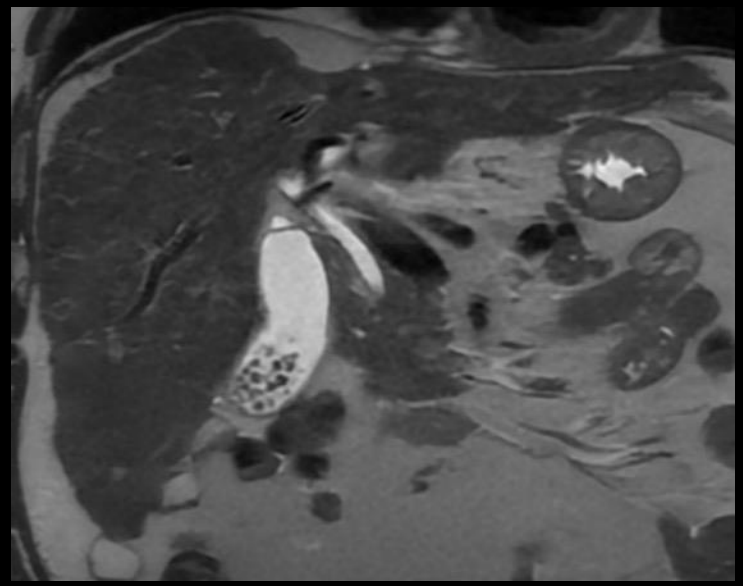
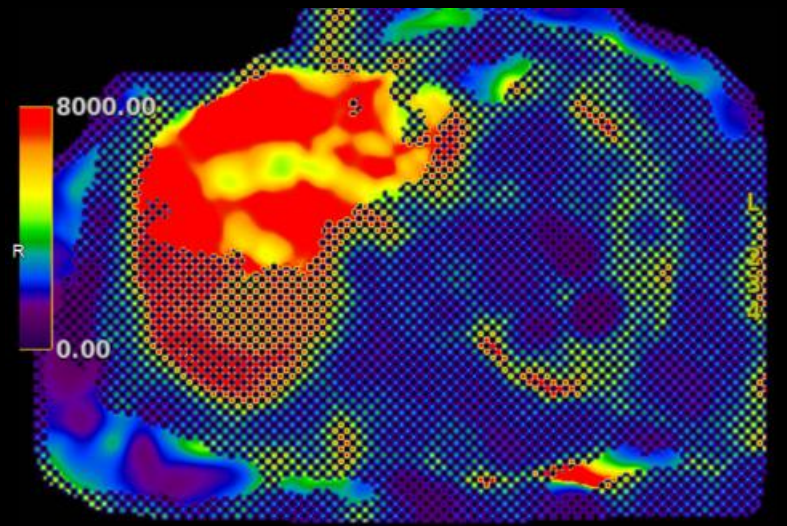
# MRI of cirrhosis






Dr David Bowden FRCR

Consultant HPB Radiologist
Cambridge University Hospitals

ESGAR Workshop: Abdominal MRI from Theory to Applications
February 2025

# Declarations

- None

# MRI of Cirrhosis

## Technique


Cambridge University Hospitals NHS

## Qualitative evaluation

Cambridge University Hospitals NHS

## Quantitative evaluation

Cambridge University Hospitals NHS

## Future directions?

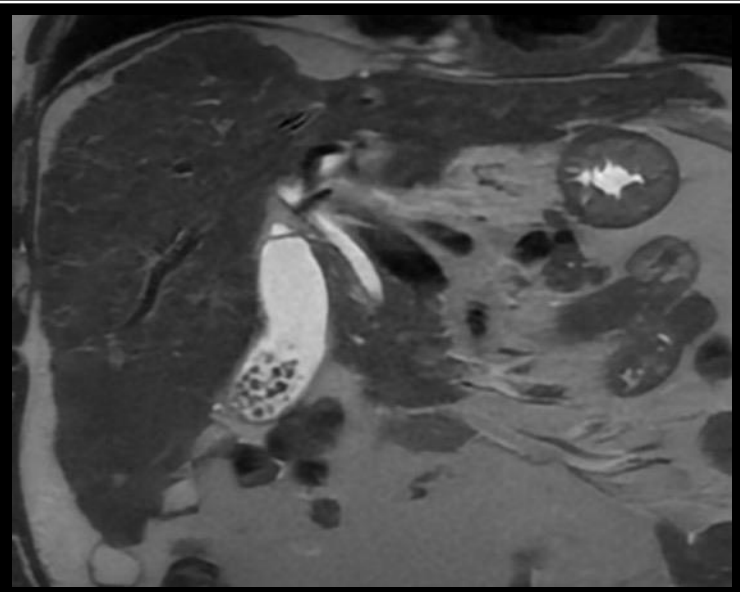
Cambridge University Hospitals NHS

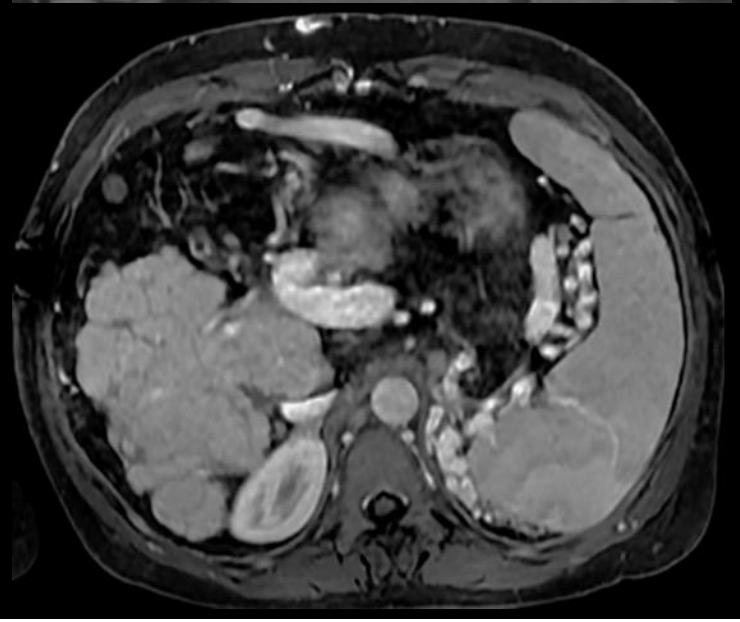
# Technique

# “You can’t make a silk purse out of a sow’s ear”


# MR Protocol – c.30 mins

- Coronal T2 single shot (3 mm SSFSE)
- Axial T2W single shot (5 mm SSFSE) +/- fatsat
- Dual echo T1W (IP/OP)
- IDEAL IQ – fat & iron quantification
- T1W GRE (LAVA/VIBE etc)
- T1W multiphase + Gd
- DWI – b100, b600 + computed/synthetic b1000
- Axial & Coronal T1W delayed
- Lava Star free breathing T1W delayed (c.70s)



