

# Female Pelvic Floor Diffusion Tensor Imaging Enabled by Multi-Shot EPI and ADMM Unrolled Reconstruction

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I have the following financial interest or relationship to disclose with regard to the subject matter of this presentation:

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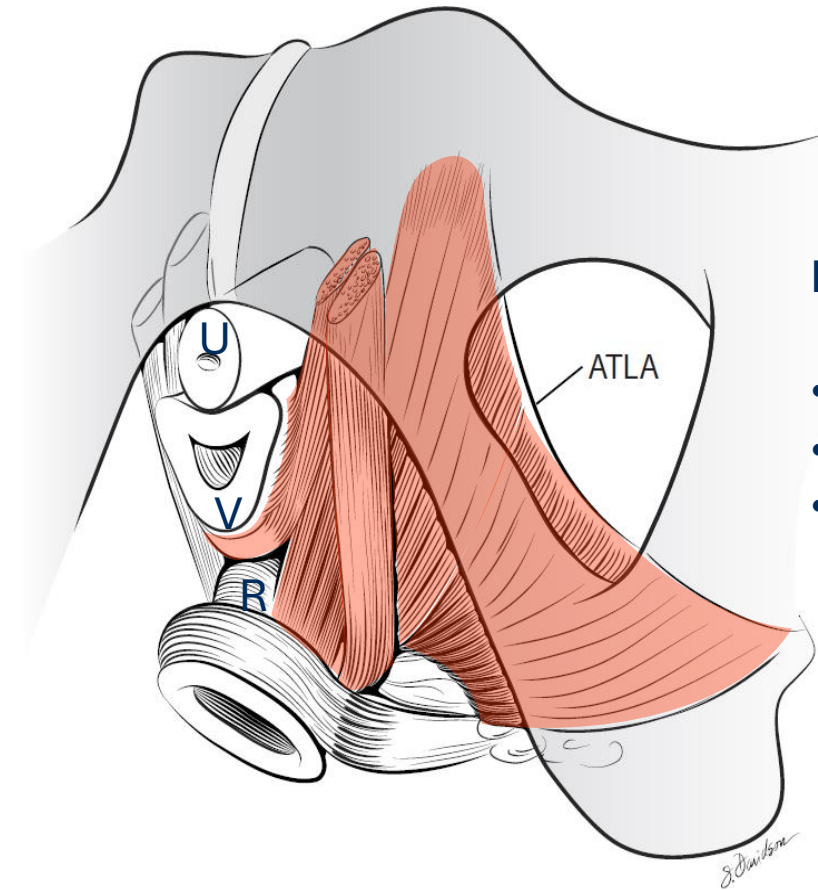
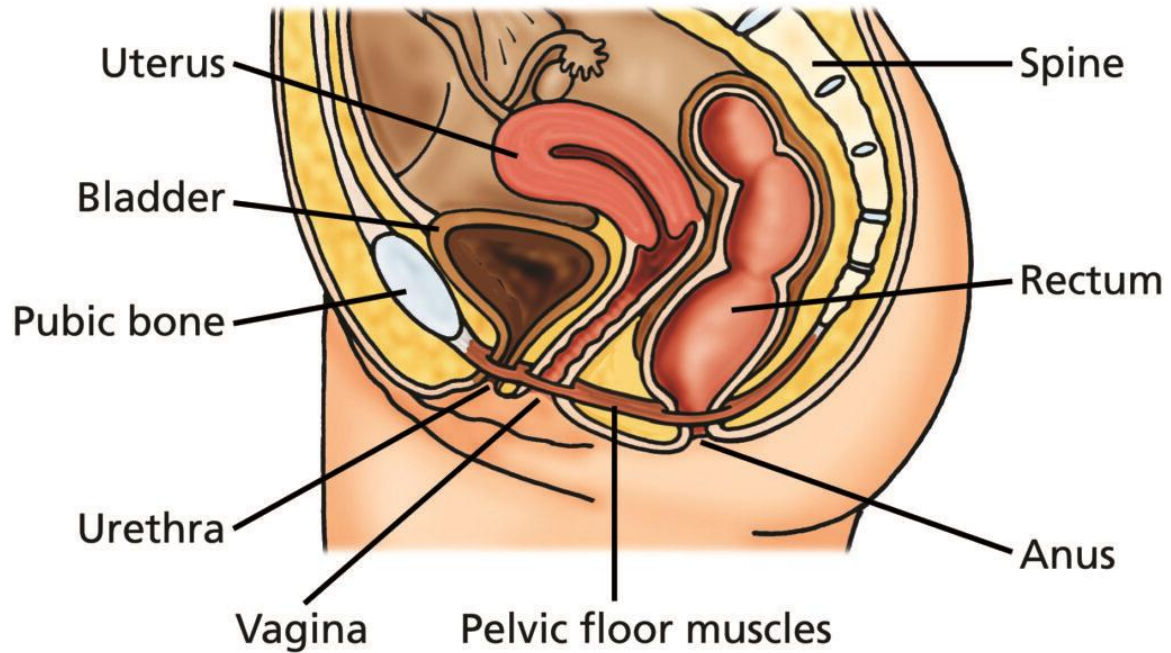
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GE Healthcare: Consulting (contrast agents)

