MR Elastography: Development and Introduction into Clinical Practice

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MAYO
CLINIC

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- **Basics of MRE method**
- **Clinical Research and Applications**
  - Liver
  - Renal
  - Brain
  - Breast

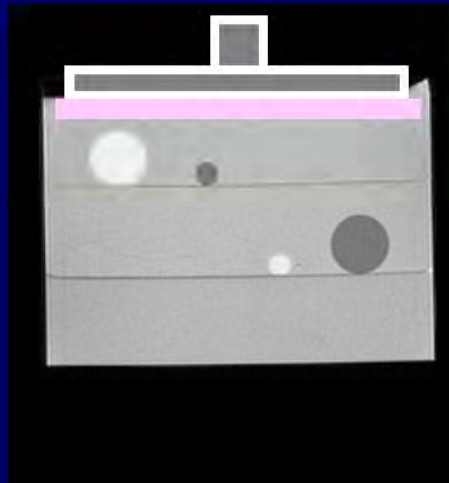- **Basics of MRE method**
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Basics of MRE method
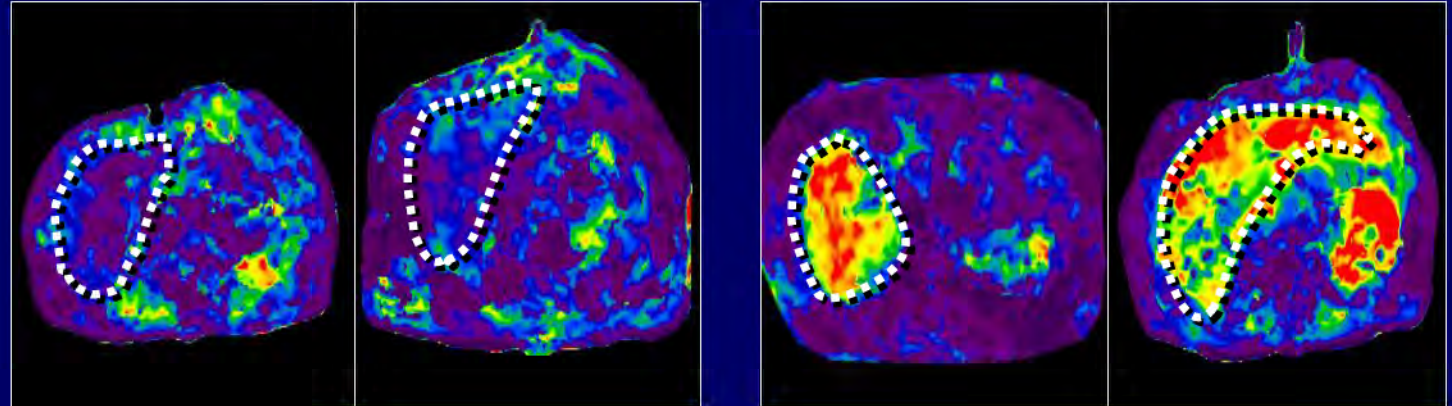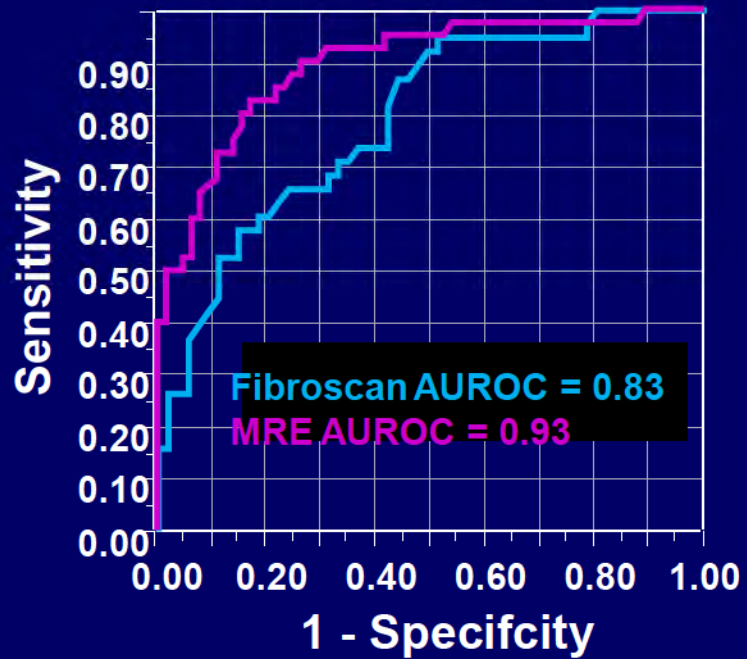
1. Vibration　　　**2. MRE Acquisition**　　　**3. Inversion**

- Basics of MRE method
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MRE in Detecting Liver Fibrosis

Diagnostic Accuracy (AUROC)

Fibroscan AUROC = 0.83
MRE AUROC = 0.93

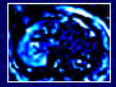**Normal Livers**

Fibrotic Livers

Liver stiffness measurement success rate

Success Rate
(Patients who underwent both MRE and VCTE)

MRE = 95.8% (92/96)
VCTE = 81.3% (78/96) (Criteria in Castera et. al.)
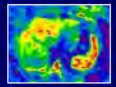VCTE = 88.5% (85/96) (Criteria in Boursier et. al.)

Hepatogram

- **Analyze relationships between predictor variables (imaging biomarkers) and outcome variables (histologic features)**
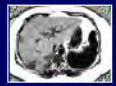
Damping ratio → Inflammation

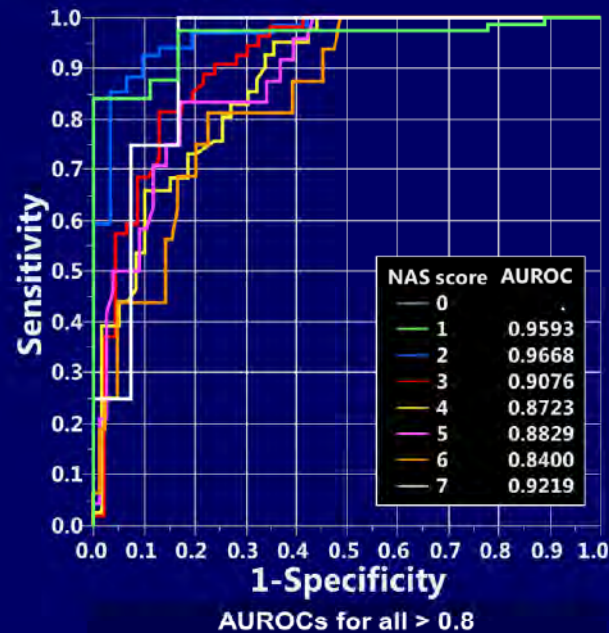**Yin M., Radiology 2017; Zhang X., Med Eng Phys. 2017**

Liver stiffness → ballooning

Rausch V., World J Hepatol. 2016; Ogawa S., J Med Ultrason. 2016

Fat fraction → steatosis

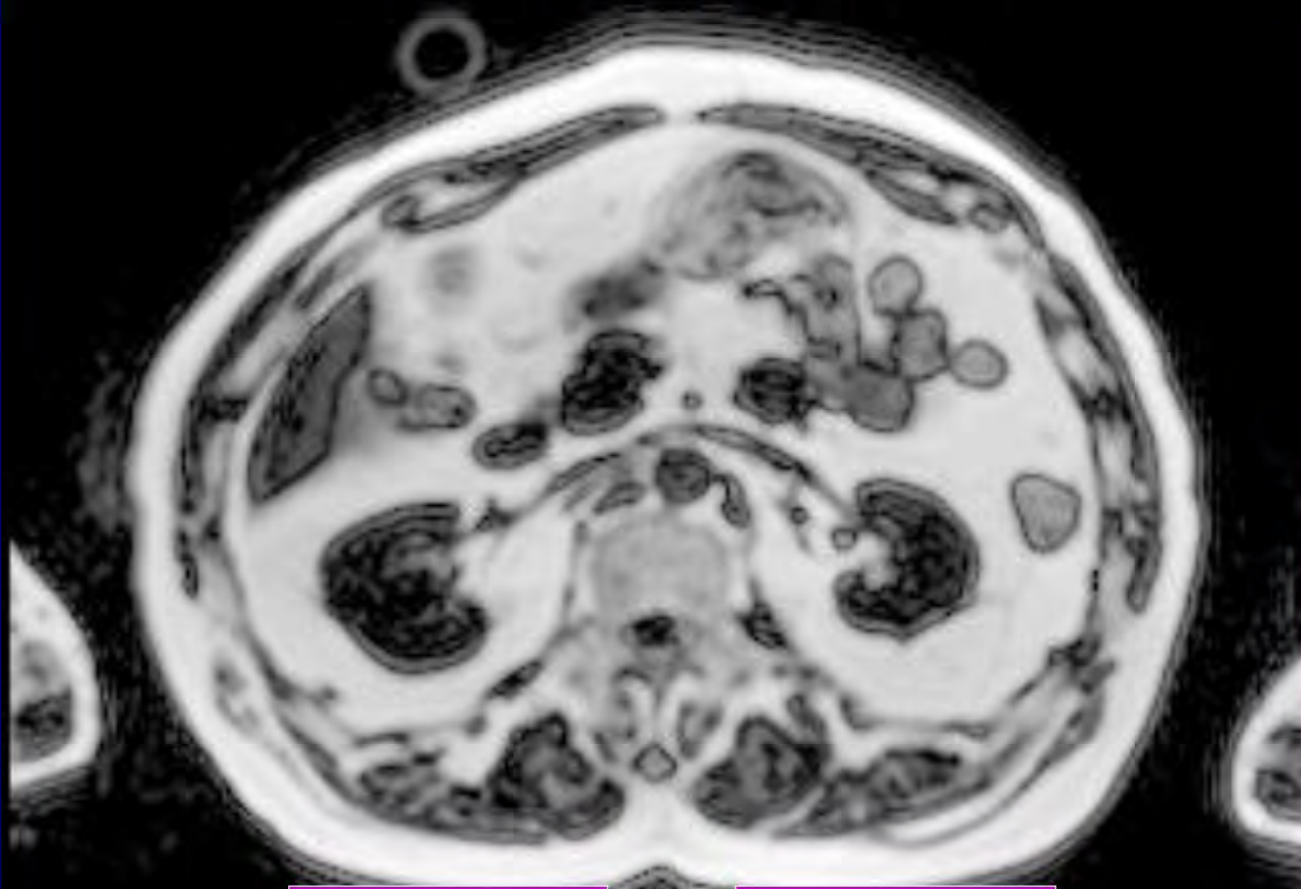**Paige JS., AJR 2017; Imajo K., Gastroenterology 2016, Tang A., Radiology 2015**

NAS score	AUROC
0	.
1	0.9593
2	0.9668
3	0.9076
4	0.8723
5	0.8829
6	0.8400
7	0.9219

AUROCs for all > 0.8

Courtesy Yin Meng, PhD

- Basics of MRE method
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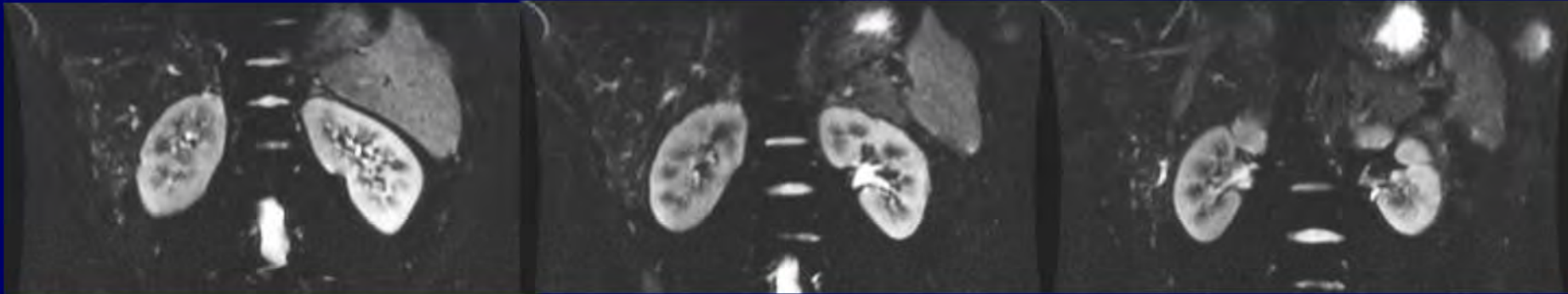# Renal MR Elastography Setup