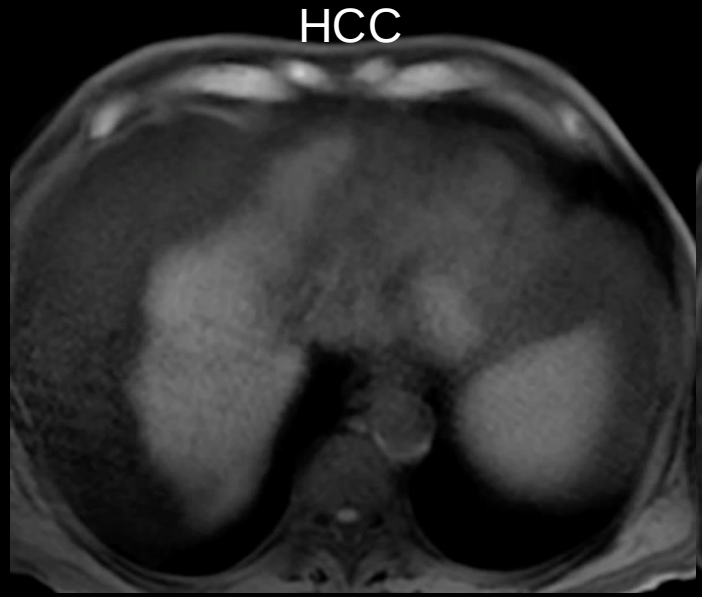


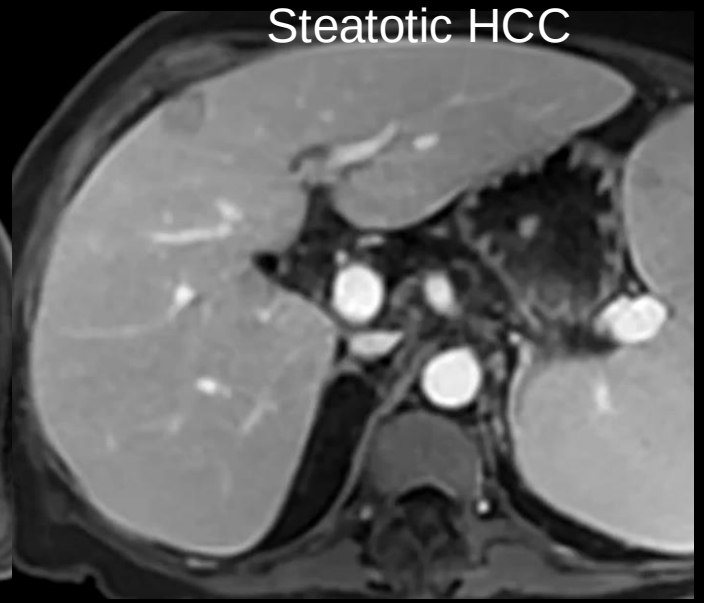
# Top tip – backup plan for difficult patients

- Coronal T2 single shot (3 mm SSFSE)
- Axial T2W single shot (5 mm SSFSE) +/- fatsat
- Dual echo T1W (IP/OP)
- IDEAL IQ – fat & iron quantification
- T1W GRE (LAVA/VIBE etc)
- T1W multiphase + Gd
  - Multiphase arterial/free breathing
  - eg.GRASP (Siemens)/DISCO Star (GE)
- DWI – b100, b600 + computed/synthetic b1000
- Axial & Coronal T1W delayed
- Lava Star free breathing T1W delayed (c.70s

**CT/MRI Diagnostic Table**

| Arterial phase hyperenhancement (APHE) | | No APHE | | Nonrim APHE | | |
|---|---|---|---|---|---|---|
| Observation size (mm) | | < 20 | ≥ 20 | < 10 | 10-19 | ≥ 20 |
| Count additional major features:<br>• Enhancing "capsule"<br>• Nonperipheral "washout"<br>• Threshold growth | None | LR-3 | LR-3 | LR-3 | LR-3 | LR-4 |
| | One | LR-3 | LR-4 | LR-4 | LR-4 / LR-5 | LR-5 |
| | ≥ Two | LR-4 | LR-4 | LR-4 | LR-5 | LR-5 |