# INTRODUCTION / MOTIVATION

# Female Pelvic Floor



## Levator Ani:

- Pubococcygeus
- Puborectalis
- Iliococcygeus

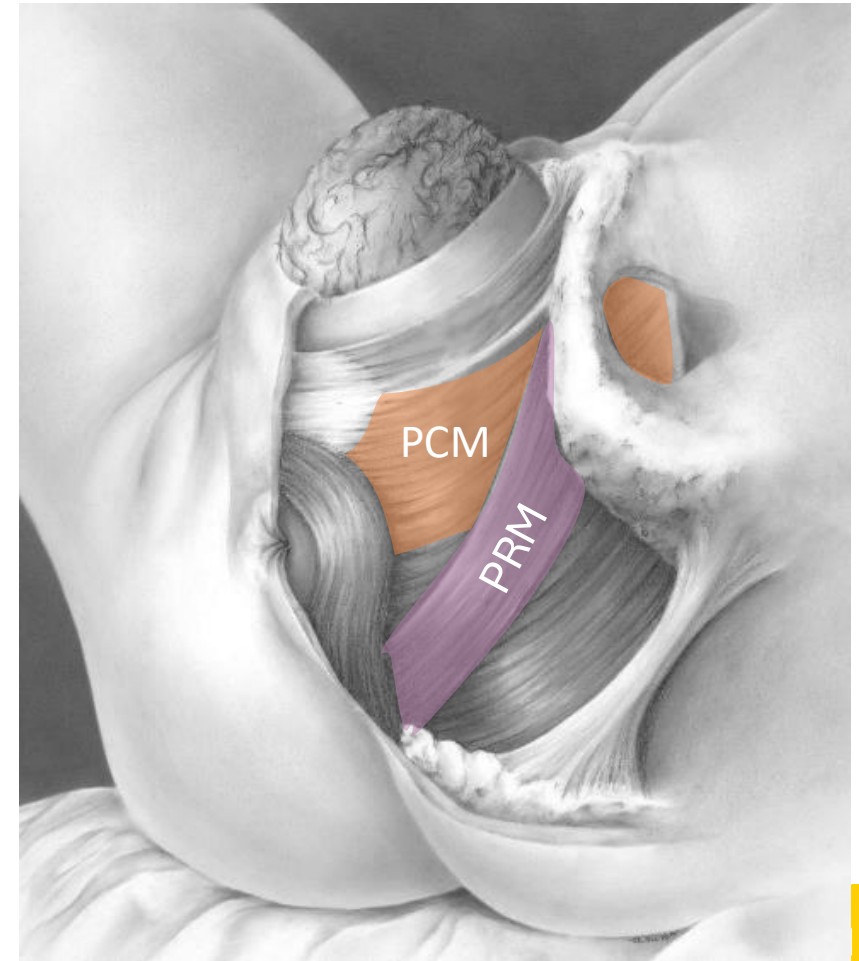
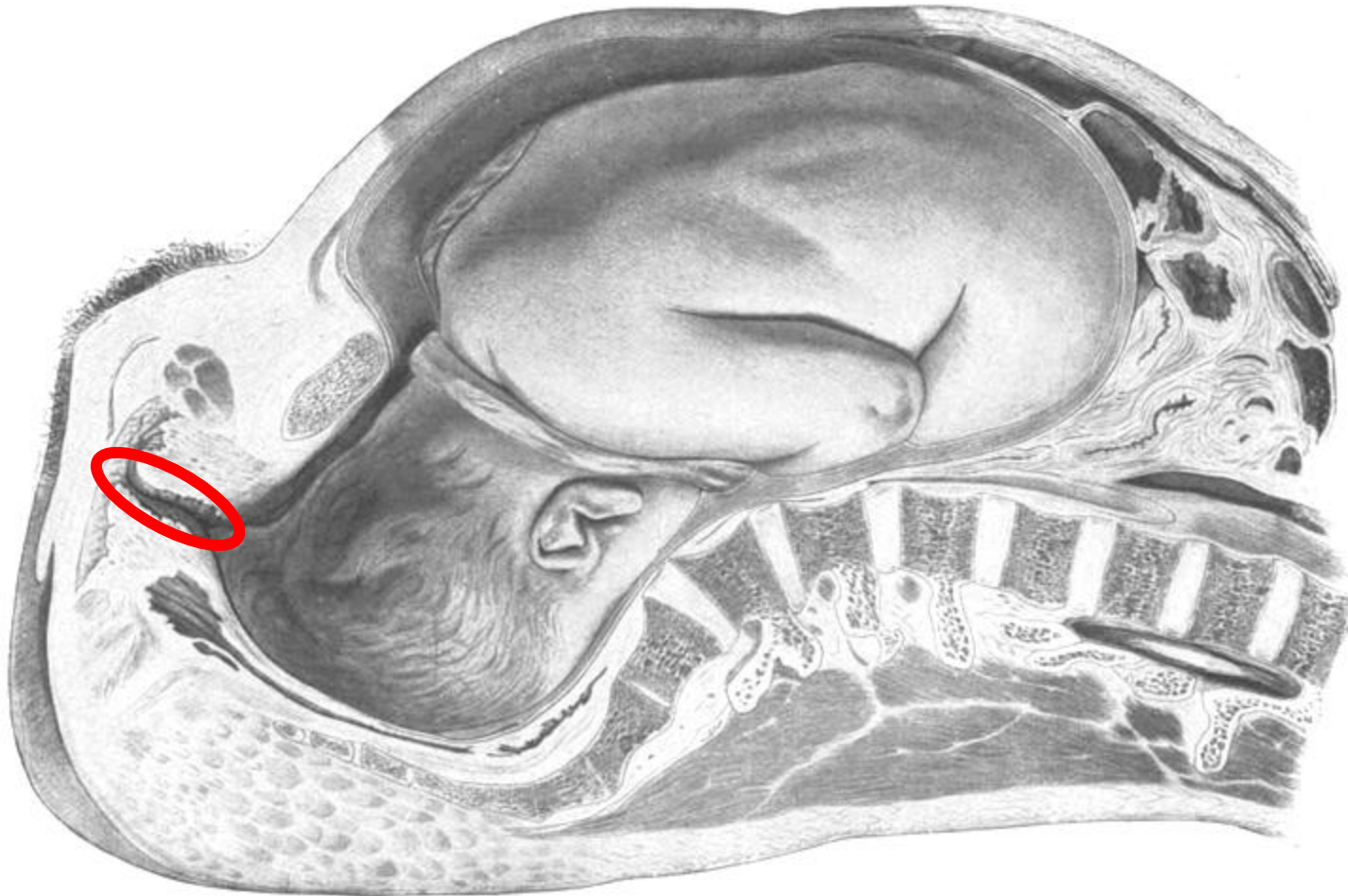
Source: The Leeds Teaching Hospitals NHS Trust

**Pelvic floor muscles support bladder, uterus, and rectum**

# Vaginal Birth Often Causes Pelvic Floor Injuries <sup>1</sup>

During birth, the levator muscle and birth canal tissues must stretch to more >3x their original length.

More than 300,000 women undergo pelvic floor surgeries every year in the US alone

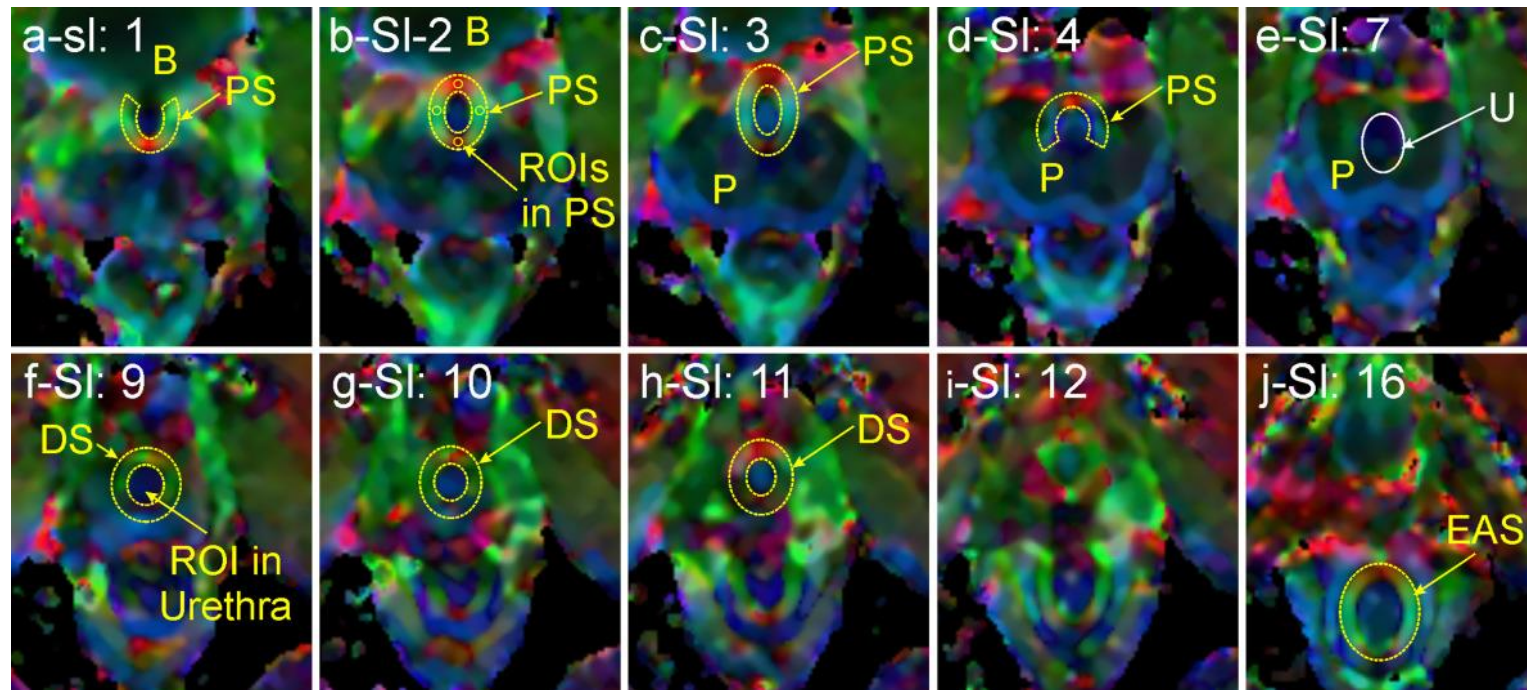


# Understanding Female Pelvic Floor Injuries

Pelvic floor muscular microstructure, its integrity and mechanisms are under studied

DTI has been explored for studying the pelvic floor  
but improvement imperative given small structures and long scan times

~2 mm resolution @ 26 minutes scan time



Zijta FM, et al. Feasibility of DTI with fibre tractography of the normal female pelvic floor. *Eur Radiol* (2011).