Prone position

Dual Renal MRE driver
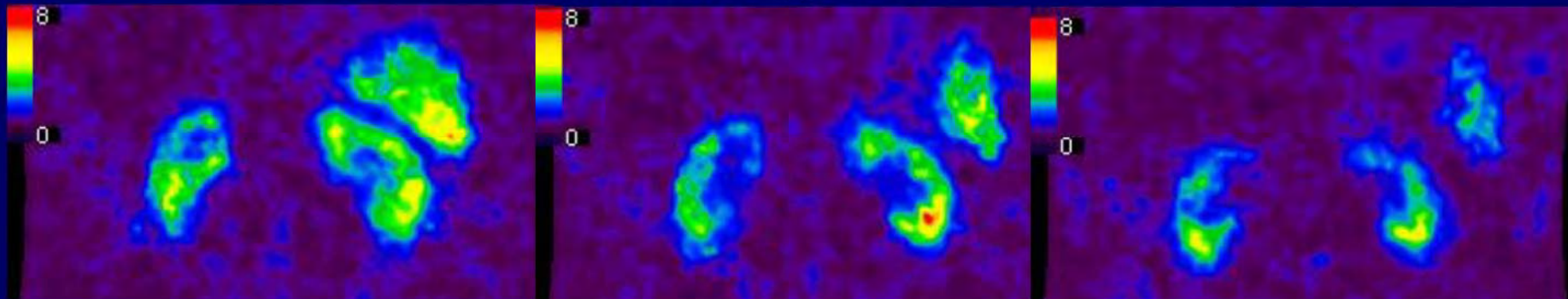
About 4 x 5 inches

Renal MR Elastography

Anatomic MRI

Elastograms

Renal MRE:

- **Evaluation of kidney function**
  - Transplant kidney dysfunction
  - Fibrosis
  - ADPKD (Autosomal dominant polycystic kidney disease)
  - Lupus Nephritis
  - Hepatorenal syndrome
  - eGFS (estimated glomerular filtration rate)
  - RBF (renal blood flow)
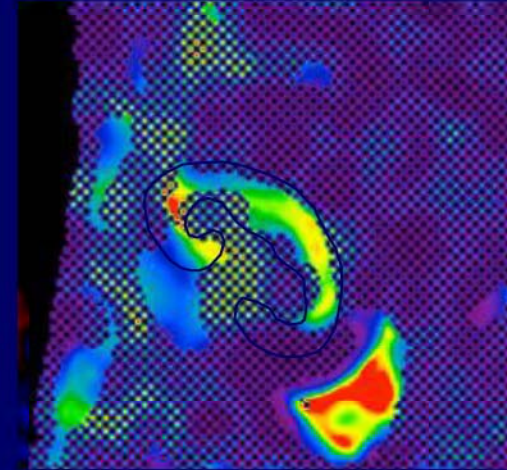- **Evaluation of Treatment efficacy**

Evaluation of TX kidney dysfunction

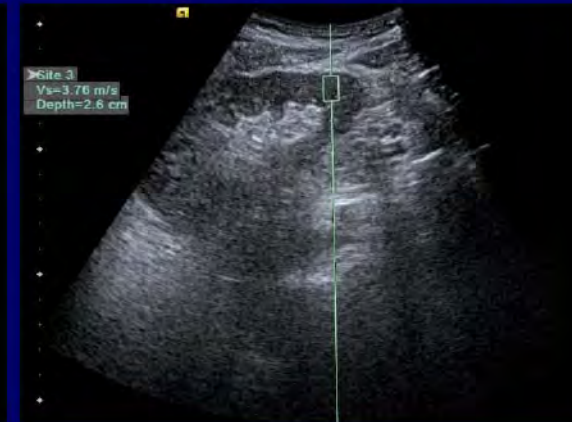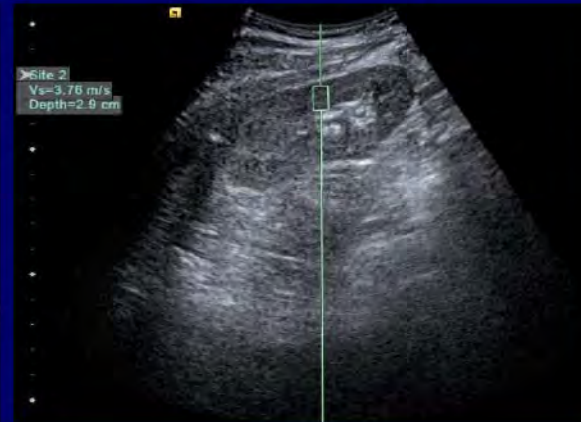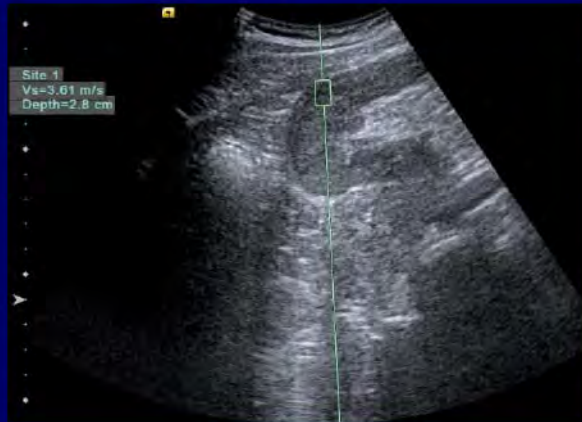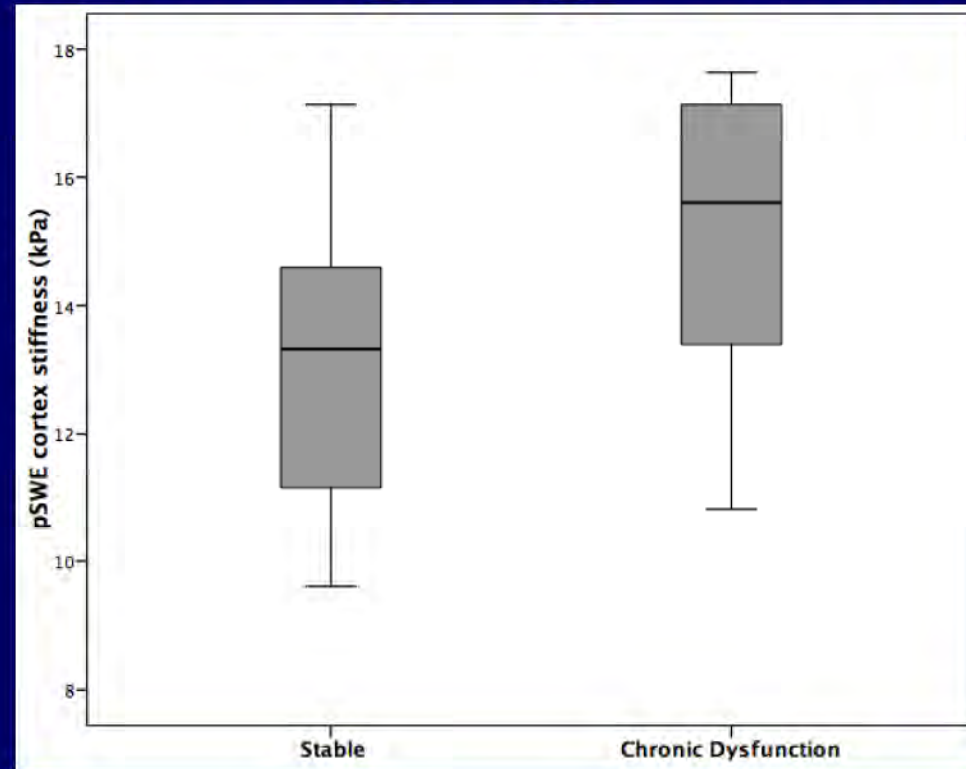## Example acquisitions in 42 year old male with RTX
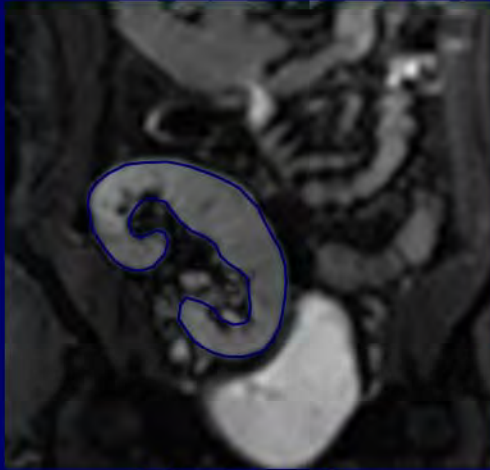
Magnitude
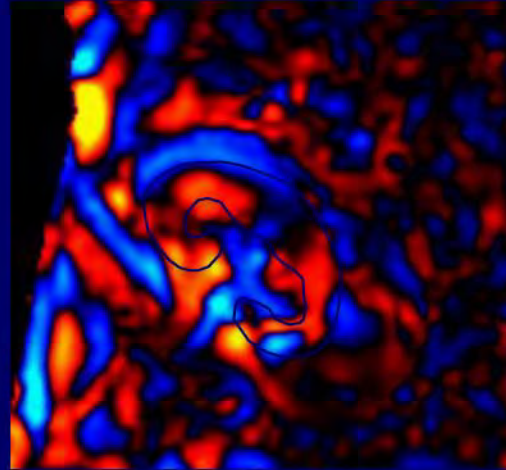
Wave Image

Confidence Map

Evaluation of TX kidney dysfunction
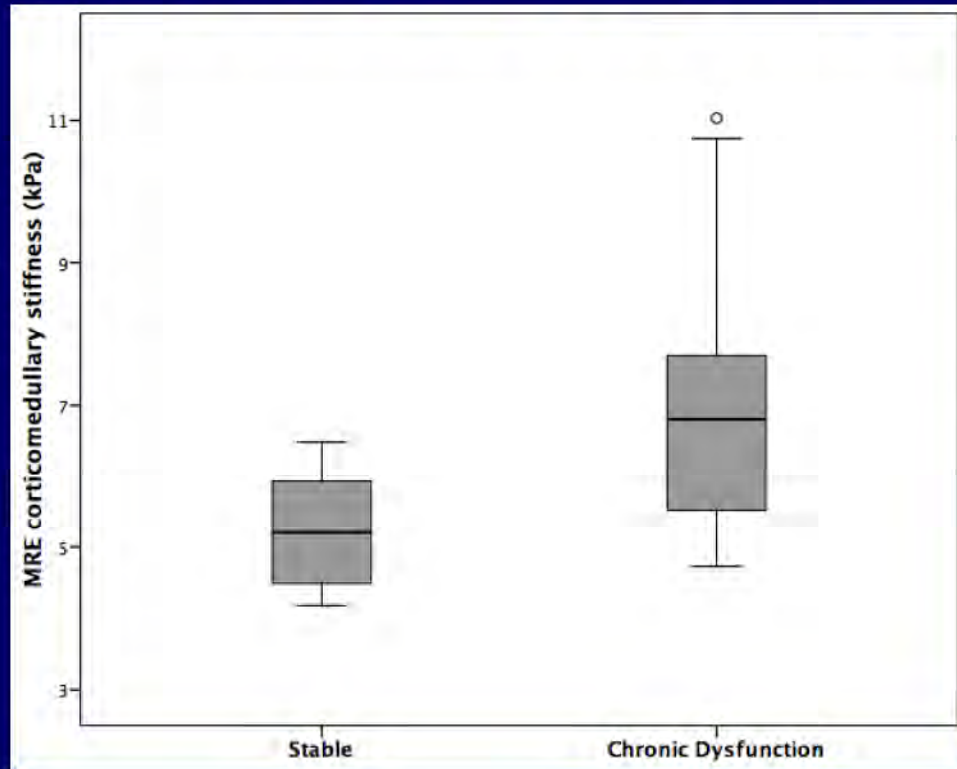
Modality	N	Stable (kPa)	Dysfunction (kPa)	p
MRE	20	5.22±0.83	7.15±2.37	0.038
pSWE	11	13.19±2.64	14.92±2.82	0.201