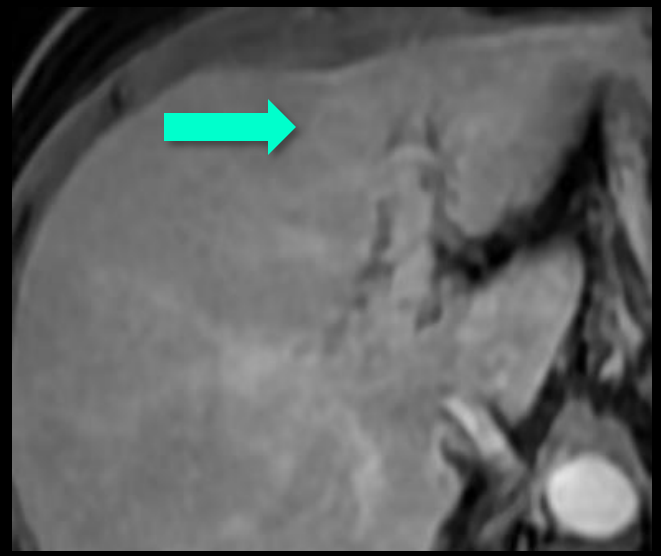


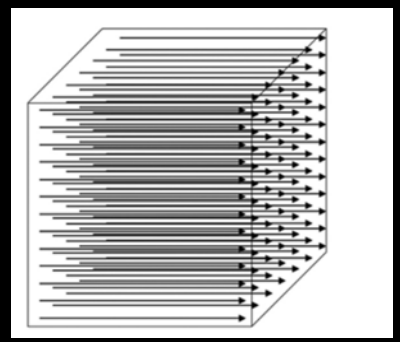

DISCO Star T1W + Gd – multiphase free breathing

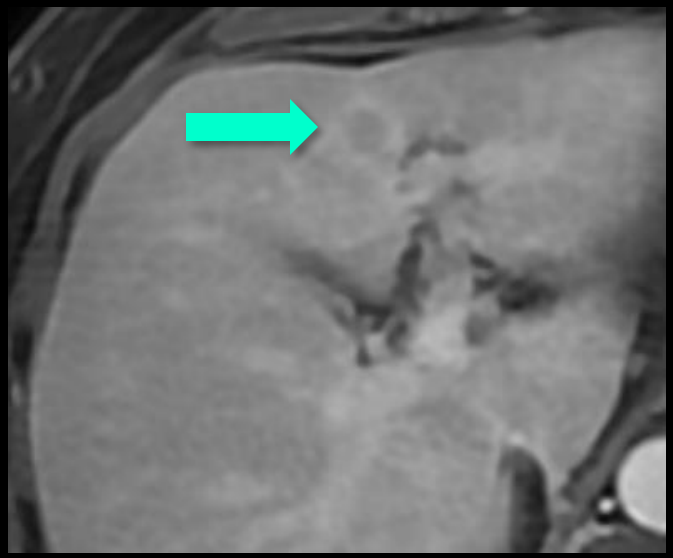
# Top tip – free breathing delayed phase

- Coronal T2 single shot (3 mm SSFSE)
- Axial T2W single shot (5 mm SSFSE) +/- fatsat
- Dual echo T1W (IP/OP)
- IDEAL IQ – fat & iron quantification
- T1W GRE (LAVA/VIBE etc)
- T1W multiphase + Gd
  - Multiphase arterial/free breathing
  - eg.GRASP (Siemens)/DISCO Star (GE)
- DWI – b100, b600 + computed/synthetic b1000
- Axial & Coronal T1W delayed
- Lava Star (GE) free breathing T1W delayed (c.70s)
  - StarVIBE (Siemens)/4D FB (Philips)



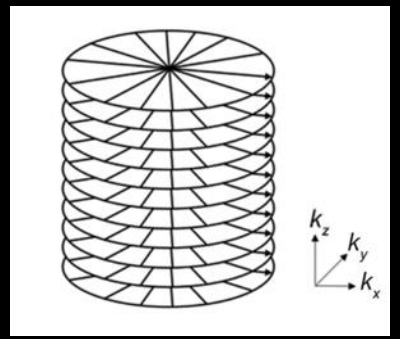
Cartesian k-space





Radial k-space trajectory

- → reduced motion artefact
- "Stack of stars"

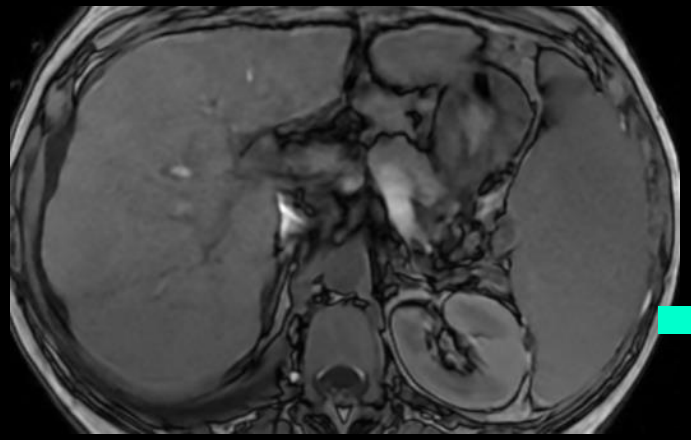


# Top tip – fat/iron quant

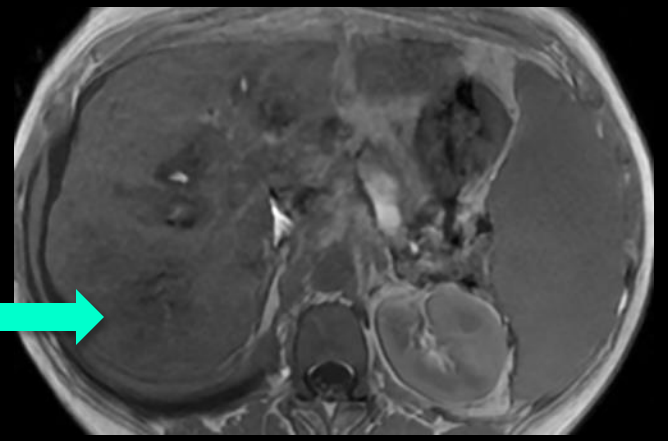
- Coronal T2 single shot (3 mm SSFSE)
- Axial T2W single shot (5 mm SSFSE) +/- fatsat
- Dual echo T1W (IP/OP)
- IDEAL IQ – fat & iron quantification
- T1W GRE (LAVA/VIBE etc)
- T1W multiphase + Gd
  - Multiphase arterial/free breathing
  - eg.GRASP (Siemens)/DISCO Star (GE)
- DWI – b100, b600 + computed/synthetic b1000
- Axial & Coronal T1W delayed

- Fe overload – 10-30% of pts with chronic liver dz
- Dual echo unreliable (coexisting steatosis/iron?)