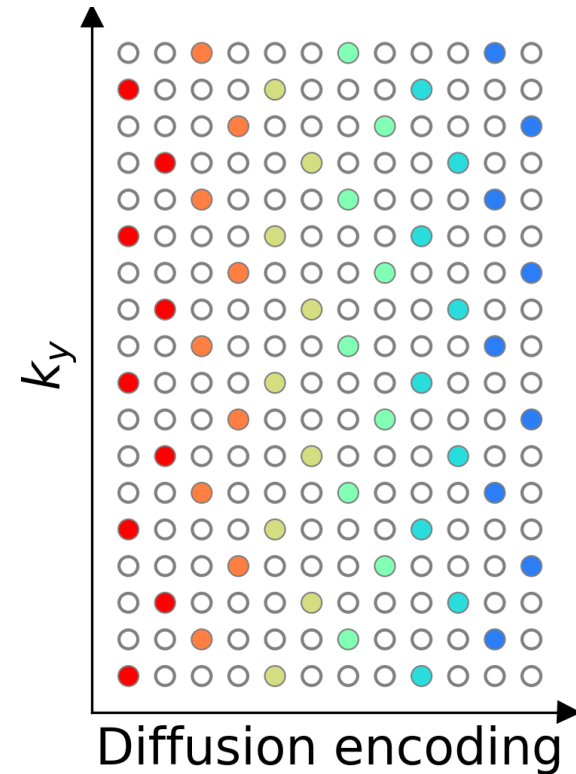
Zifan A, et al. Connectivity of the superficial muscles of the human perineum: A DTI-based global tractography study. *Nature Sci Rep* (2018).

Sinha S, et al. Exploration of male urethral sphincter complex using DTI-based fiber-tracking. *J Magn Reson Imaging* (2018).

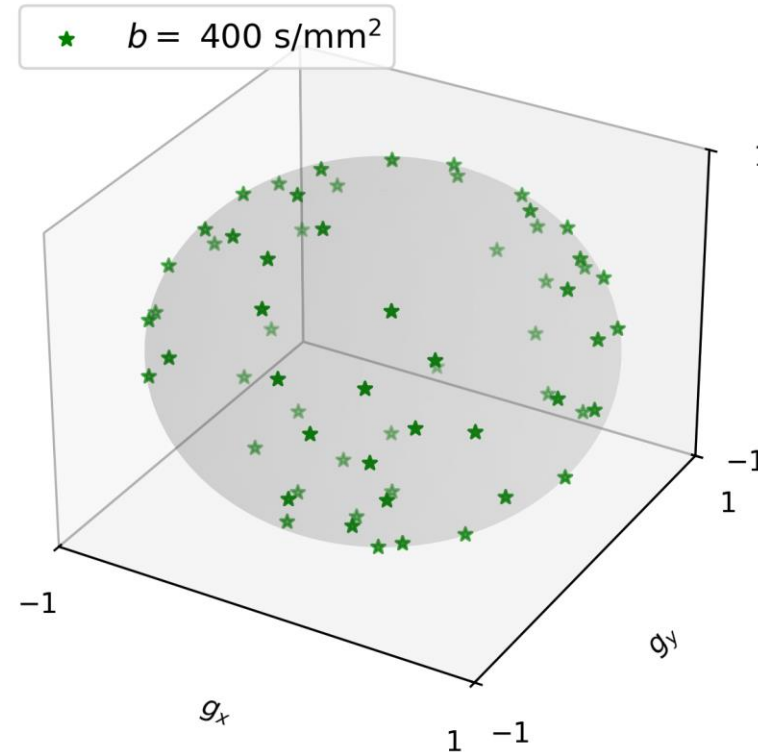
# METHODS

# Accelerated 2-Shot EPI Acquisition

ky-shift encoding



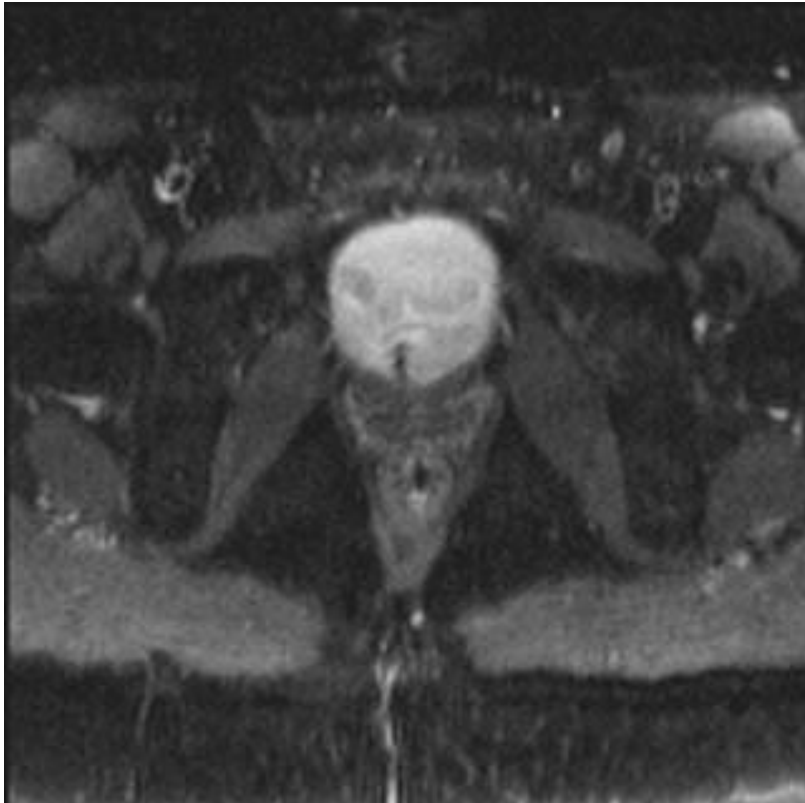
Single-shell q-space sampling



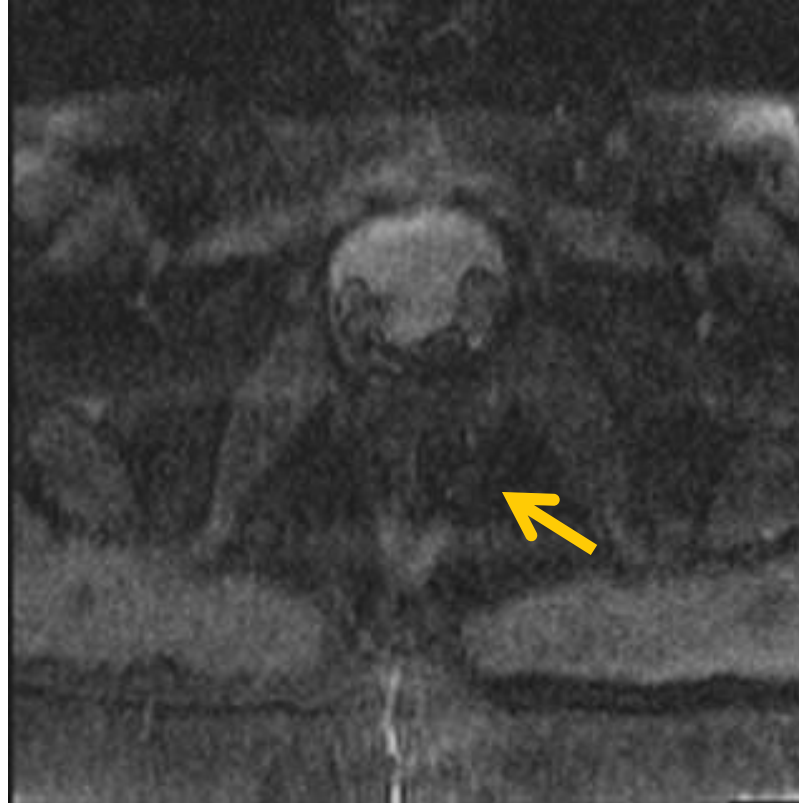
Magnet (T)	2.89
Gradient	60/200
Voxel Size (mm <sup>3</sup> )	1.5 x 1.5 x 3.0
Slices	30
Diffusion Directions	64
TE/TR (ms)	49/3600
Scan Time (min)	7:58