Courtesy of Paul Kennedy PhD and Bachir Taouli MD

Evaluation of TX kidney dysfunction
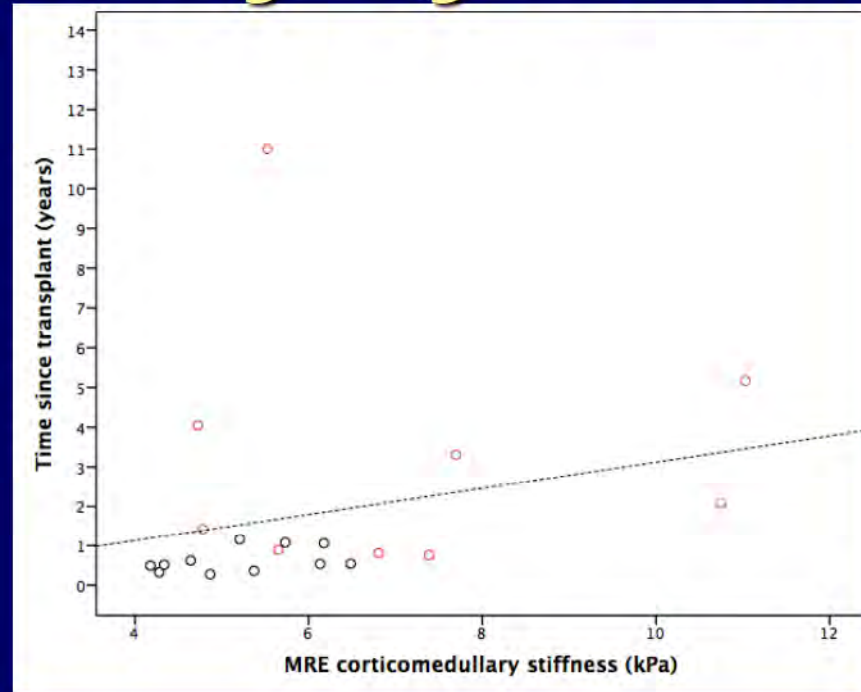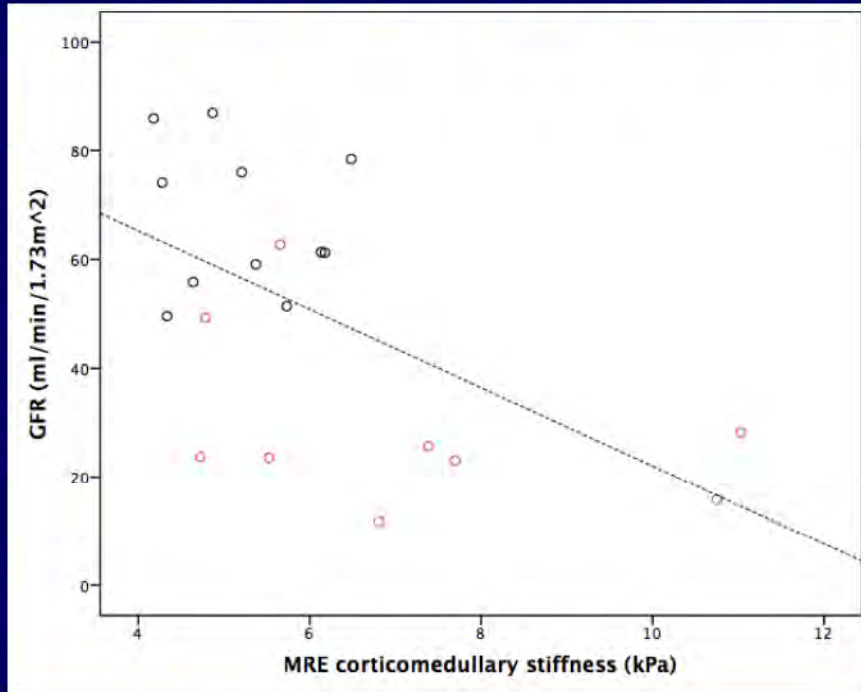
MRE correlation with	r	p
Time since Tx	0.464	**0.040**
GFR	-0.477	**0.034**

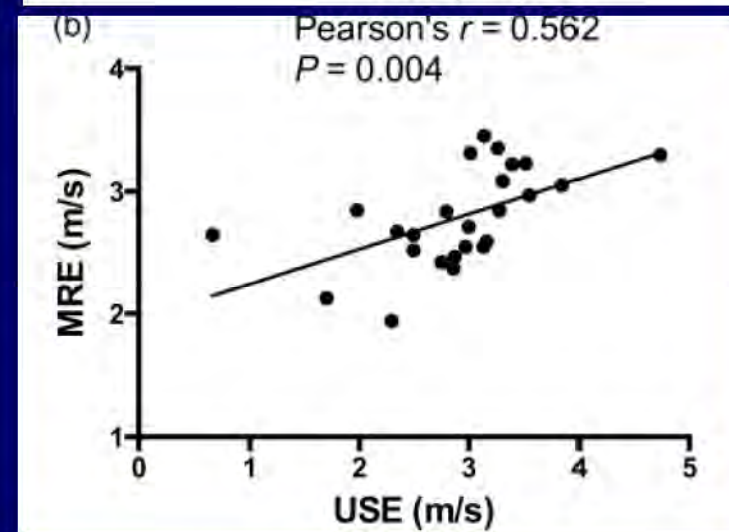| pSWE correlation with	r	p
Time since Tx	0.429	0.289
GFR	0.095	0.823

Courtesy of Paul Kennedy PhD and Bachir Taouli MD

Evaluation of TX kidney dysfunction
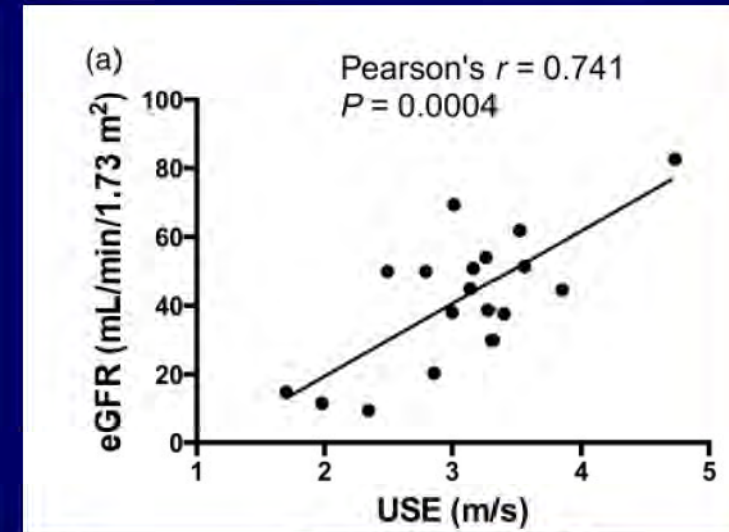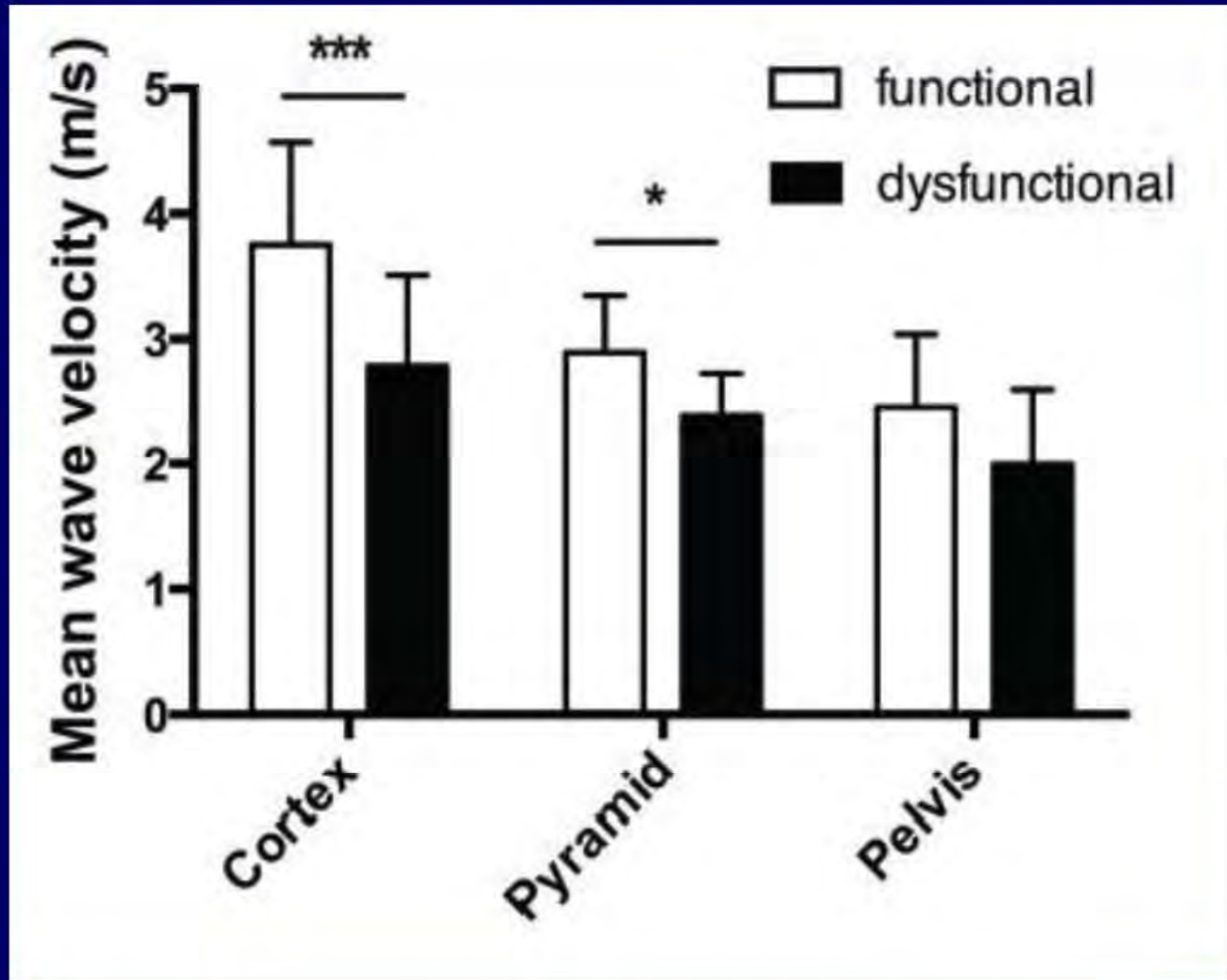
Medullary stiffness and fibrosis: RAS
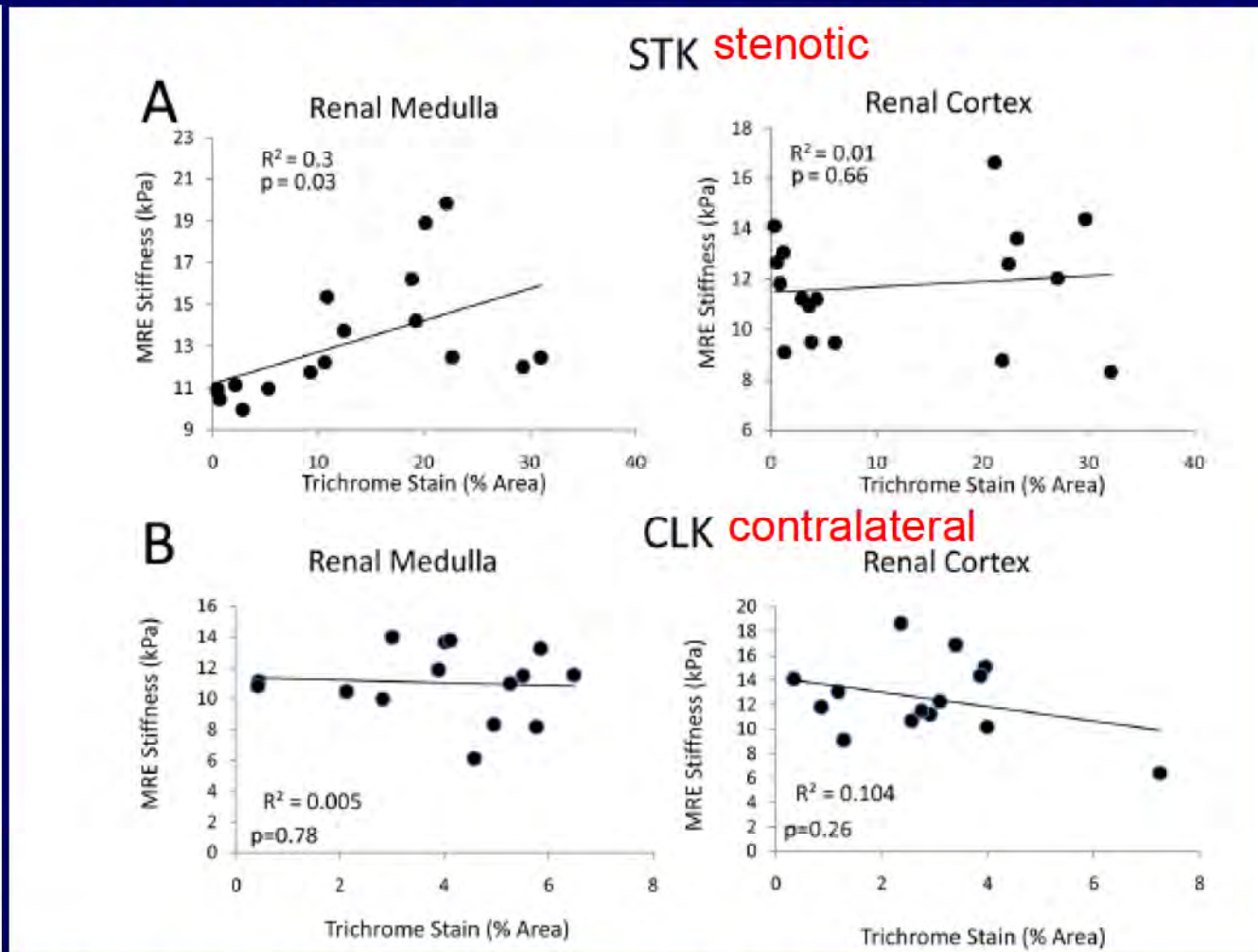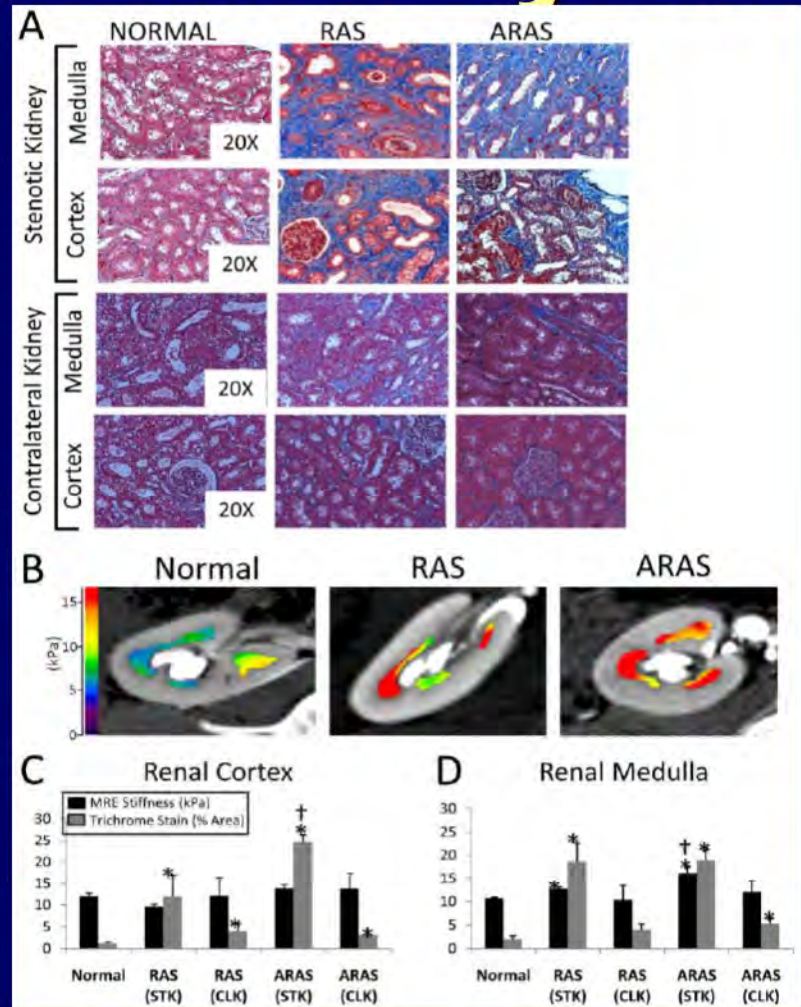
- Medullary stiffness significantly correlated with histological degree of fibrosis
- Renal blood flow and function were similarly decreased in RAS and ARAS compared to normal