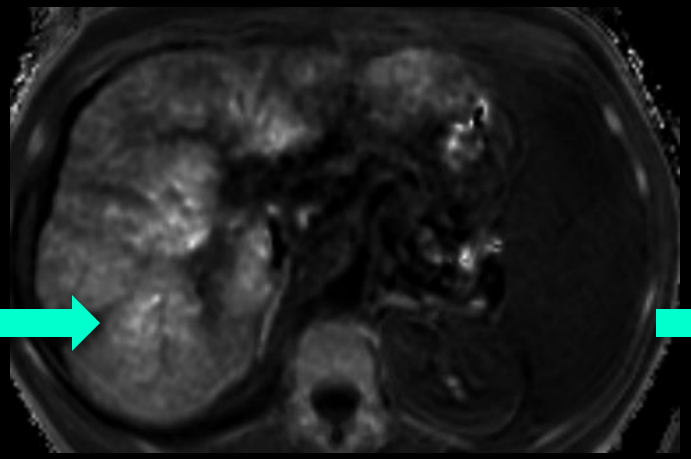
Unexpected Fe overload – moderate severity



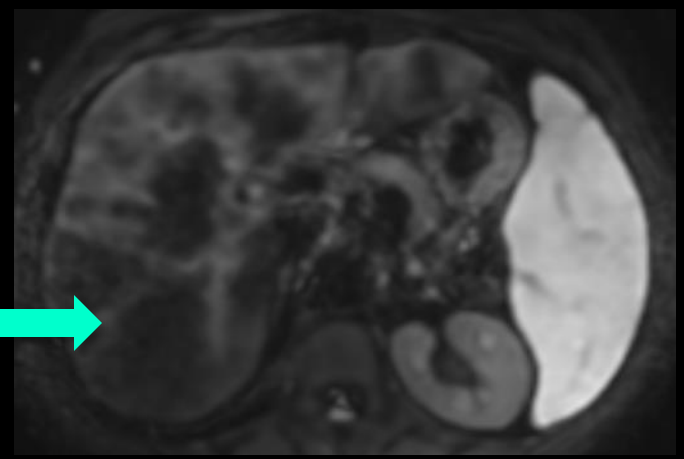
Dual echo OP 2.3 ms



IP 4.6 ms



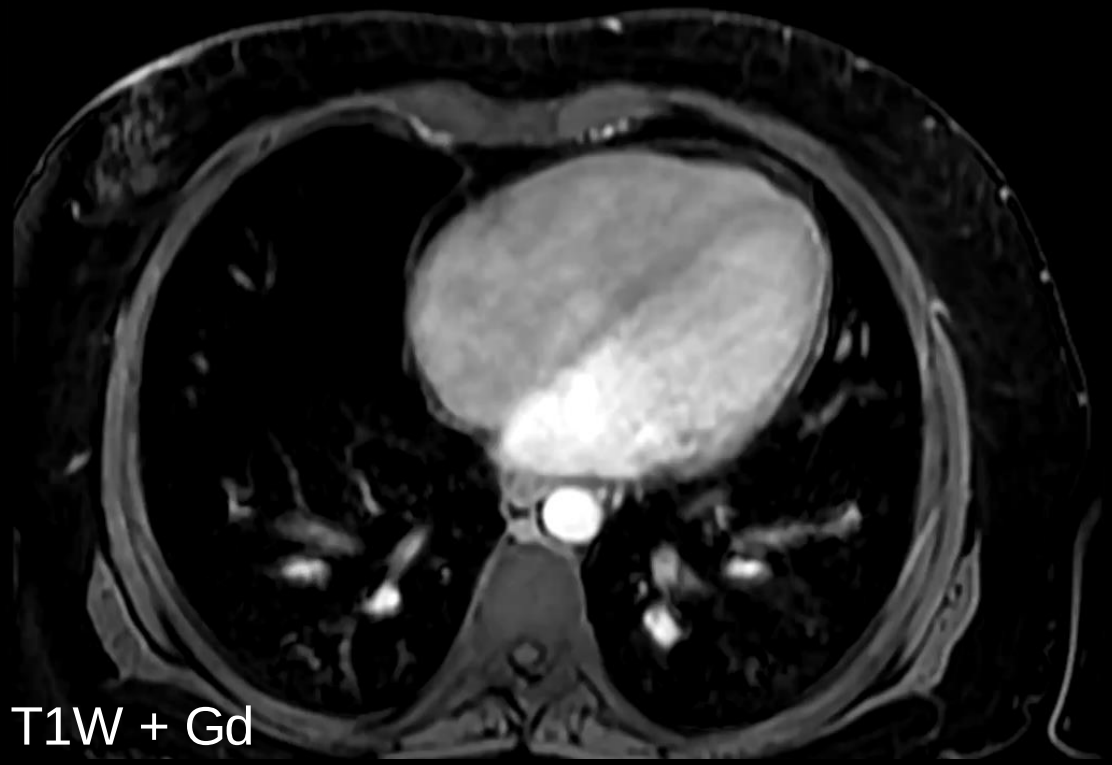
IDEAL IQ – R2*



DWI b600

# Qualitative evaluation

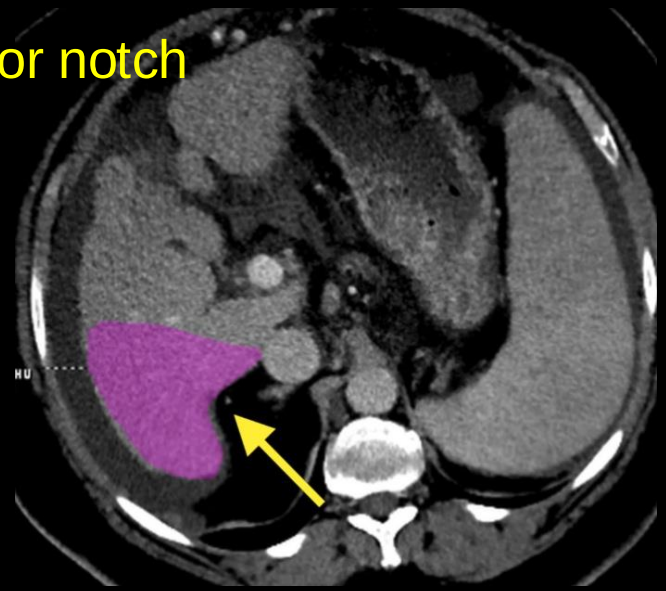
# Morphologic changes - limitations

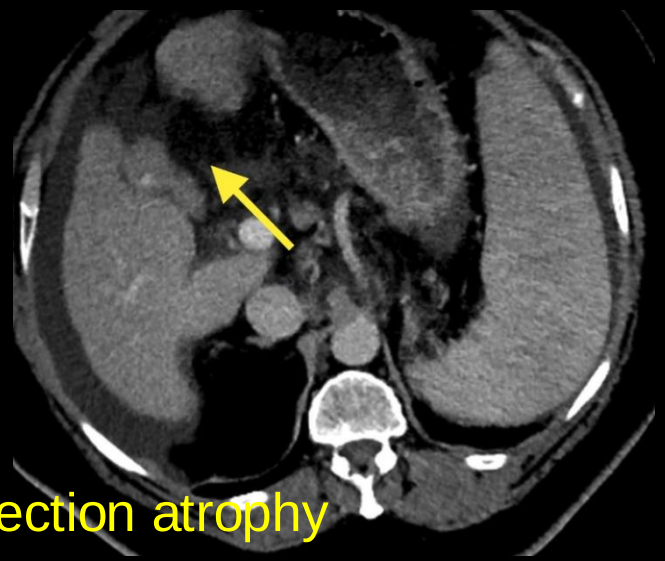


T1W + Gd

- Often more subtle at MR