# Phase Inconsistency Between Shots

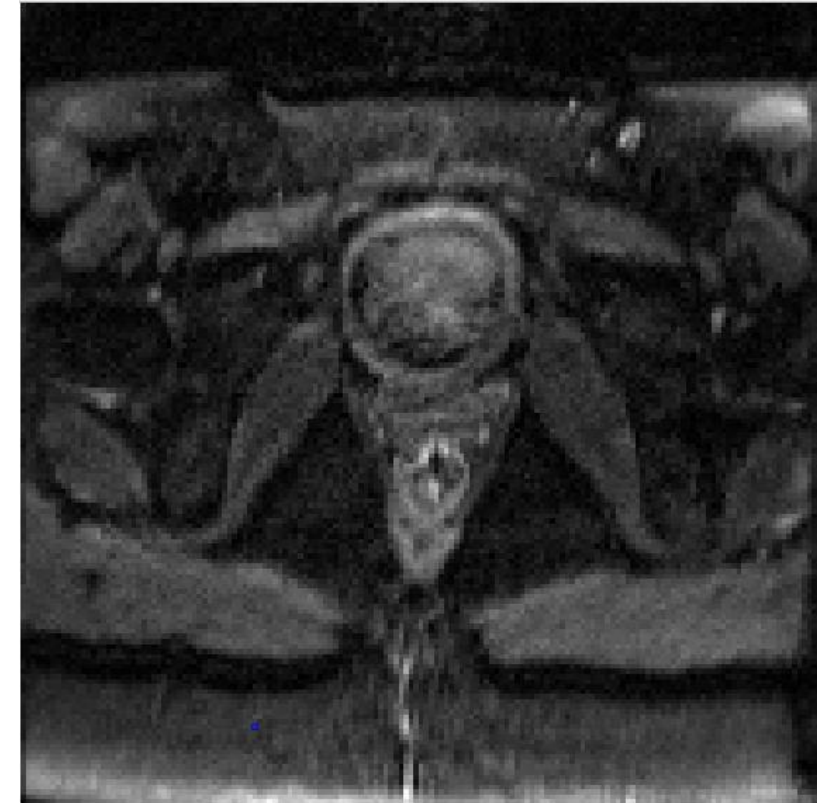
Non-diffusion-weighted image (b0)



2-shot DWI (Online)



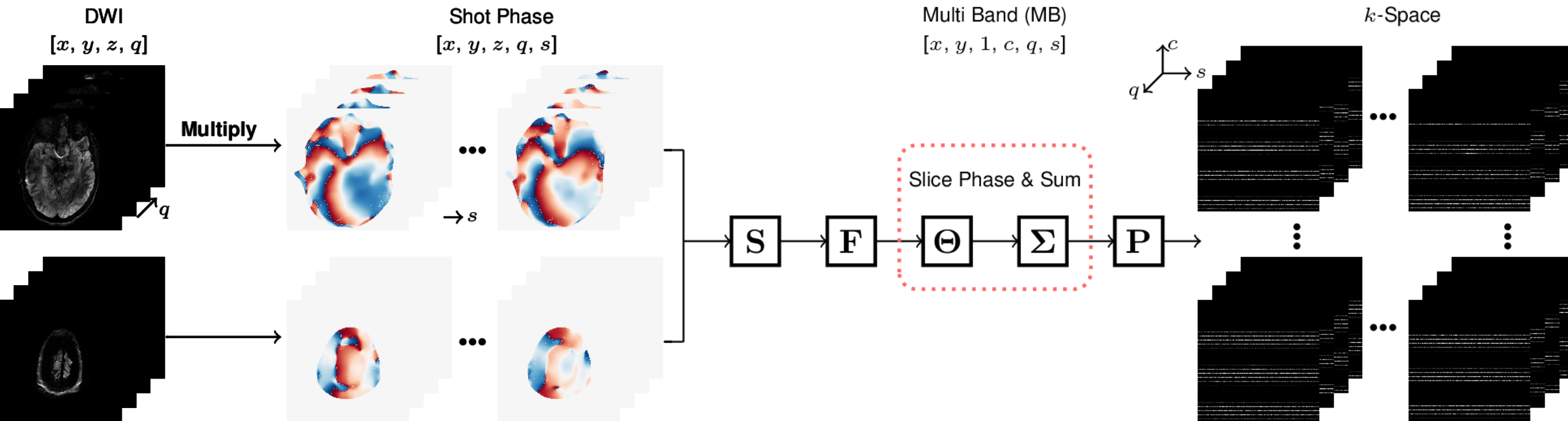
DeepDWI



Uecker M, Karaus A, Frahm J. Inverse reconstruction method for segmented multishot diffusion-weighted MRI with multiple coils. *Magn Reson Med* (2009).  
Chen NK, et al. A robust multi-shot scan strategy for high-resolution DW MRI enabled by multiplexed sensitivity-encoding (MUSE). *NeuroImage* (2013).  
Tan Z, et al. High-resolution diffusion-weighted imaging with self-gated self-supervised unrolled reconstruction. *Magn Reson Med* (2026).

# Joint k-q-Slice Reconstruction With Self Gating

- Joint k-q-slice forward model and reconstruction



$$\operatorname{argmin}_{\mathbf{x}} \|\mathbf{Ax} - \mathbf{y}\|_2^2 + \lambda \mathcal{D}_{\omega}(\mathbf{x})$$