Evaluation of ADPKD
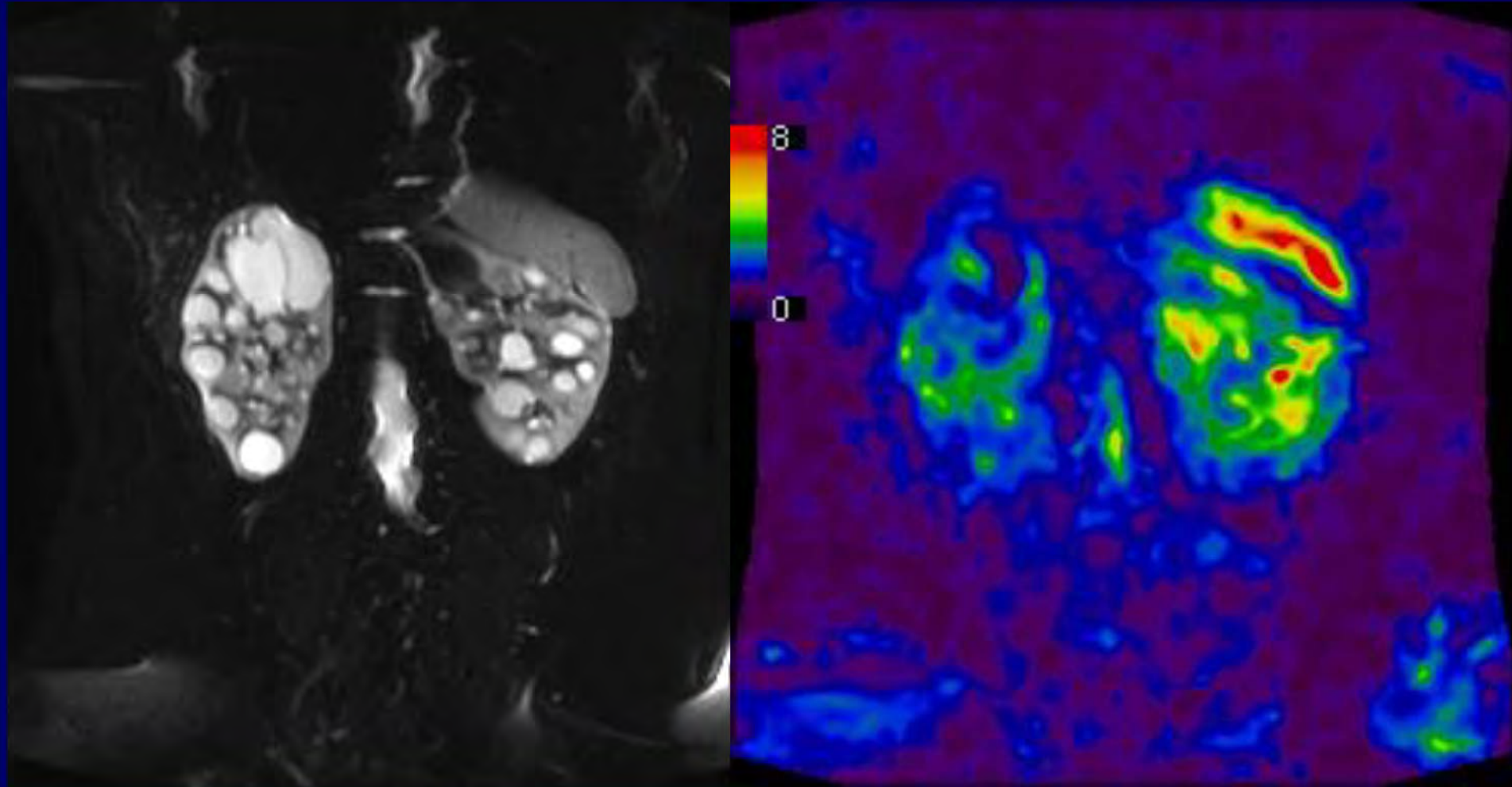
Courtesy of Venkatesh Sudhakar MD

Evaluation of ADPKD
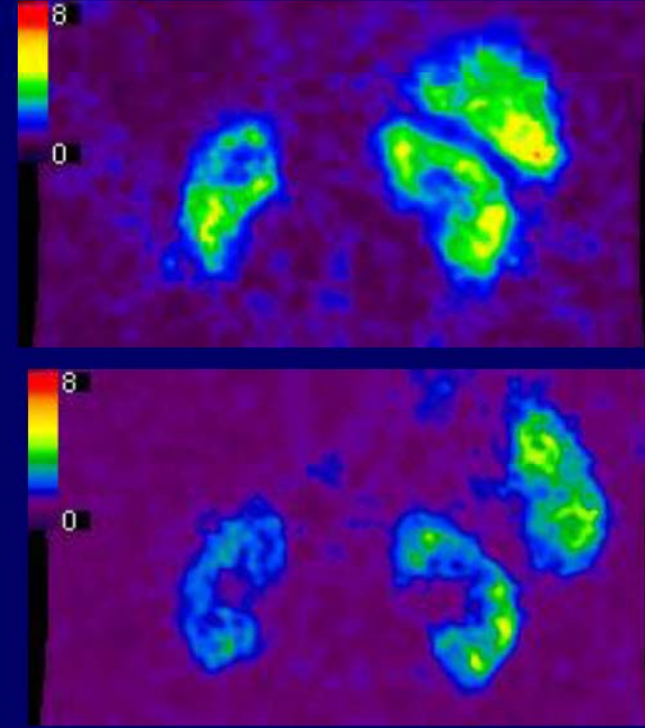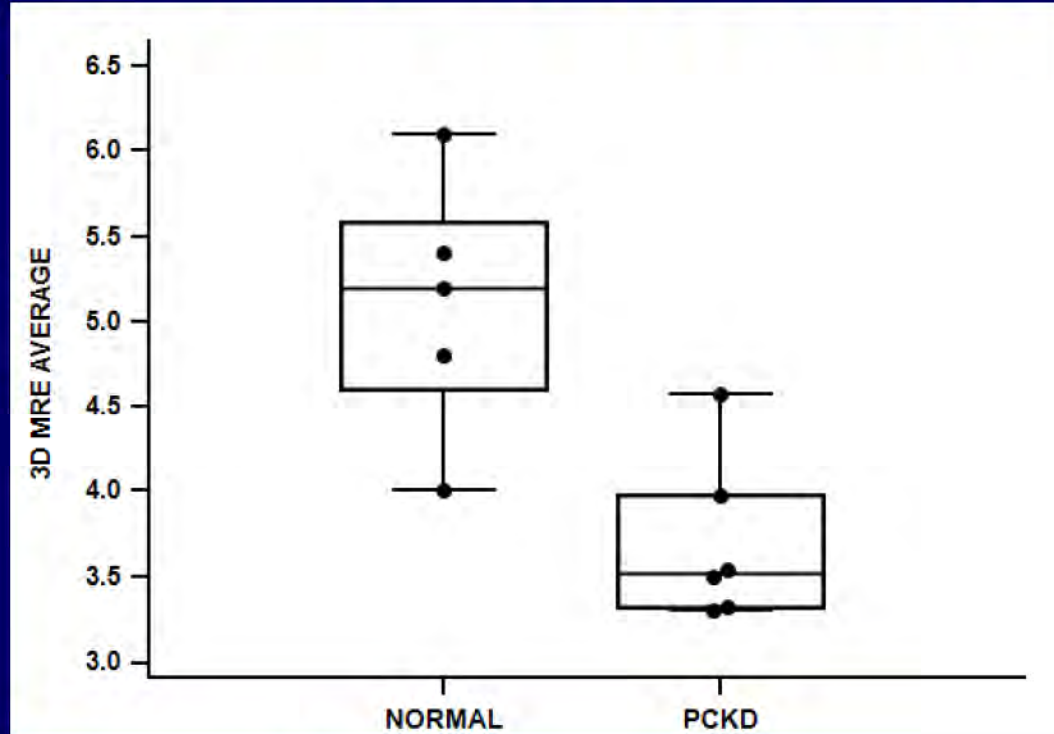
Normal : **5.1 ± 0.77 kPa**

