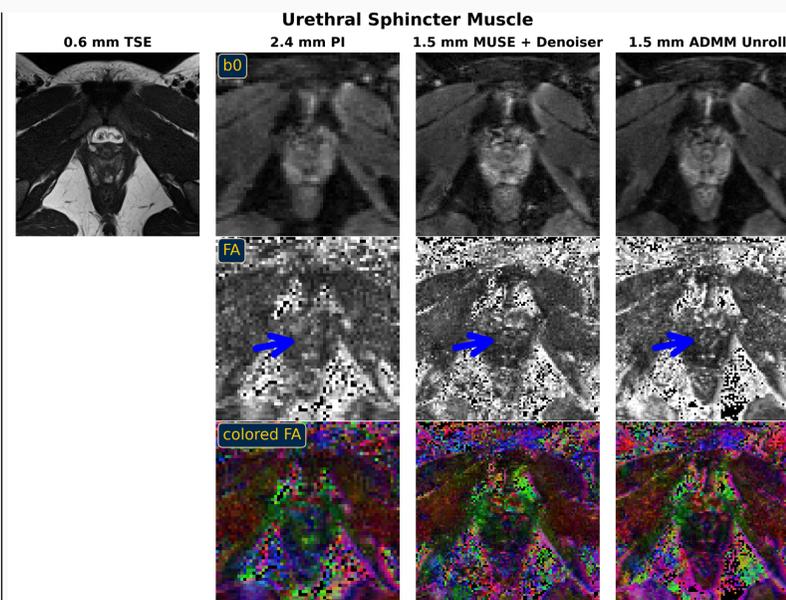

Figure 3: Highlights of the urethral sphincter muscle (blue arrows). The urethral sphincter is a set of ring-like thin muscles (about 6 mm in diamter) that controls urine flow from the bladder. Our high-resolution protocol clearly and sharply delineates the ring structure of the urethral sphincter, whereas Procotol #1 with lower resolution is insufficient for the visualization of urethra from the displayed maps.
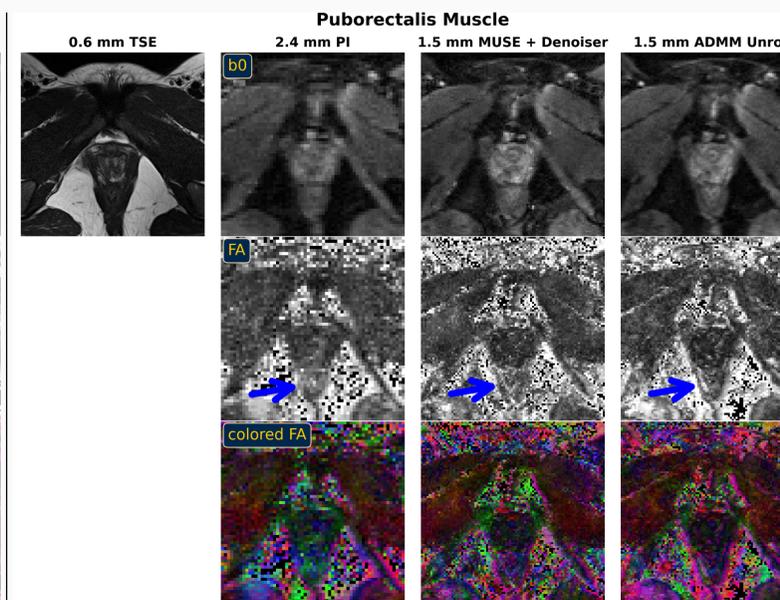

Figure 4: Highlights of the puborectalis muscle, which is clearly depicted by the proposed ADMM unrolling reconstruction. Green colors in the color FA map of the ADMM unrolling reconstruction indicate that the puborectalis muscular fiber goes from anterior to posterior. Puborectalis muscle forms a U-shape sling wrapping around the posterior side of the anorectal junction, the most important muscle for maintaining fecal continence.

4. REFERENCES

[1] DeLancey J, et al. Pelvic floor injury during vaginal birth is life-altering and preventable: what can we do about it? *Am J Obstet Gynecol* (2024). 10.1016/j.ajog.2023.11.1253

[2] Zijta FM, et al. Evaluation of the female pelvic floor in pelvic organ prolapse using 3.0-Tesla diffusion tensor imaging and fibre tractography. *Eur Radiol* (2012). 10.1007/s00330-012-2548-5

[3] Zifan A, et al. Connectivity of the Superficial Muscles of the Human Perineum: A Diffusion Tensor Imaging-Based Global Tractography Study. *Sci Rep* (2018). 10.1038/s41598-018-36099-4

[4] **Tan Z**, et al. JETS-NAViEPI. *Imaging Neuroscience* (2024). 10.1162/imag_a_00085

[5] Uecker M, et al. ESPIRiT. *Magn Reson Med* (2014). 10.1002/mrm.24751.

[6] Ong F, Lustig M. SigPy: A Python Package for High Performance Iterative Reconstruction. *ISMRM* (2019).

[7] Chen NK, et al. MUSE. *NeuroImage* (2013). 10.1016/j.neuroimage.2013.01.038

[8] **Tan Z**, et al. High-resolution diffusion-weighted imaging with self-gated self-supervised unrolled reconstruction. *Magn Reson Med* (2026). 10.1002/mrm.70250

[9] Cordero-Grande L, et al. Complex diffusion-weighted image estimation via matrix recovery under general noise models. *NeuroImage* (2019). 10.1016/j.neuroimage.2019.06.039