Right posterior notch

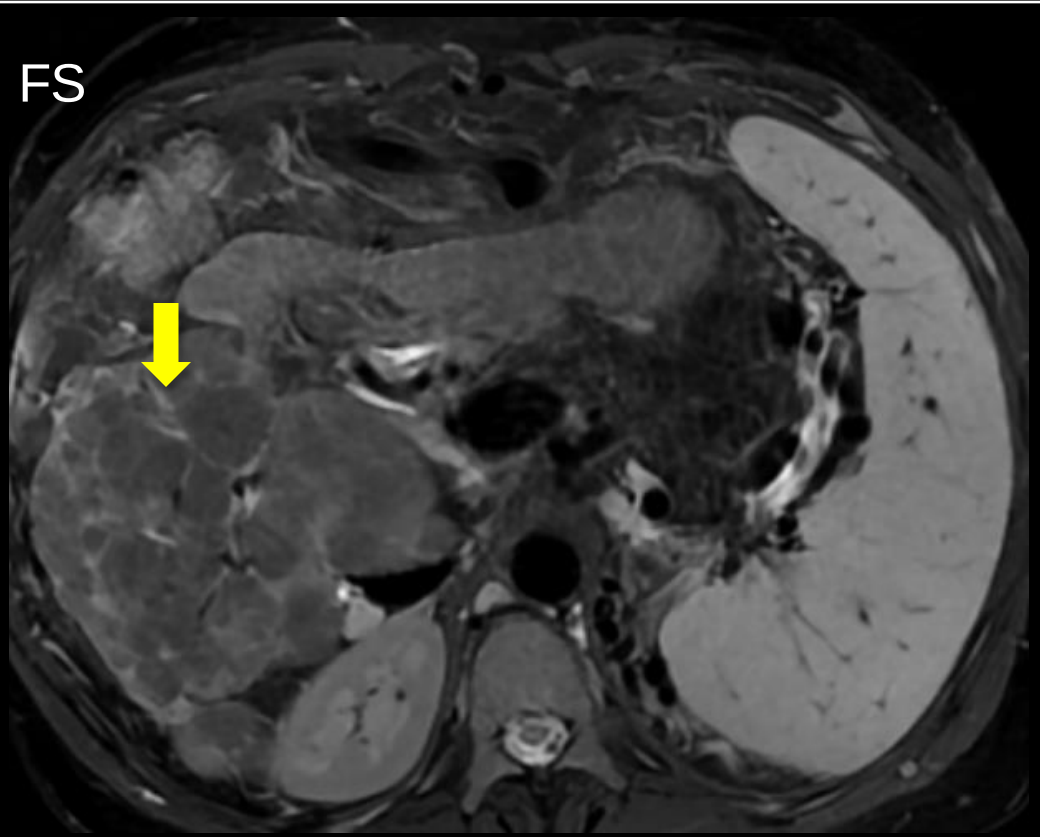




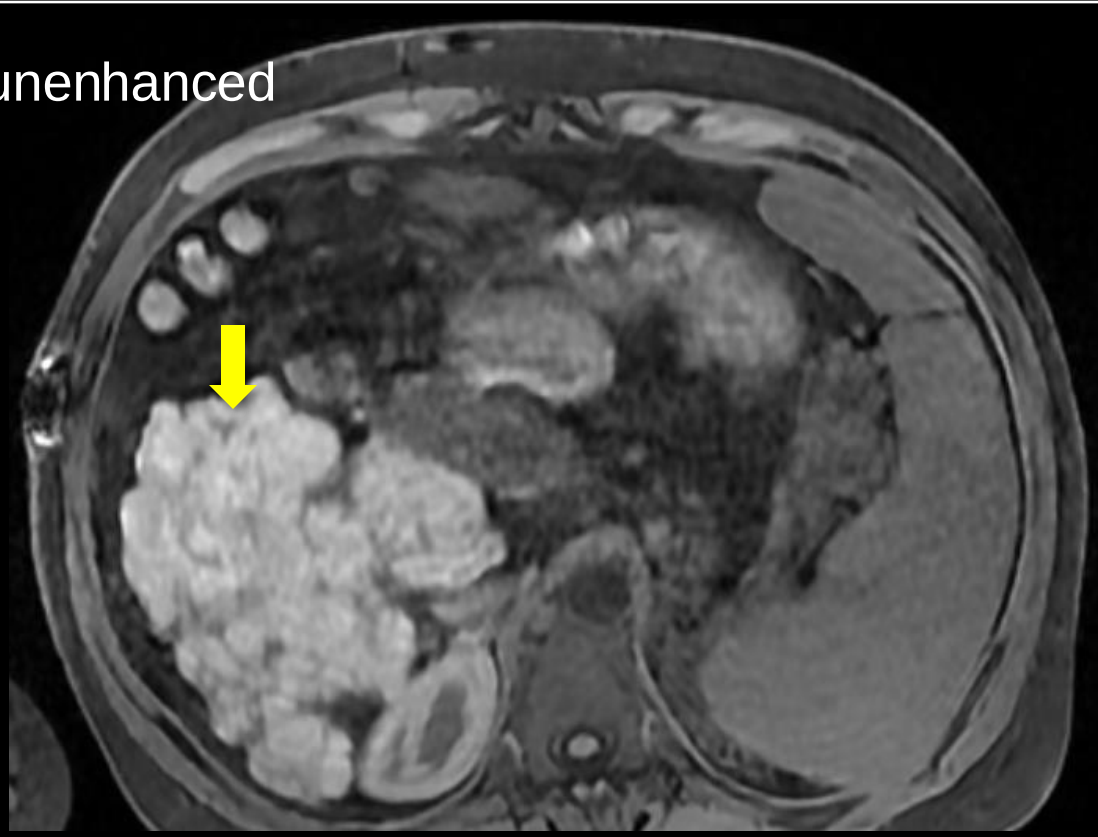
Left medial section atrophy

# Parenchymal changes – fibrosis

T2 FS



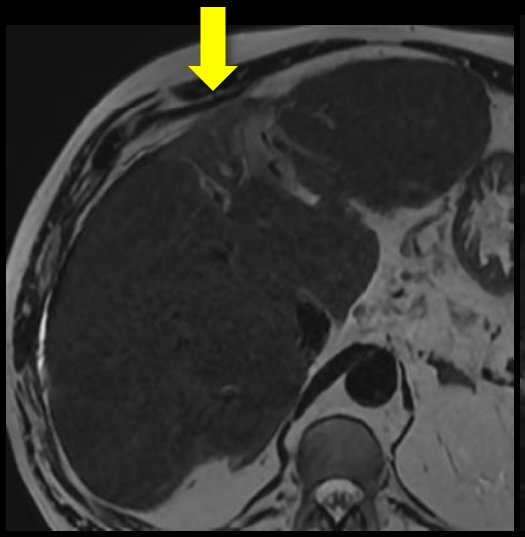
T1 - unenhanced



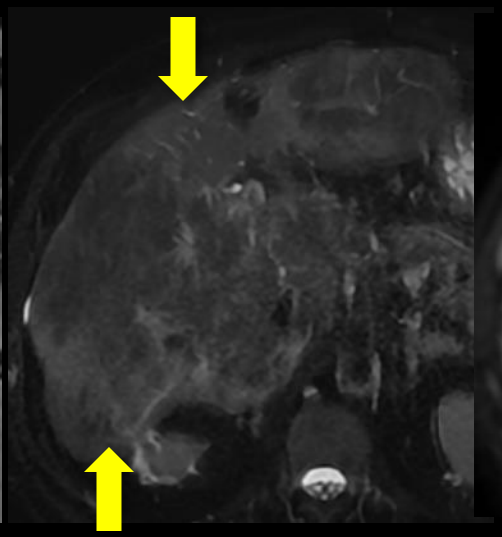
- Increased $H_2O$ content within fibrosis → increased T1 & T2 relaxation times
- Bands of T2 hyper/T1 hypointensity