PCKD : **3.7 ± 0.5 kPa**

P<0.005

ADPKD parenchyma is softer than normal kidney parenchyma!
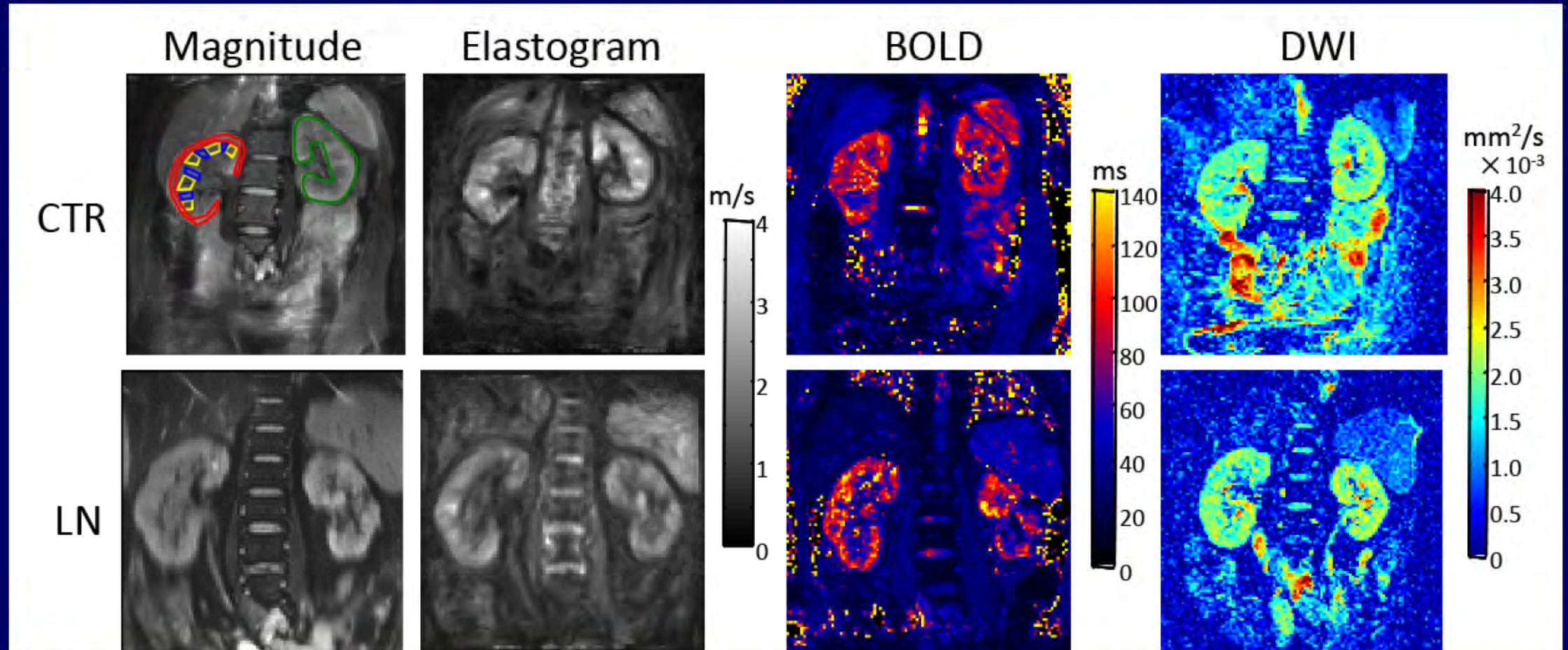
Courtesy of Venkatesh Sudhakar MD

Evaluation of Lupus Nephritis

ROI: entire parenchyma (green), medulla (yellow), inner cortex (blue), and outer cortex (red).
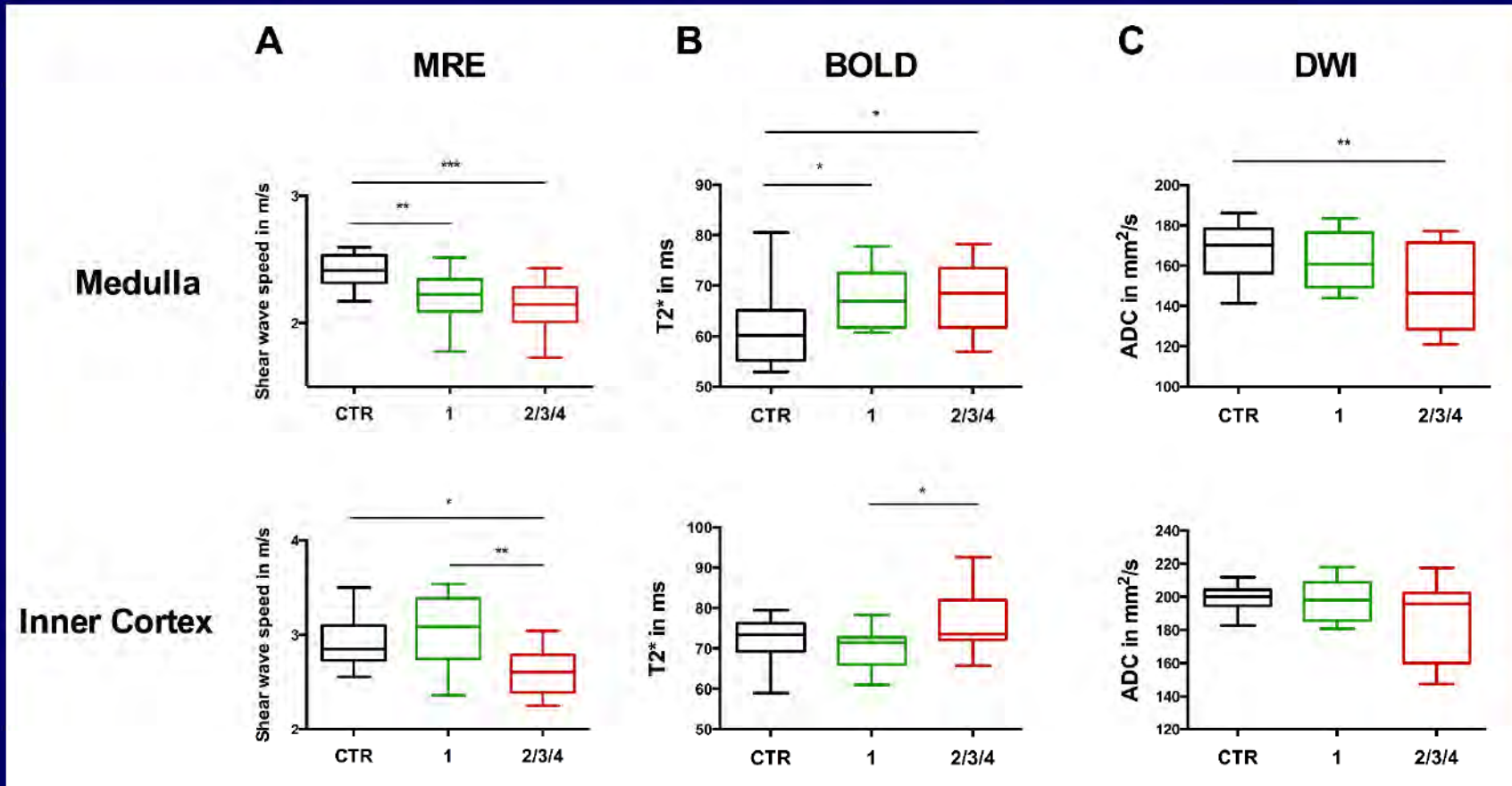
Evaluation of Lupus Nephritis

Healthy controls (CTR) ; Patients with lupus nephritis of normal renal function (CKD = 1) and impaired renal function (CKD = 2/3/4),
***p < 0.001, **p < 0.01, *p < 0.05.

Courtesy of Jing Guo PhD

Evaluation of hepatorenal syndrome
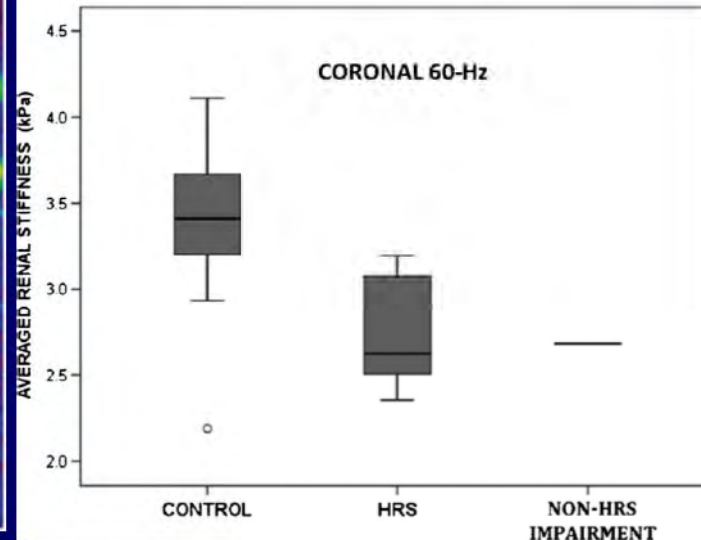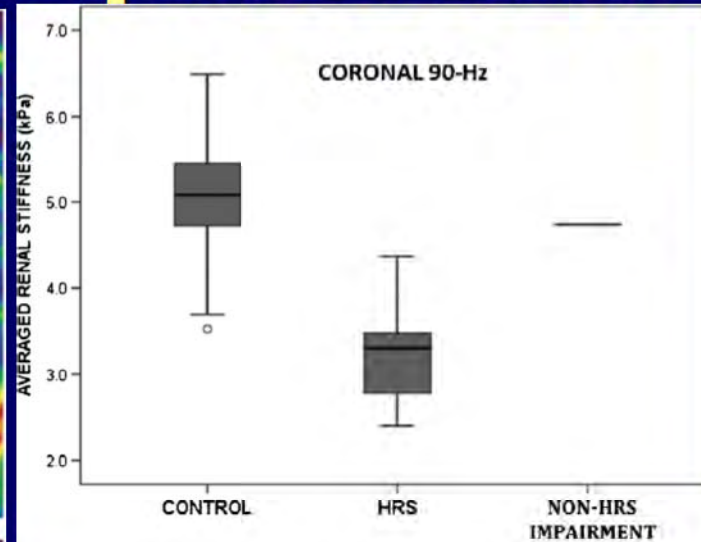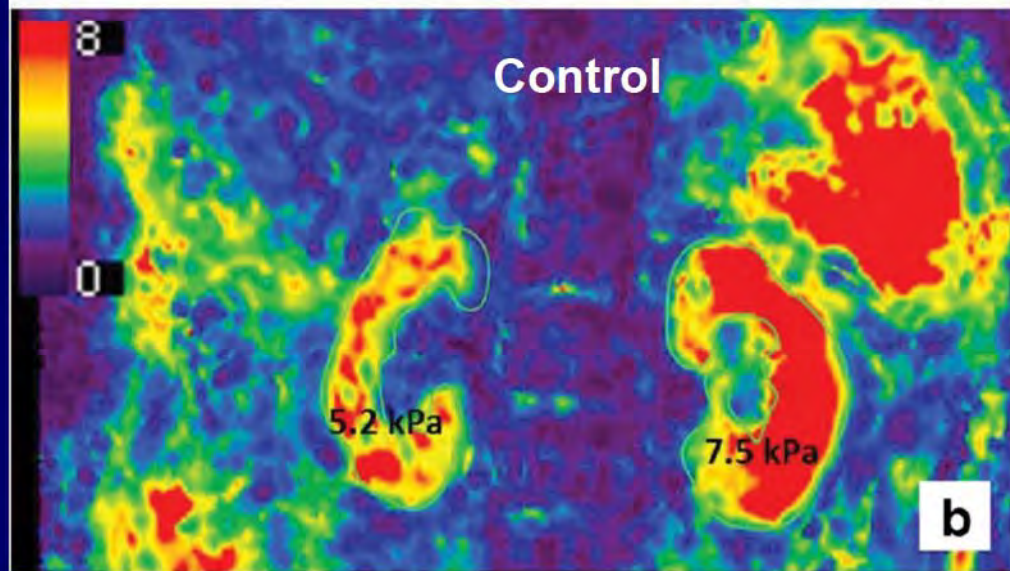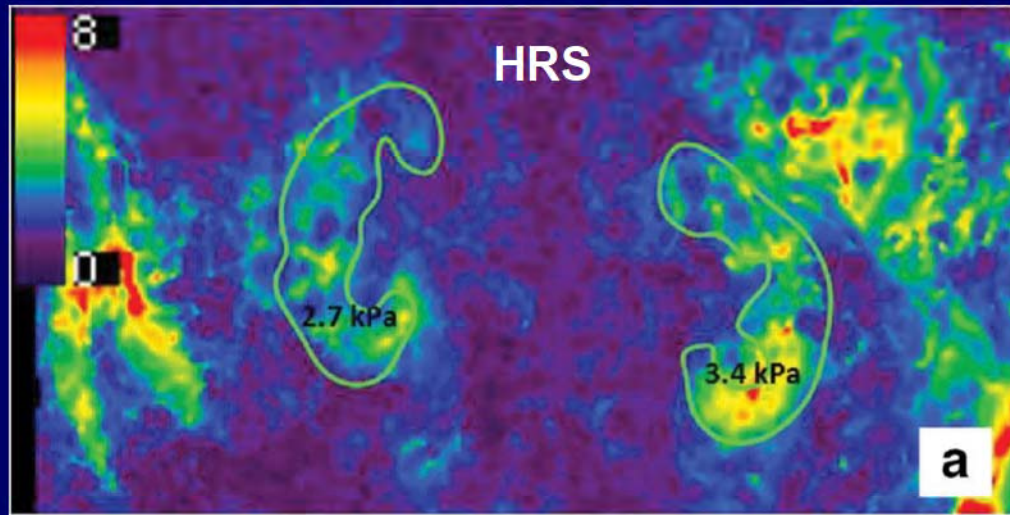
MRE to detect HRS