# RESULTS

# No multiband (slicewise reconstruction)

$1.5 \times 1.5 \times 3 \text{ mm}^3$

# Sanity Check: Obturator Internus Muscle

Postmortem

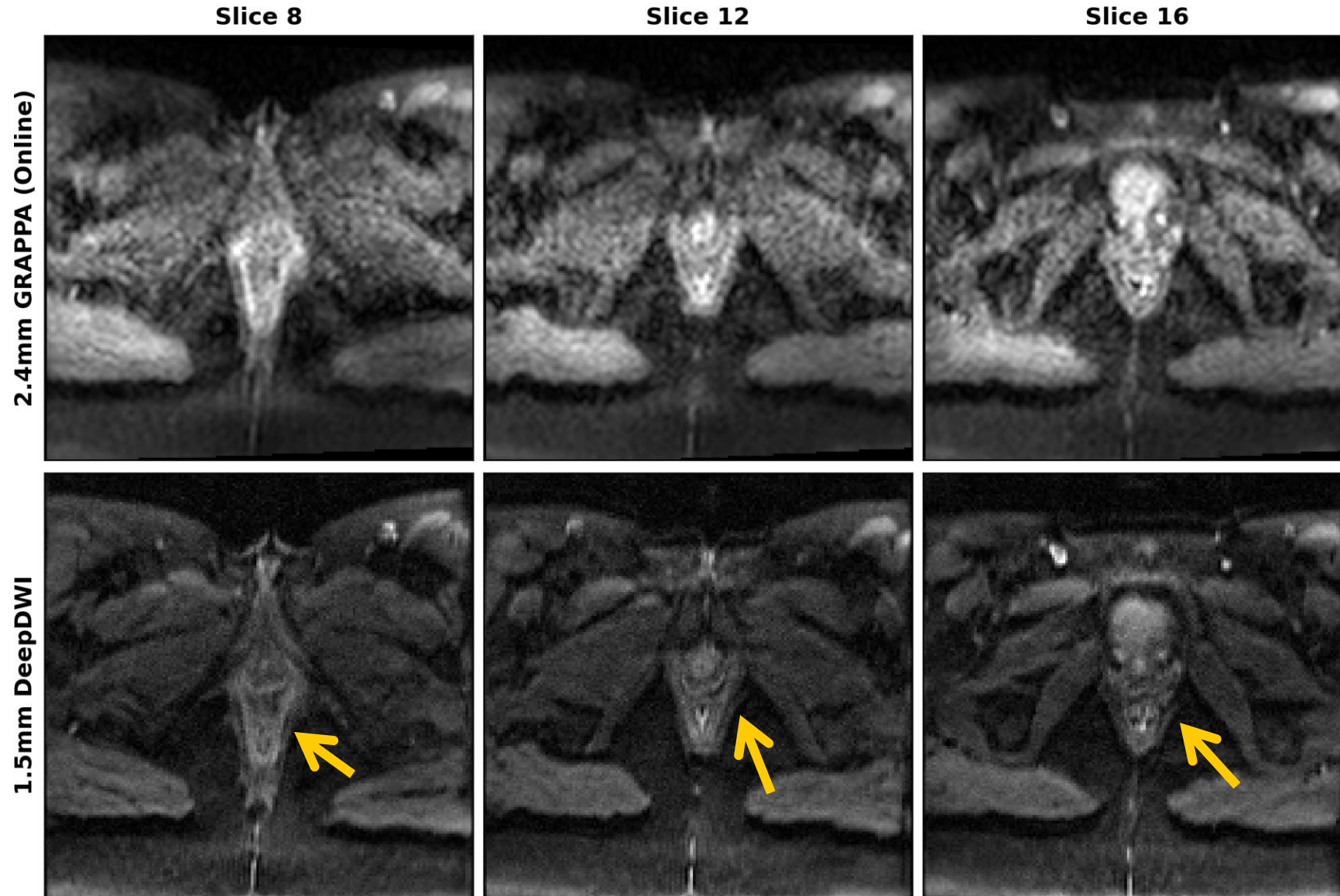


Courtesy: Prof. Dr. Helga Fritsch  
@ Medizinische Universität Innsbruck

Volunteer

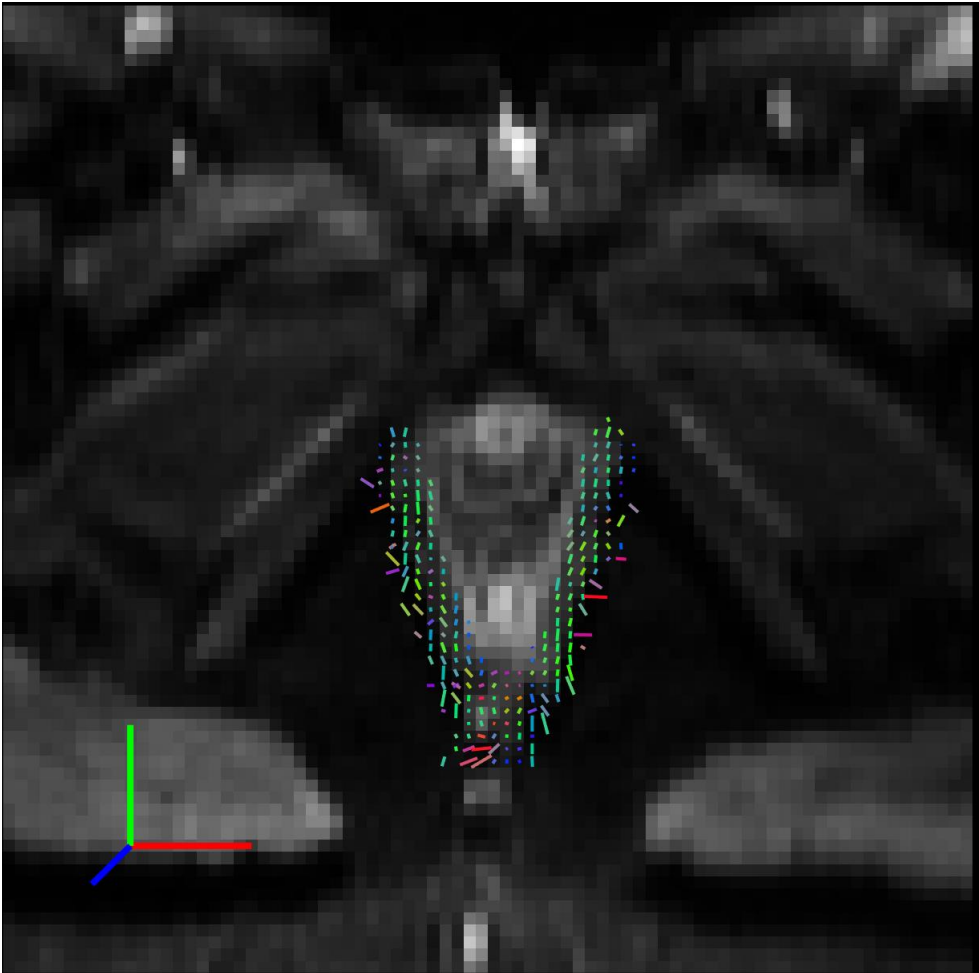