# Parenchymal changes – confluent fibrosis

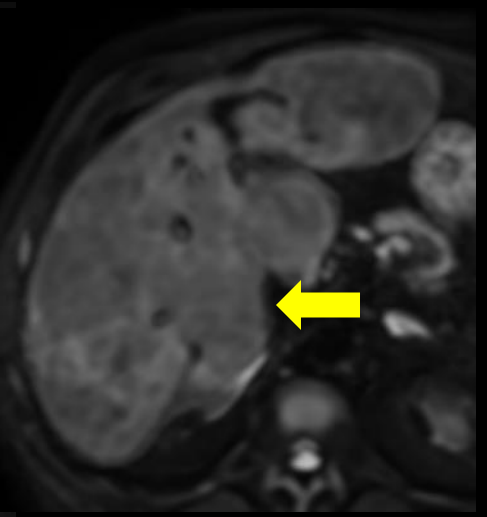
T2



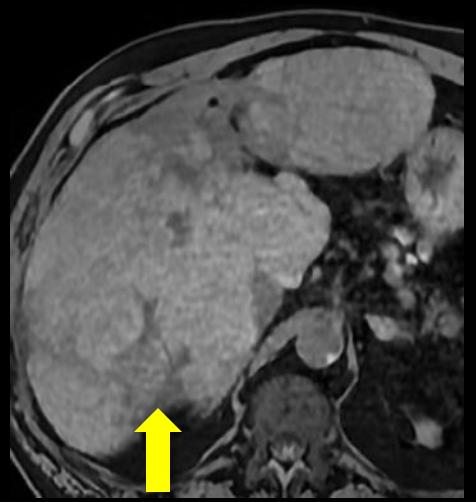
T2 FS



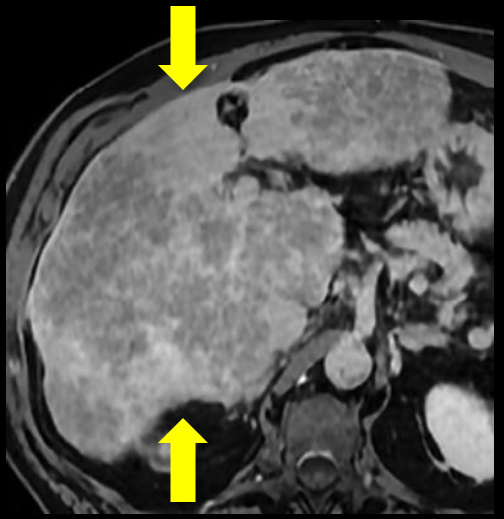
b600 DWI



T1



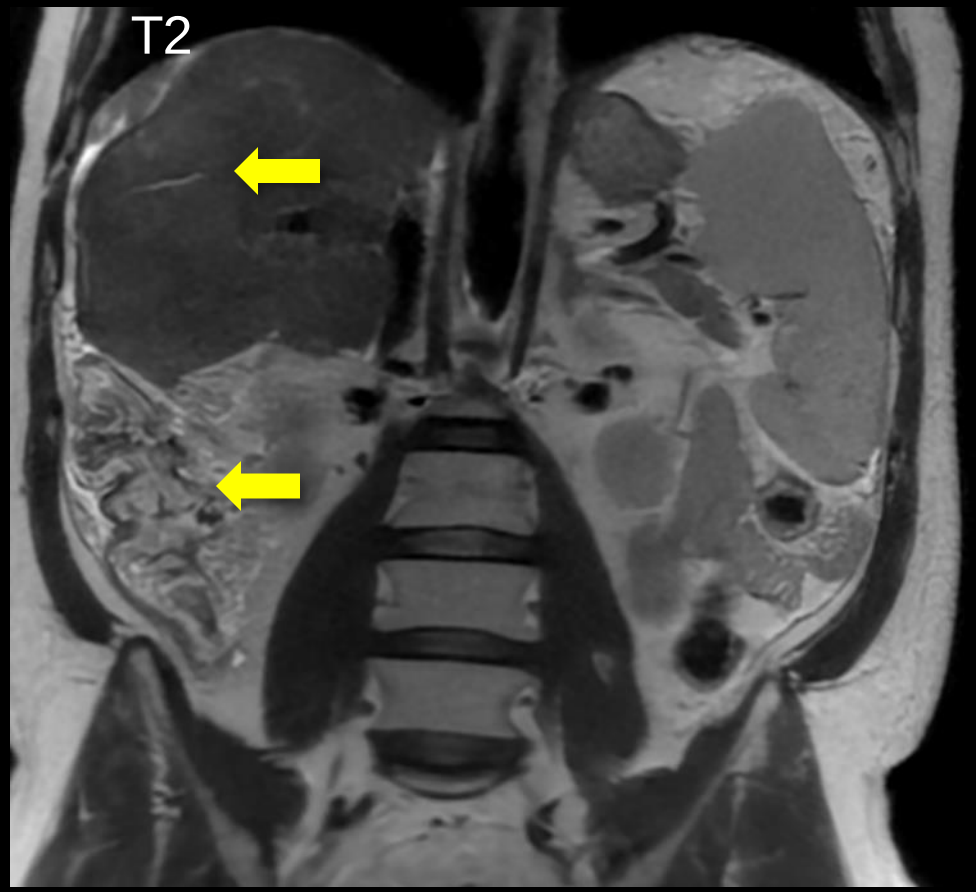