AUROC:
90Hz = 0.94
60Hz = 0.89

Gavin Low, et. al., Eur Radiol (2015) 25:2851–2858

Perfusion Effect: Renal Arterial Stenosis

Lizette W et al. Investigative Radiology 2011;46(8);509-514
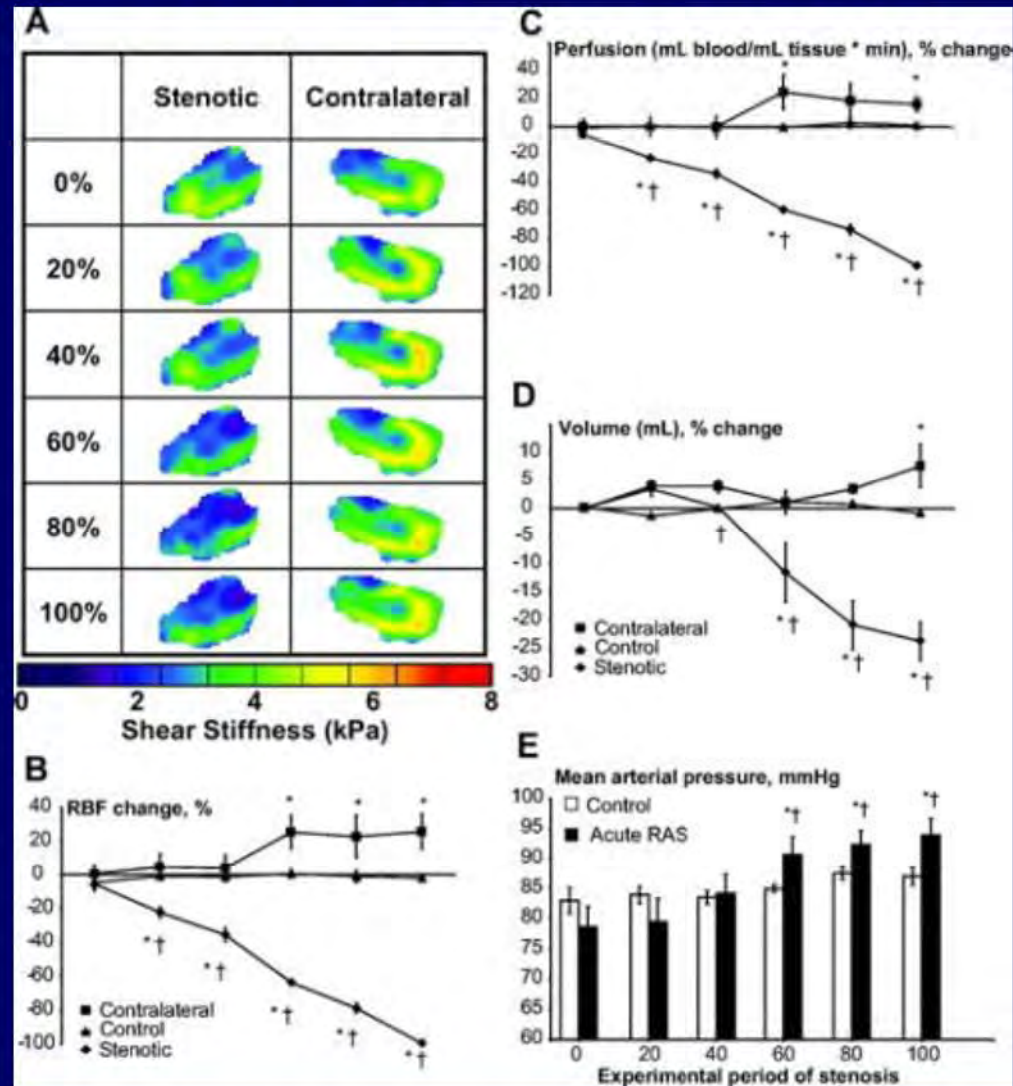
Perfusion Effect: Renal Arterial Stenosis
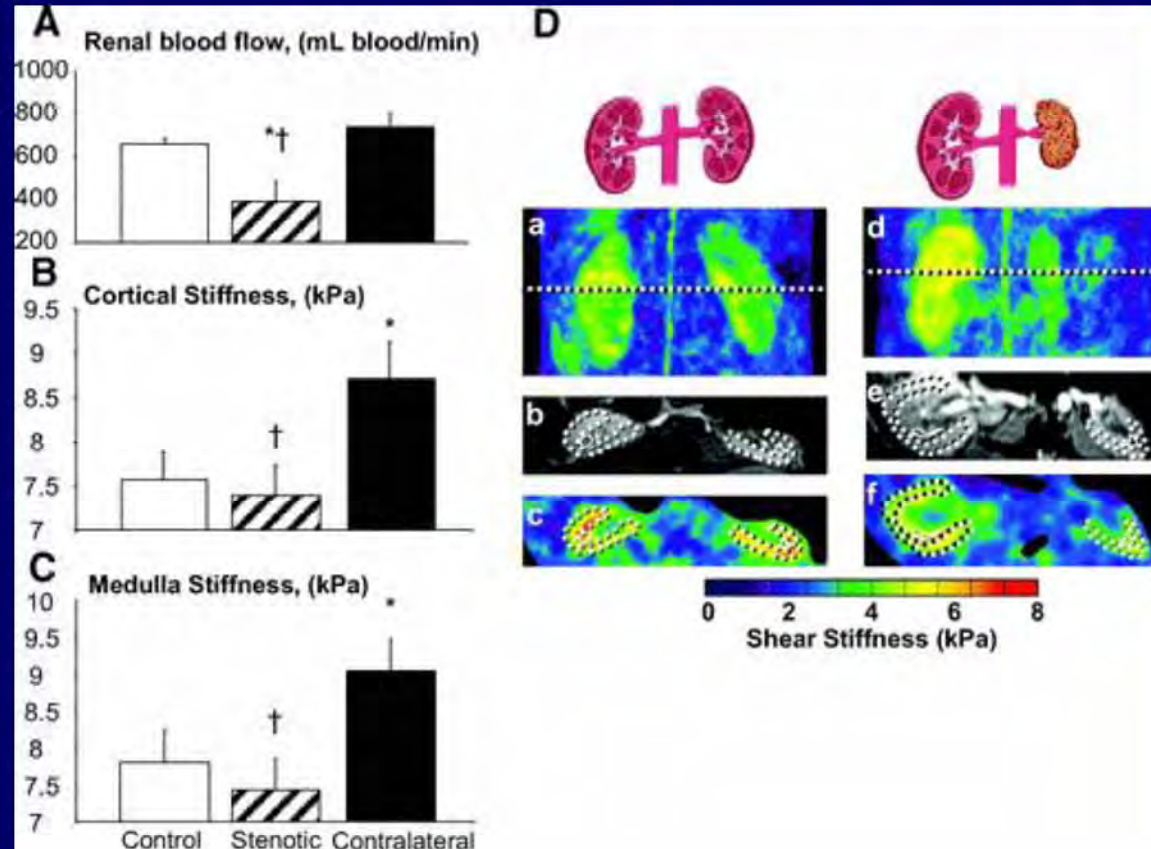
Control (D: a–c), chronic RAS (D: d–f) animals
*P < 0.05 versus control kidney, †P < 0.05 versus contralateral kidney.

Evaluation of Treatment efficacy

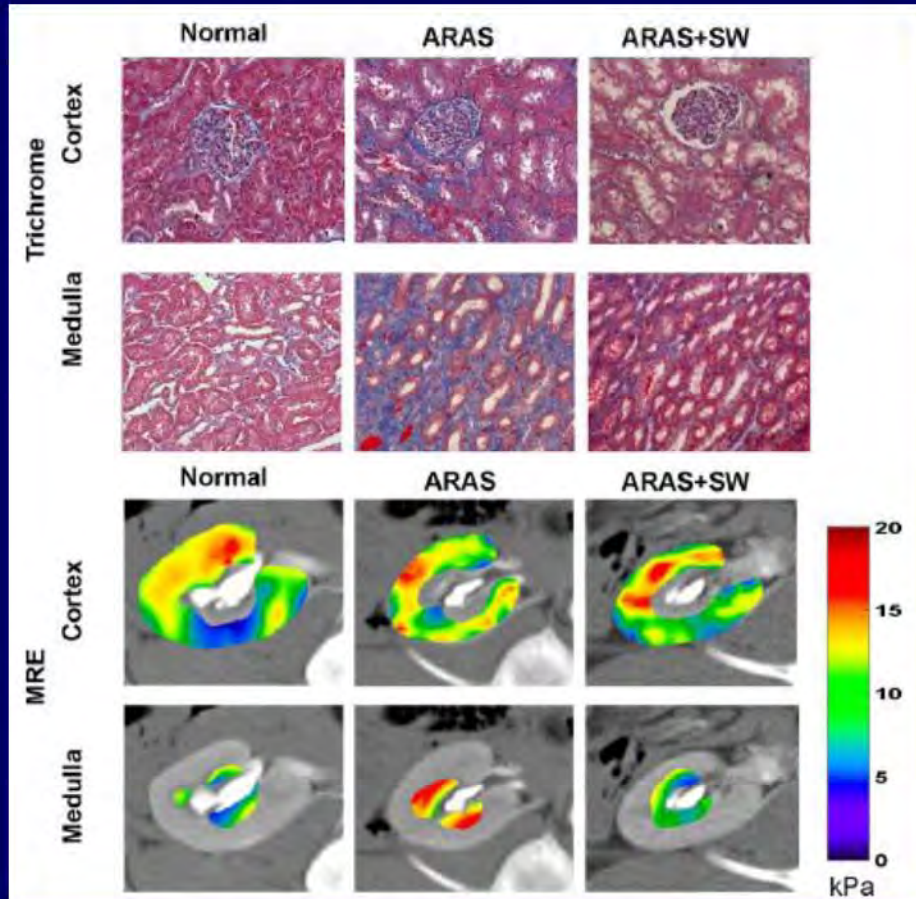| Renal fibrosis	Normal (n=7)	ARAS (n=7)	ARAS+SW (n=7)
Trichrome STK Cortex (%)	1.2±0.5	4.9±0.7 [#]	1.5±0.5 [#]
STK Medulla (%)	1.7±0.2	10.4±1.8 [*]	2.9±0.2 [*#]
Trichrome CLK Cortex (%)	1.3±0.4	1.2±0.3	1.0±0.4
CLK Medulla (%)	1.6±0.3	6.8±0.9 [*]	3.7±0.6 [#]
MRE STK Cortex (kPa)	12.0±0.7	12.9±0.9	11.7±1.7
STK Medulla (kPa)	10.2±0.4	15.3±2.1 [*]	10.4±0.8 [*#]
MRE CLK Cortex (kPa)	12.0±0.8	12.8±0.9	11.2±1.0
CLK Medulla (kPa)	10.7±0.2	11.3±0.8	11.3±1.6

Data are expressed as mean±SEM. STK stenotic kidney; CLK contralateral kidney;

[*] Bonferroni-corrected p<0.05 vs. Normal.

[#] Bonferroni-corrected p<0.05 vs. ARAS

Medullar stiffness increased due to ARAS and decreased in response to the shockwave treatment of ARAS, which was significantly correlated to the change of medullar fibrosis.

Xin Zhang, et. al., MAGMA. 2018 June ; 31(3): 375–382.

- Basics of MRE method
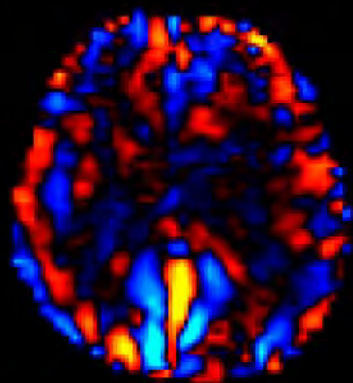- **Clinical Research and Applications**
  - Liver
  - Renal
  - **Brain**
  - Breast