# Delineation of fine structures

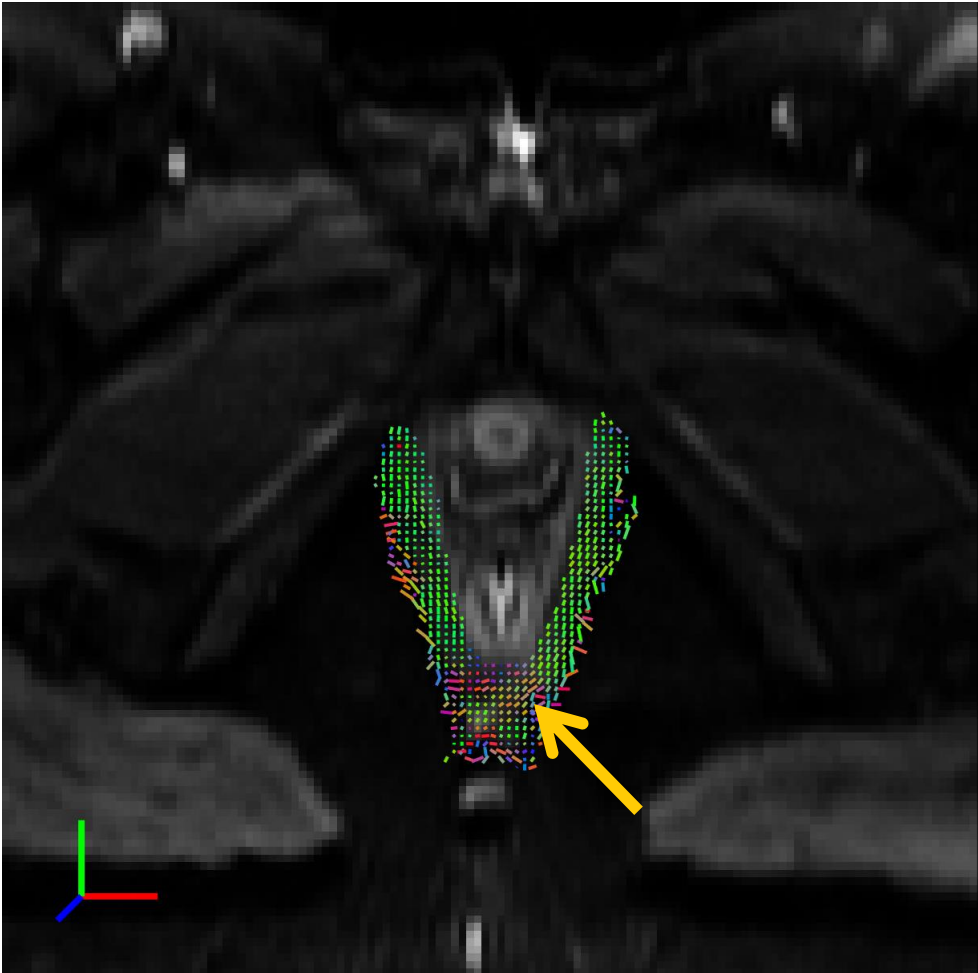


# Puborectalis Muscle: Higher Resolution Enables Finer Structure Delineation

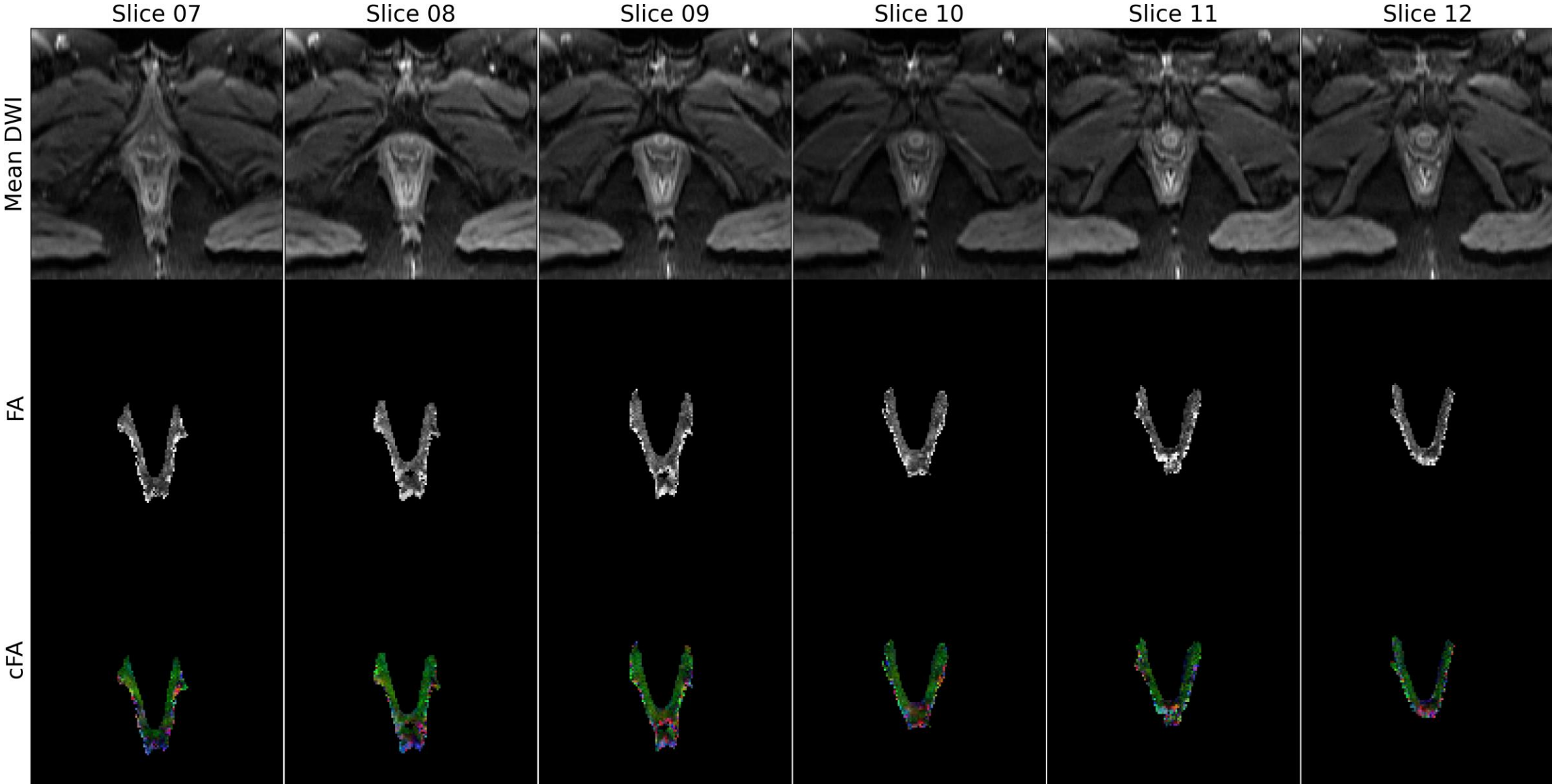
2.4mm



1.5mm



# Puborectalis Muscle: Quantitative Fractional Anisotropy (FA)



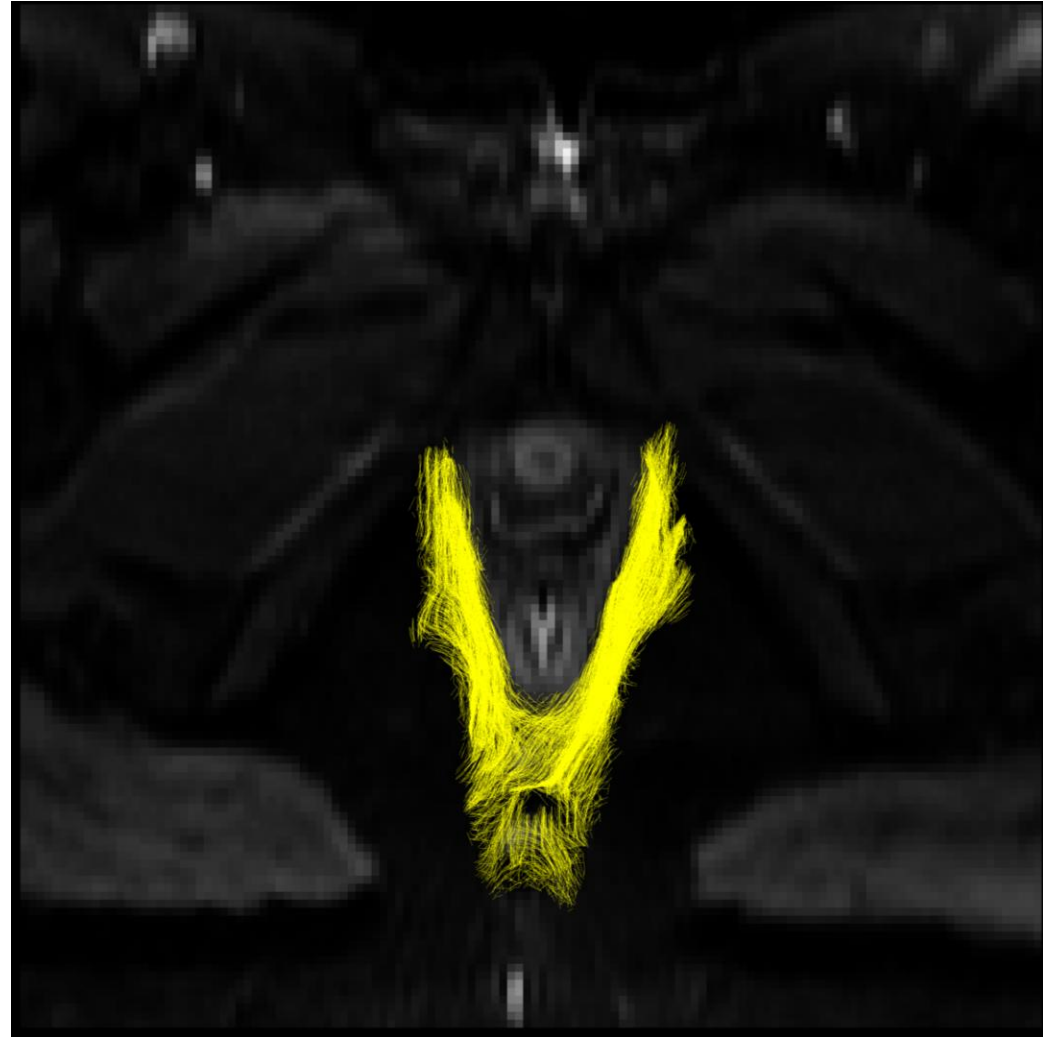
# Puborectalis Muscle: Fiber Tracking

Postmortem