T1 + Gd – 4 min

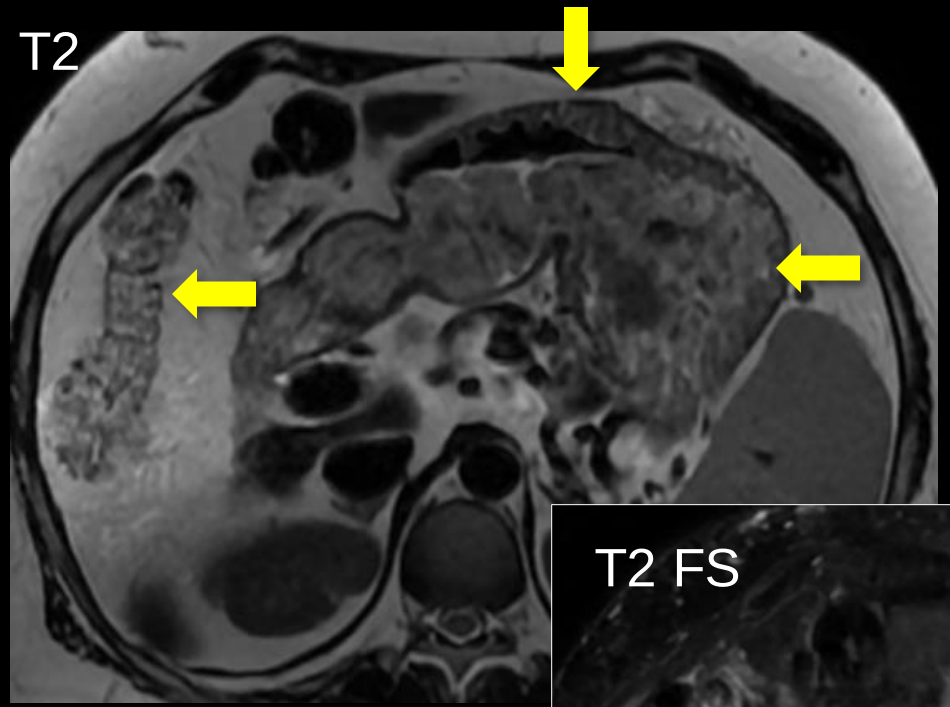


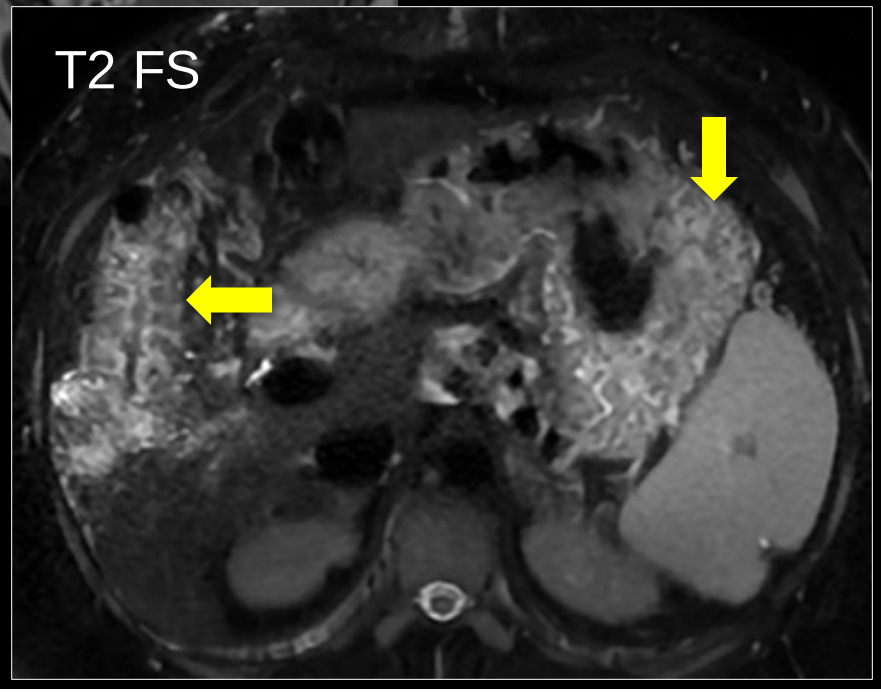
CT

- Subtle on CT
- T2 hyperintensity – esp fatsat, delayed enhancement
- Capsular retraction
  - Confluent fibrosis vs CCA? Biliary dilatation?