Brain MRE setup

T1w	Wave X	Y	Z	Elastogram

Displacement (μm): -10, 0, +10

Shear Stiffness (kPa): 0, 4, 8
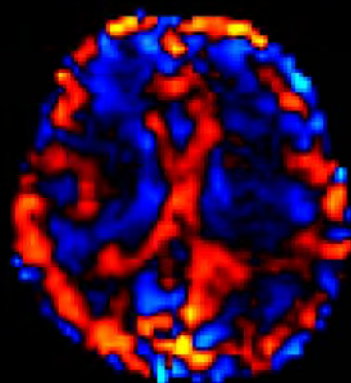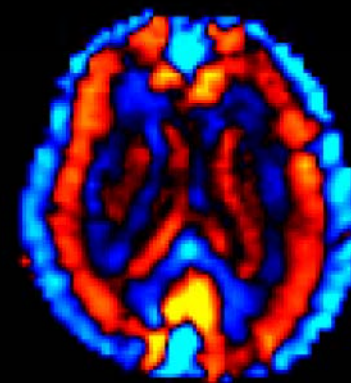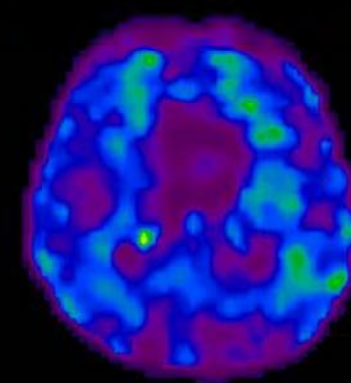
Meningioma
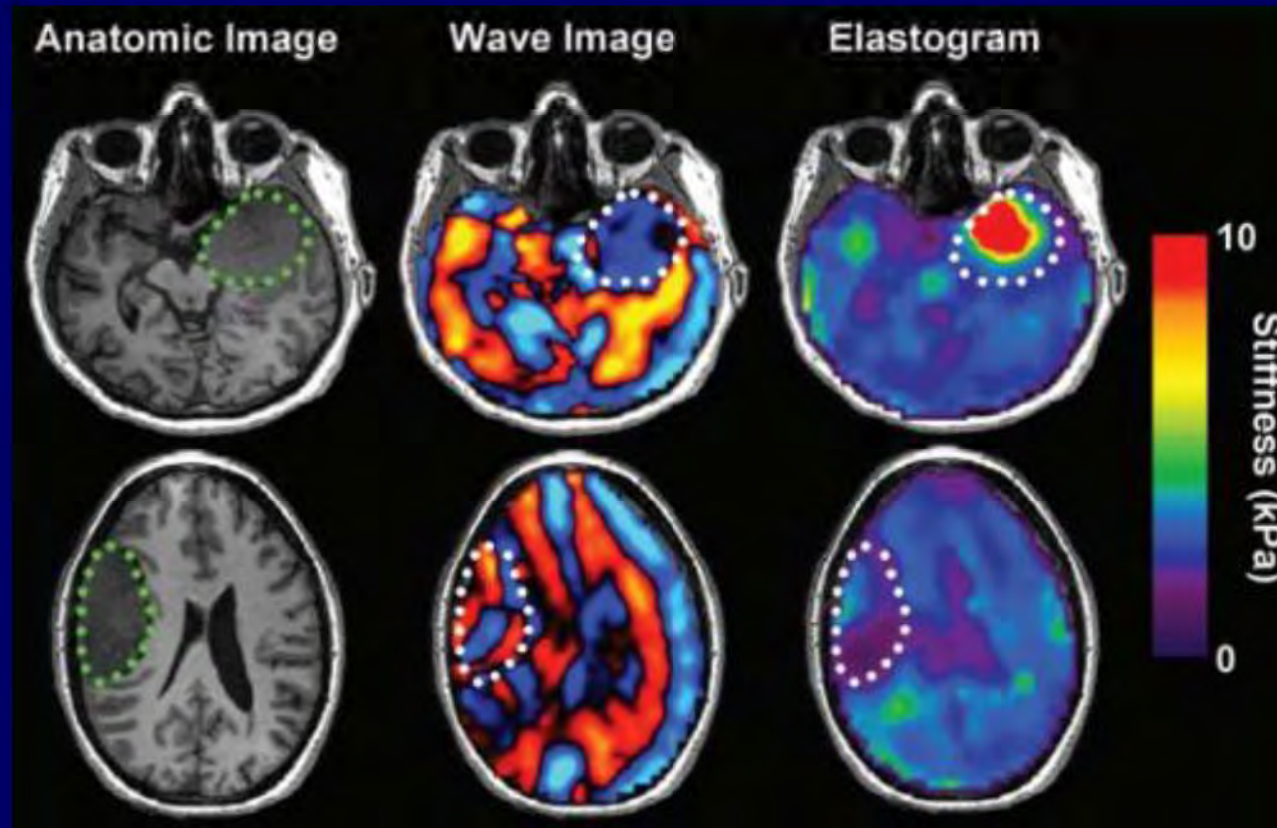
Murphy et al. (2013) J Neurosurg 118: 643-648.

- **Physical consistency has important implications for operative procedures**

Alzheimer's Disease
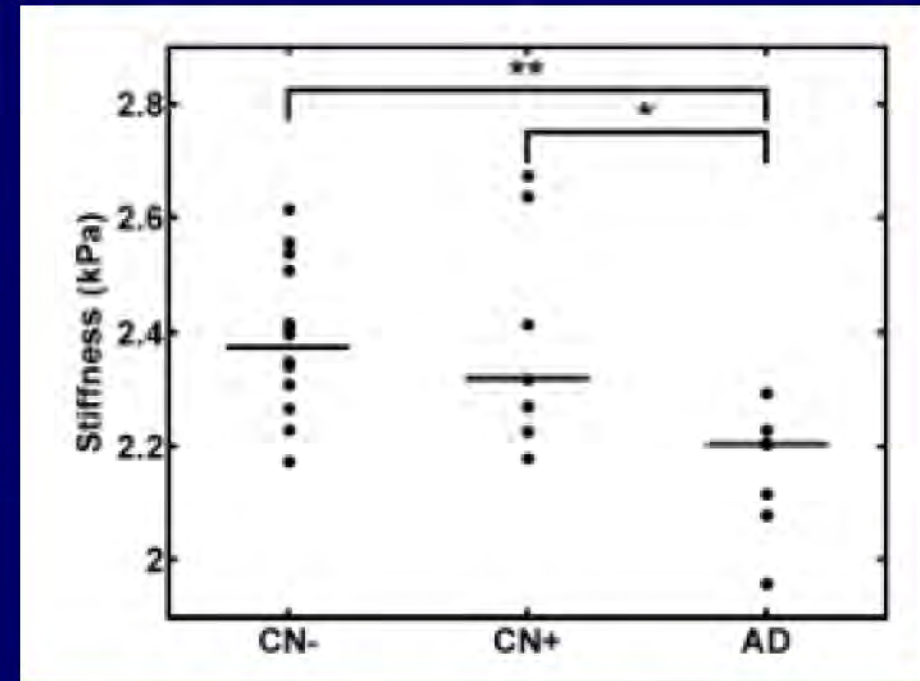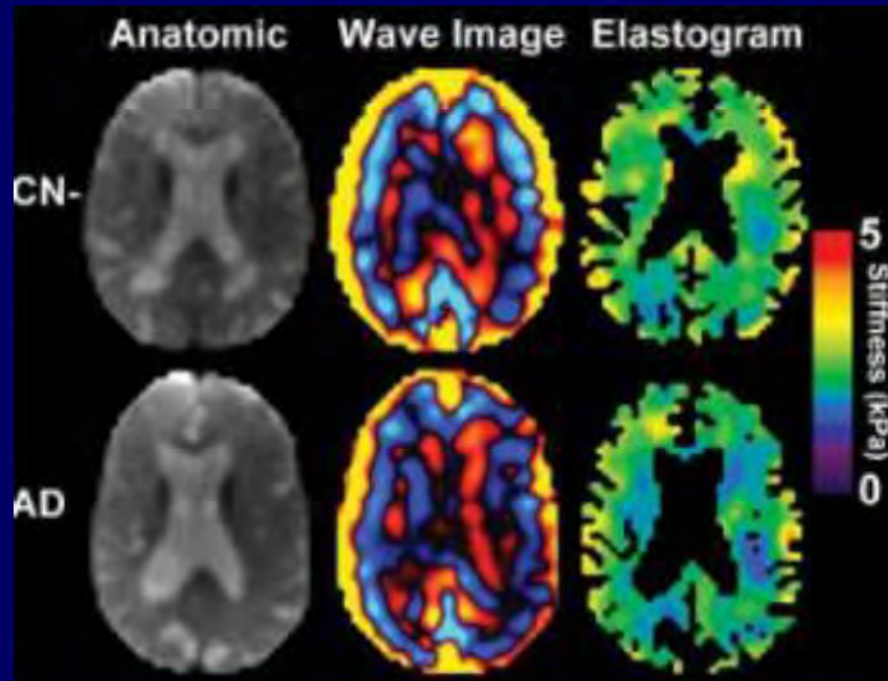
- **Significantly reduced brain tissue stiffness in Alzheimer's Disease (AD)**

Murphy et al. (2011) JMRI 34: 494-498.

Slip Interface Imaging (SII)

Octahedral Shear Strain (OSS)
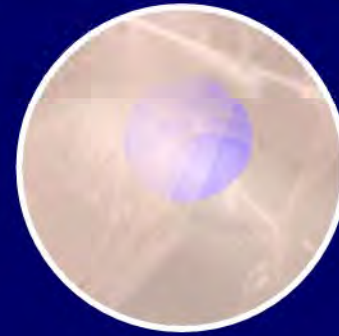
Surgical Findings
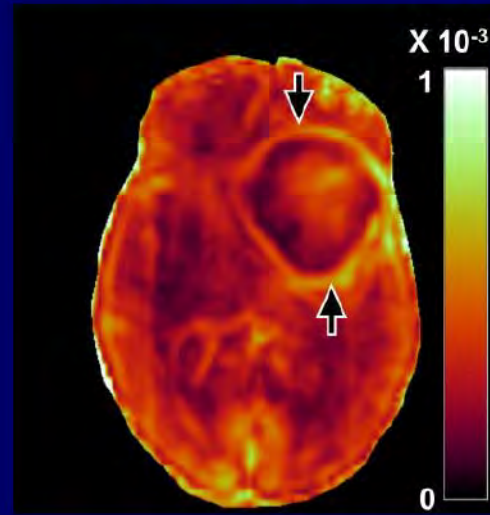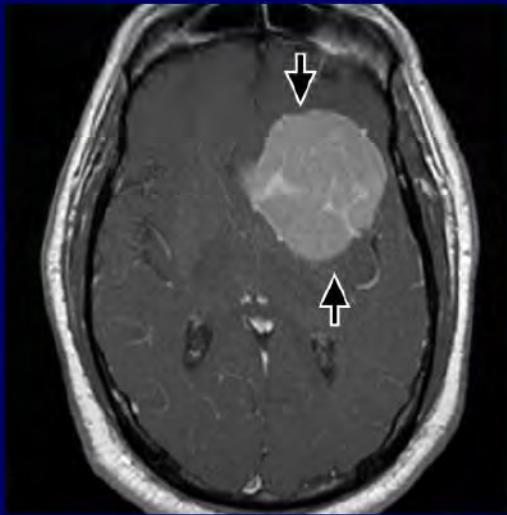
Slip Interface ⇒ No adhesion — No adhesion
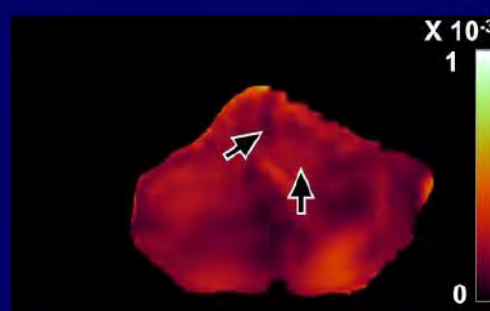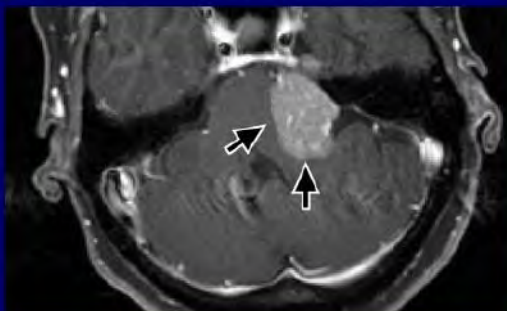
No slip Interface ⇒ Adhesion — Adhesion

Yin Z. et al.. ISMRM 2016, 4175

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- **Clinical Research and Applications**
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  - **Breast**

BIRADS (2013) for mammography, US, and MRI

| Likelihood of malignancy | Category 0: | Mammography: Incomplete – Need Additional Imaging Evaluation and/or Prior Mammograms for Comparison | | |
		Ultrasound & MRI: Incomplete – Need Additional Imaging Evaluation		
	Category 1:	Negative		
	Category 2:	Benign		
0% - 2%	Category 3:	Probably Benign		
2% - 95%	Category 4:	Suspicious	Mammography & Ultrasound:	Category 4A: Low suspicion for malignancy
				Category 4B: Moderate suspicion for malignancy
				Category 4C: High suspicion for malignancy
95%-100%	Category 5:	Highly Suggestive of Malignancy		
	Category 6:	Known Biopsy-Proven Malignancy		

- Category 4 has a large range of likelihood of malignancy, from 2% to 95%, which prompt many patients with only benign lesions being biopsied.
- While a high sensitivity can be achieved by breast MRI, high specificity or low false positive rate is desired to avoid biopsies on benign lesions to reduce medical cost, medical complications and patient anxieties.