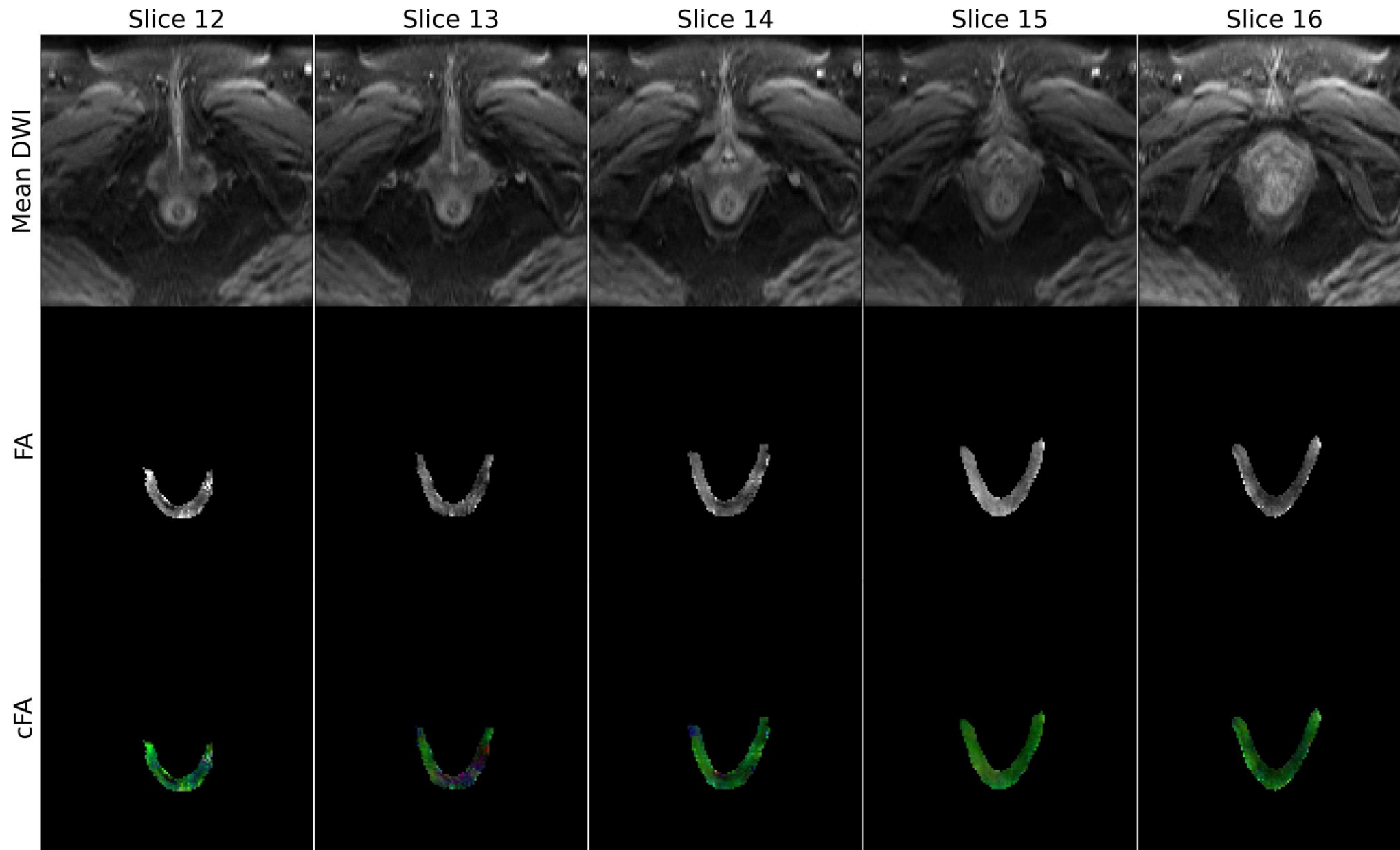
Courtesy: Prof. Dr. Helga Fritsch  
@ Medizinische Universität Innsbruck

Volunteer

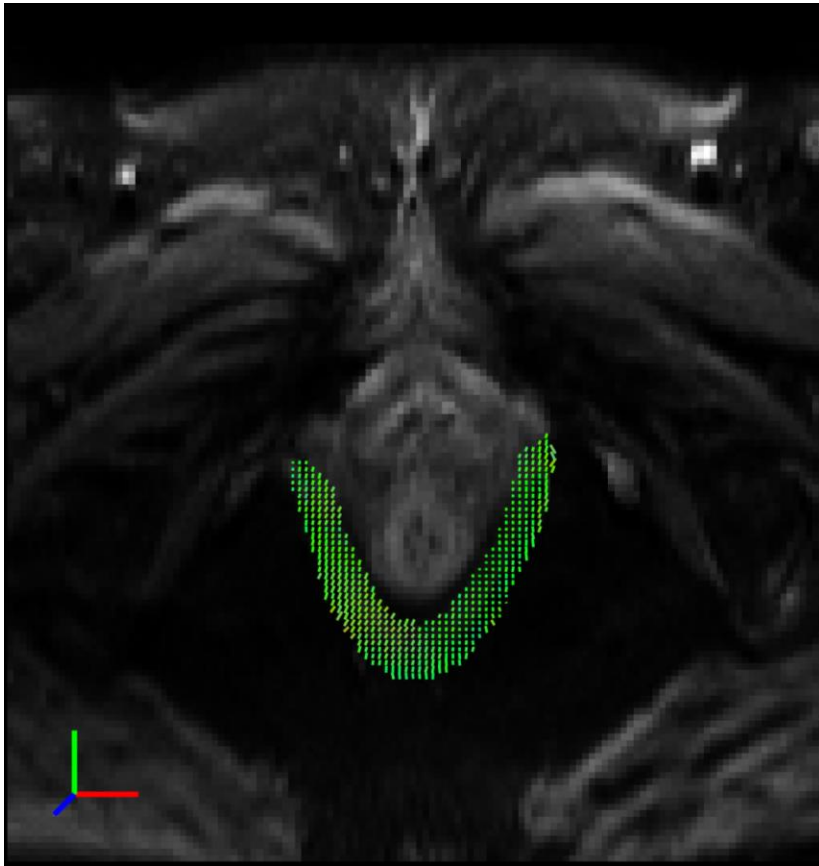


# Results From A 73-Year-Old Female Volunteer

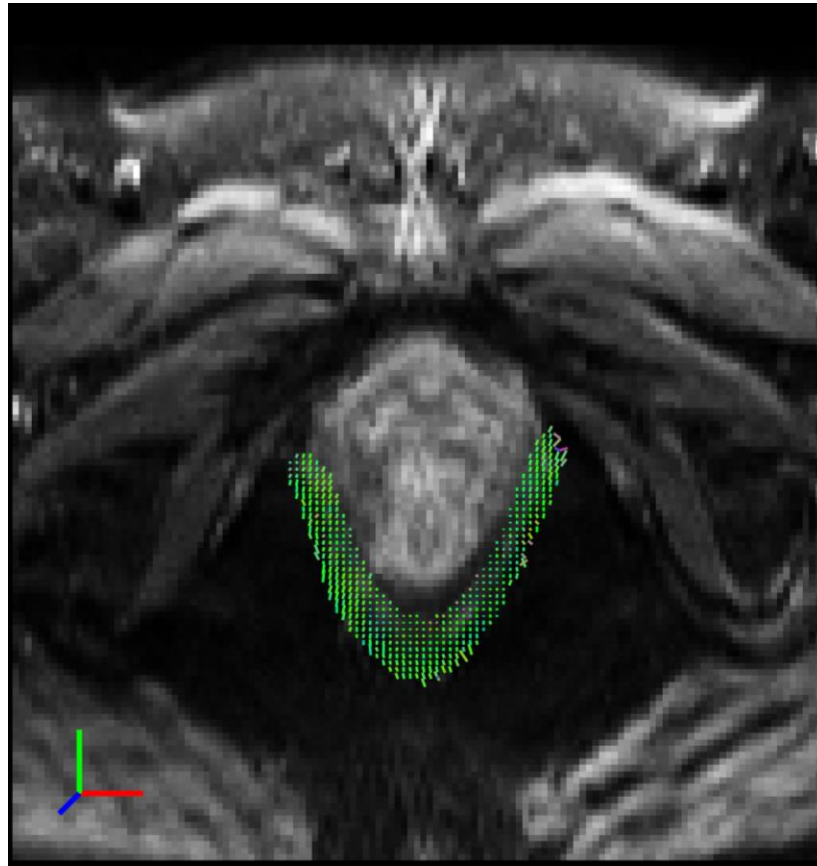
# Puborectalis Fibers Appear Predominantly in a Single Direction