Breast Self-exams: Palpation

http://www.hercampus.com/school/davidson/breast-self-examination-and-early-detection
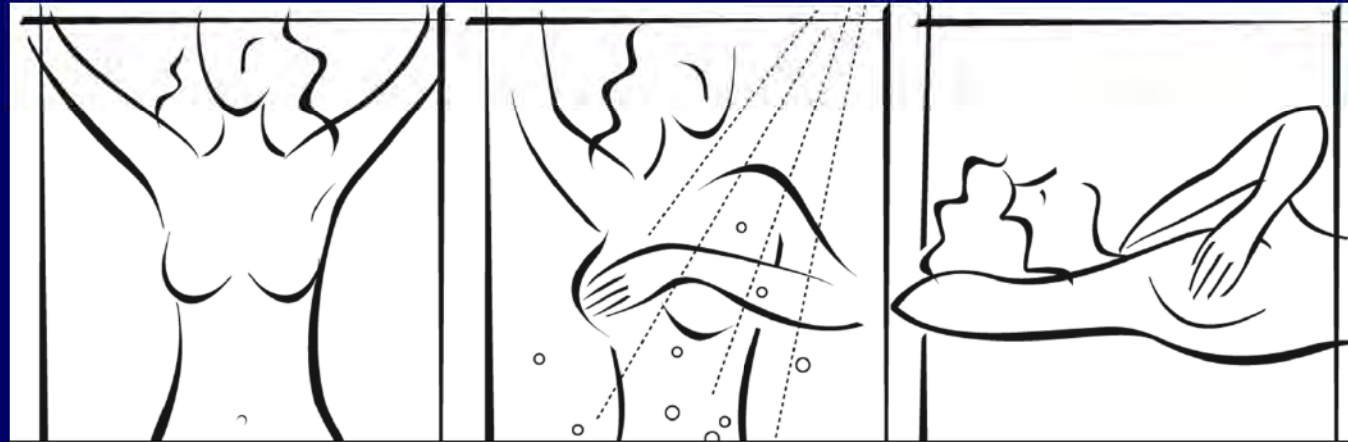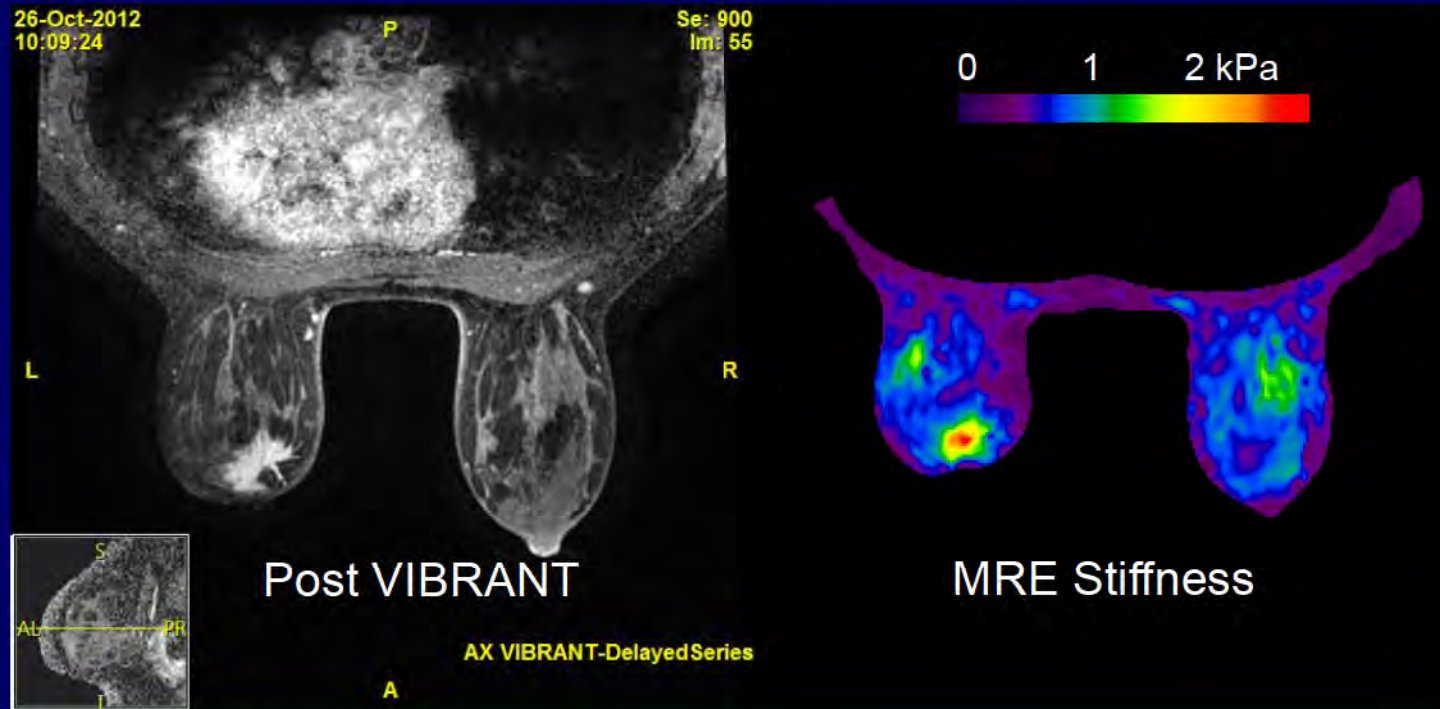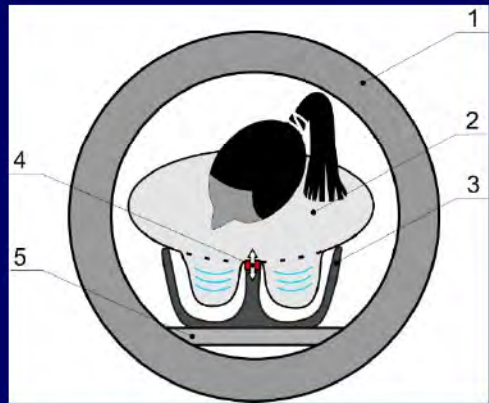
- **Normal breast tissue feels soft**

Soft

- **Breast lump can feel very stiff**
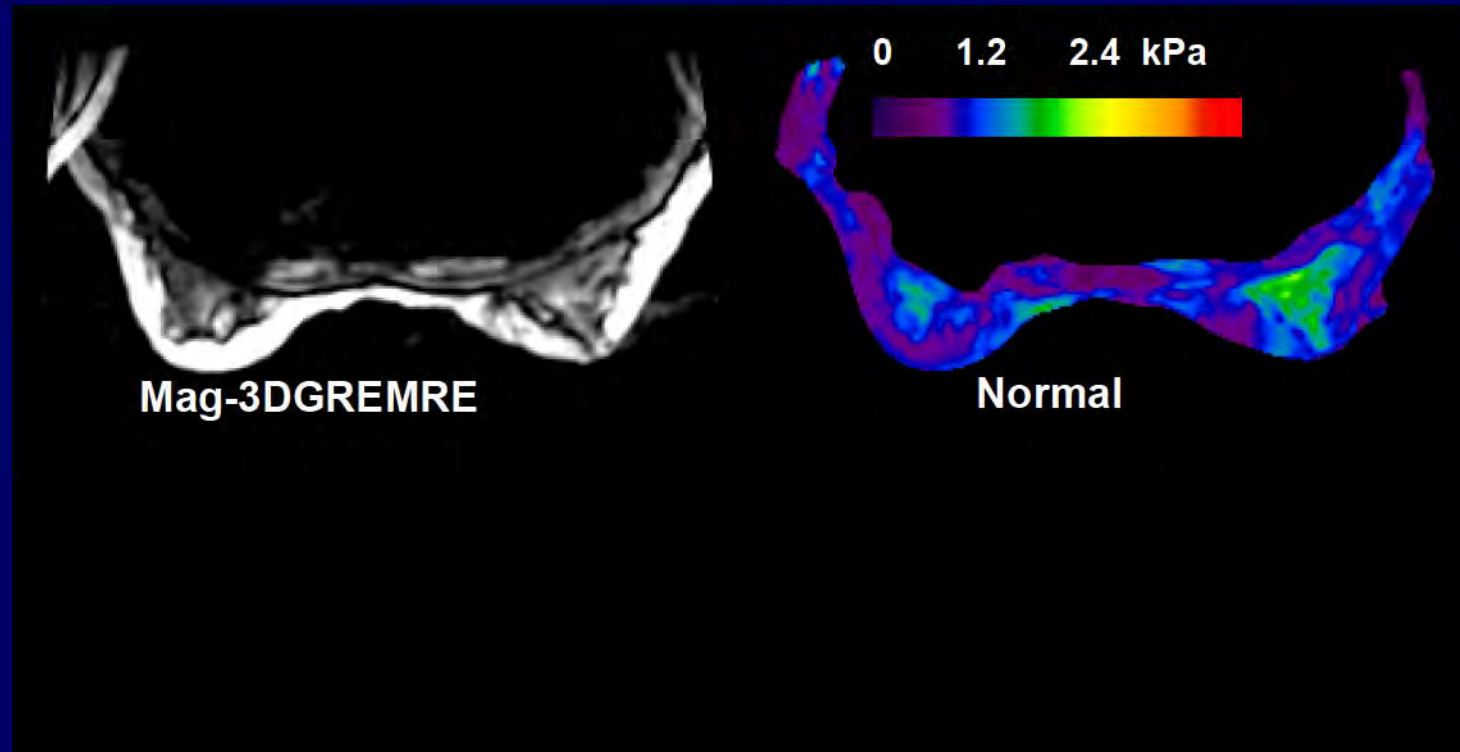

Stiff

A 41-year-old female patient with invasive ductal carcinoma

- **MRI BI-RADS:**
  - **6 Known biopsy proven malignancy.**
- **MRE**
  - **Adipose tissue = 0.41 ± 0.10 kPa,**
  - **glandular tissue = 0.90 ± 0.18 kPa**
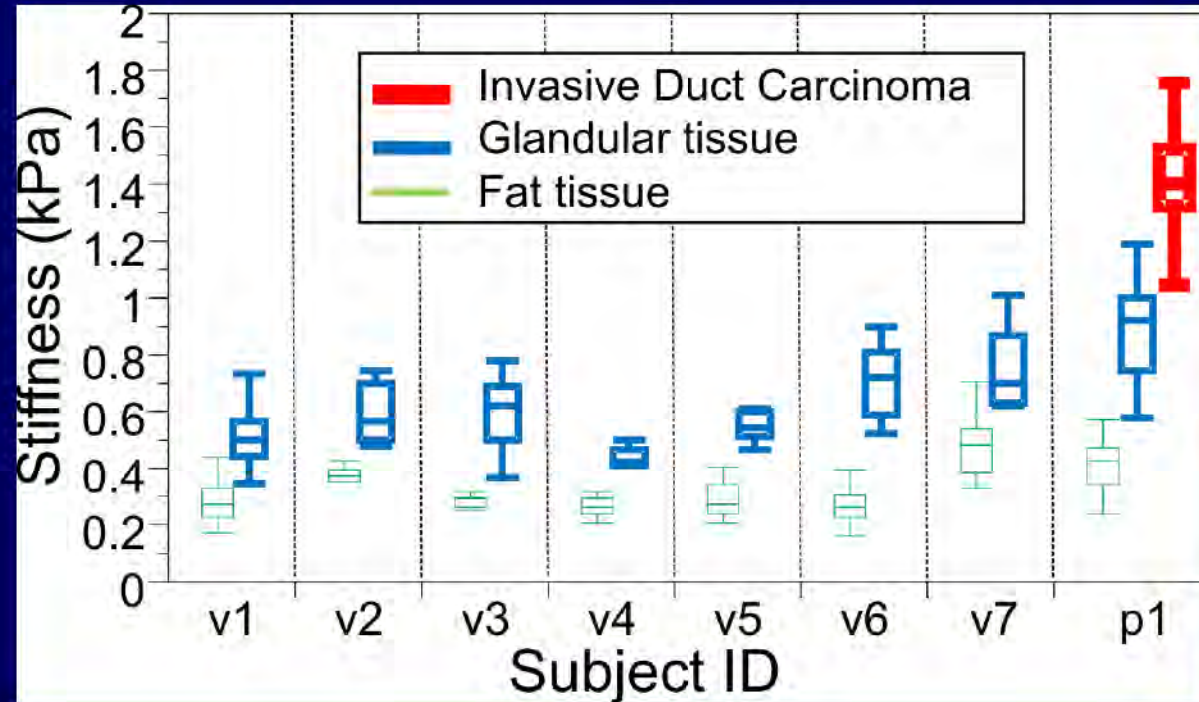 - **IDC = 1.42 ± 0.17 kPa.**

A 21 yo female volunteer without known breast disease

MRE:

- Fat stiffness = 0.30 - 0.59 kPa
- Fibroglandular stiffness = 0.57 - 1.0 kPa

Patient/Volunteer Data Summary

On-going studies at Mayo:
- MRE to reduce false positive ratio in BIRADS 4 and 5 (less biopsies in benign lesions).
- MRE to characterize/predict breast cancer in patients with dense breast tissue.

Magnetic Resonance Elastography

- Provides an array of new quantitative imaging biomarkers
- Basic technology platform now widely deployed worldwide
- Established as a reliable, more comfortable, and less costly alternative to liver biopsy for assessing hepatic fibrosis
- Many other promising applications (including kidney) are being explored

Thank you!