Slice 15



Slice 16



Fiber Tracking



# Preliminary Quantitative Analysis

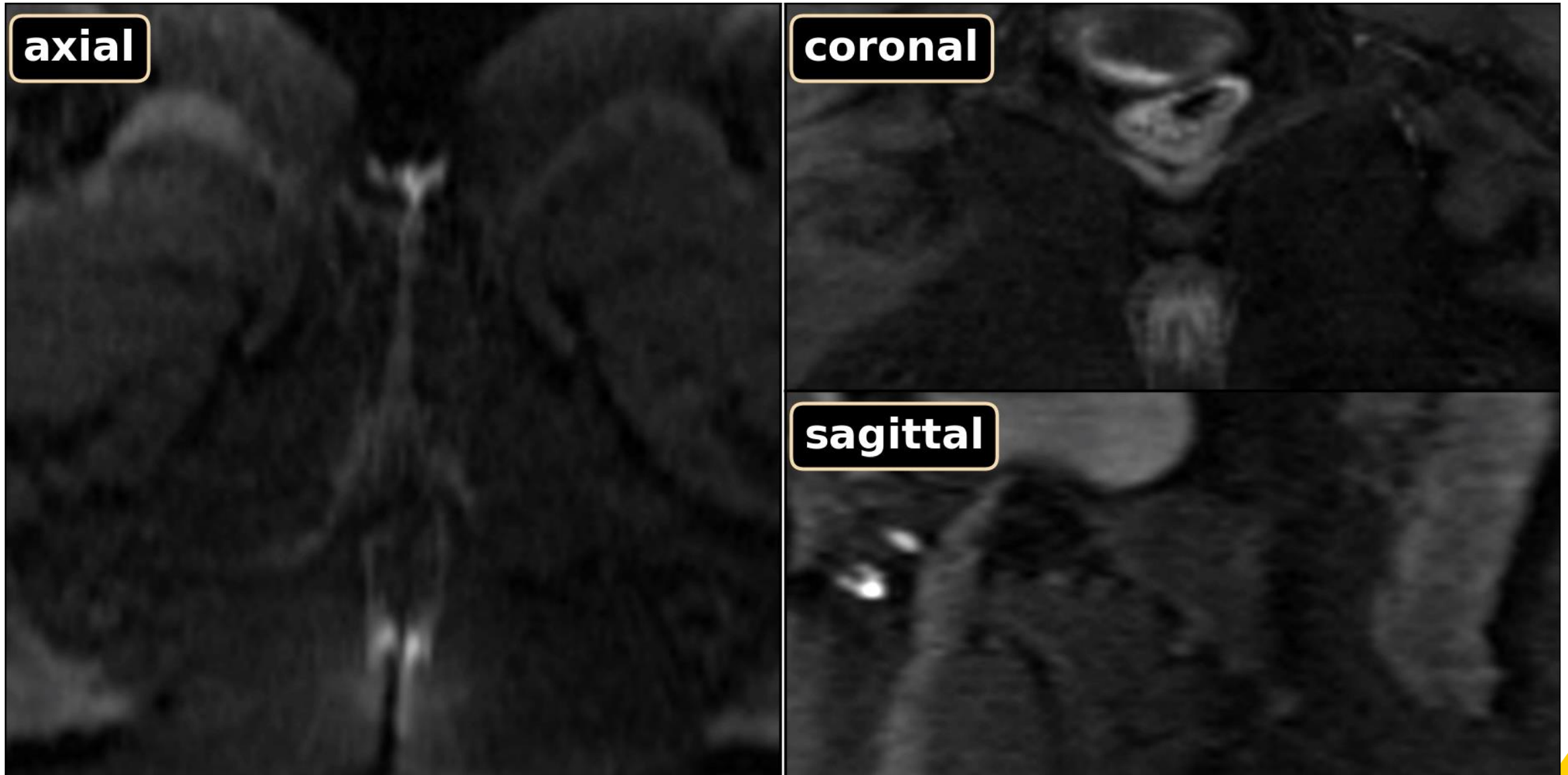
Volunteer	Mean Diffusivity ( $\times 10^{-3}$ mm <sup>2</sup> /s)	Fractional Anisotropy
#1	1.46 $\pm$ 0.68	0.38 $\pm$ 0.24
#2	1.26 $\pm$ 0.51	0.41 $\pm$ 0.22
#3	1.36 $\pm$ 0.54	0.46 $\pm$ 0.22

Zijta FM, et al. Feasibility of DTI with fibre tractography of the normal female pelvic floor. *Eur Radiol* (2011).

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)

Liu G. et al., Paradoxical puborectalis syndrome on diffusion-weighted imaging: a retrospective study of 72 cases,, *Sci Rep.* (2017)

# 1.5 mm Isotropic Resolution Enabled by SMS and DeepDWI

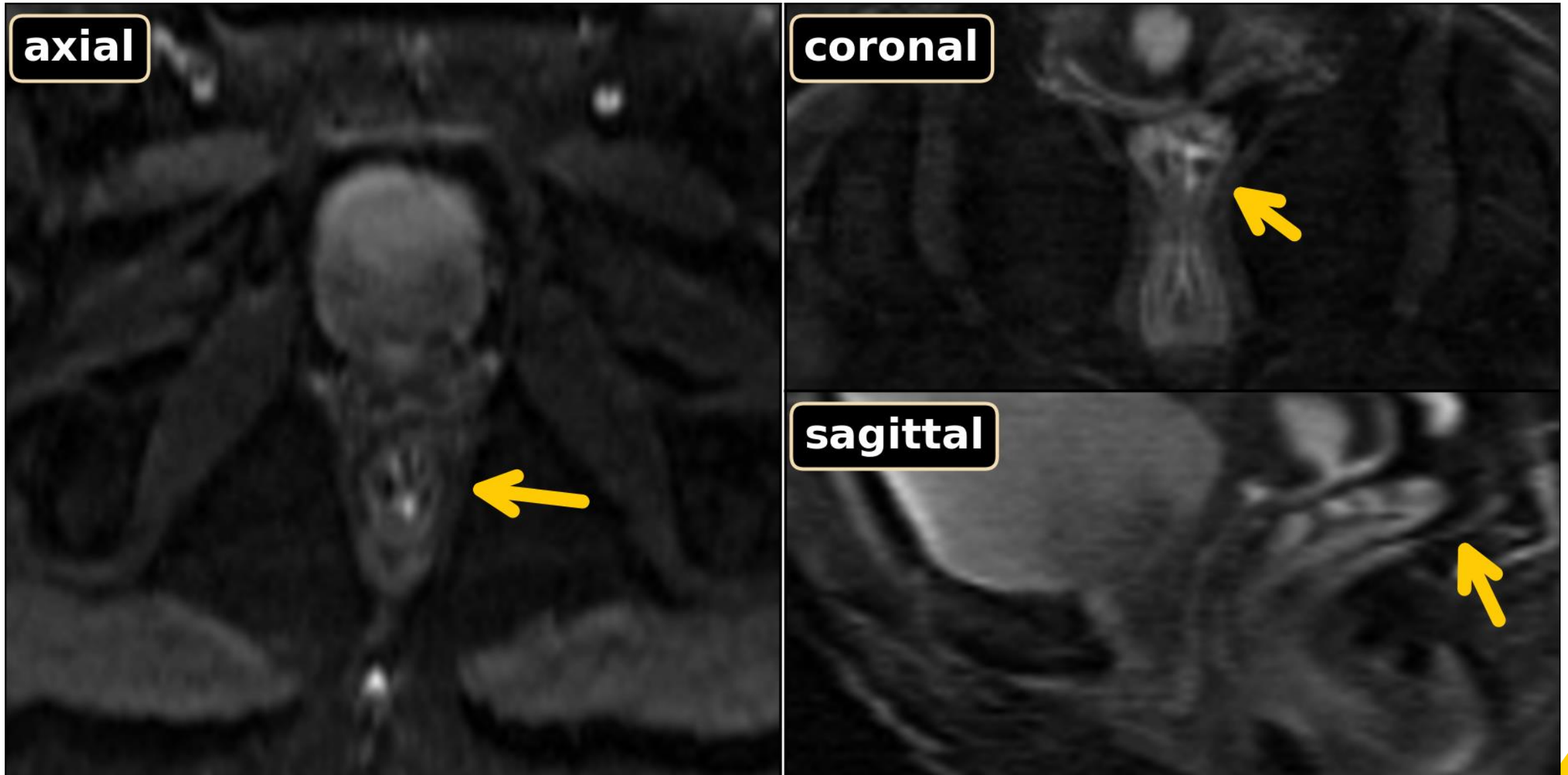


Weaver JB. Simultaneous multislice acquisition of MR images. *Magn Reson Med* (1988).

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# Next steps

- Broader validation on a larger number of subjects
- Apply to clinical settings and for patients with injury
- Aid in studying early interventions

# SUMMARY

- **Pelvic floor injuries during vaginal childbirth pose a significant health problem**
- **Non-invasive, high-resolution, and fast DeepDWI facilitates the understanding of the pelvic floor microstructure and integrity**
- **Goal: Foster safe & effective therapeutics for pregnancy and postpartum recovery**



“Which is more important,” asked Big Panda, “the journey or the destination?”

“The company.” said Tiny Dragon.

[jamesnorbury.com](http://jamesnorbury.com)



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Siemens Healthineers



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