# Ancillary features

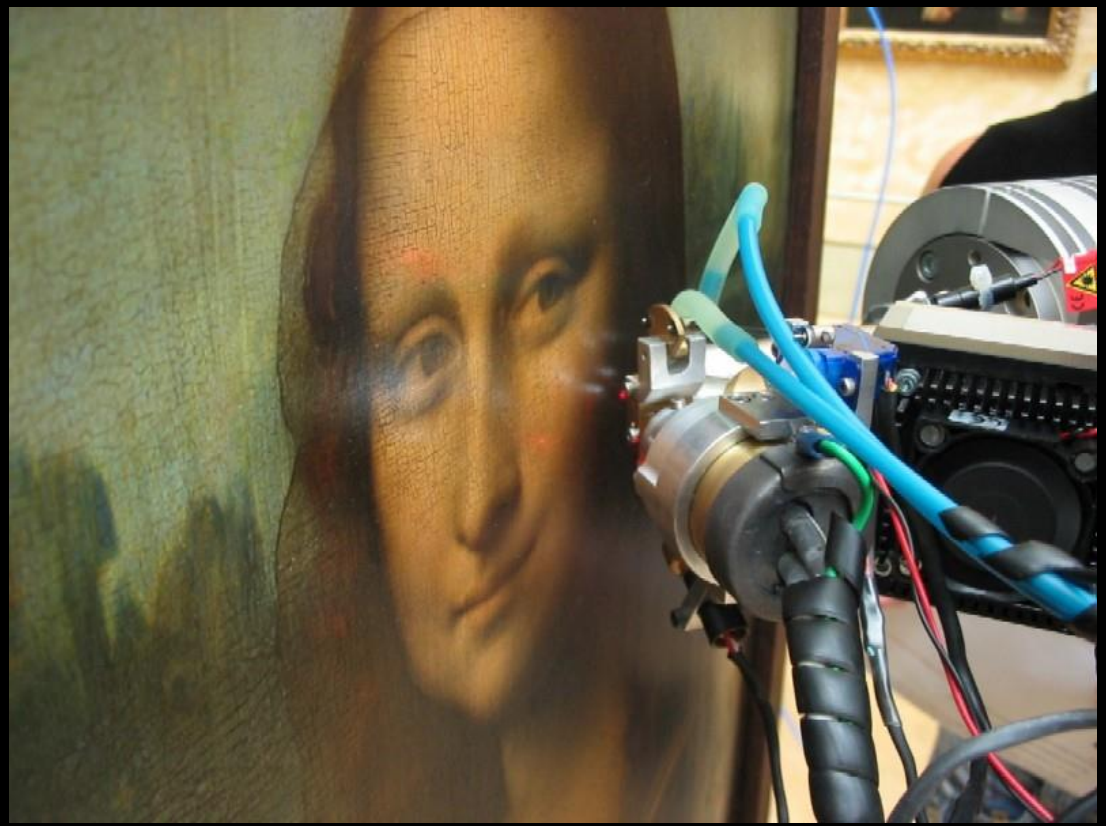


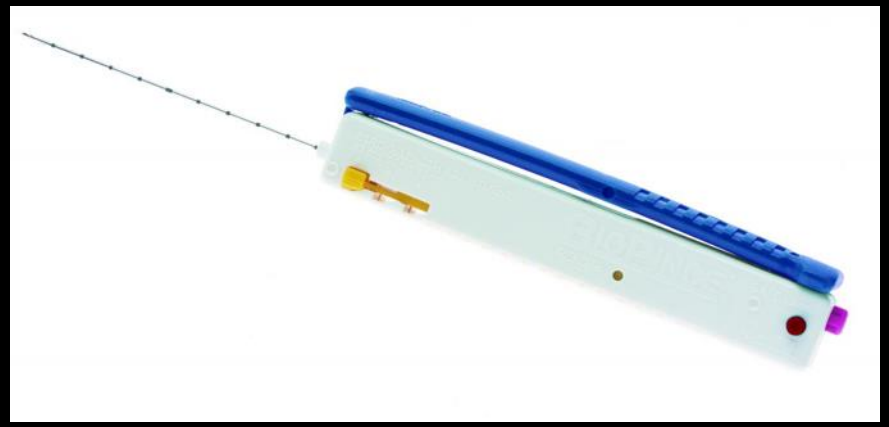



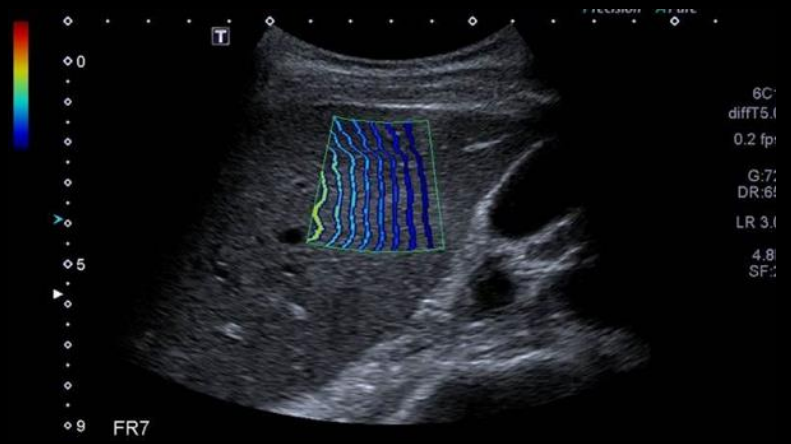

- Portal colopathy, enteropathy, gastropathy

# Quantitative evaluation

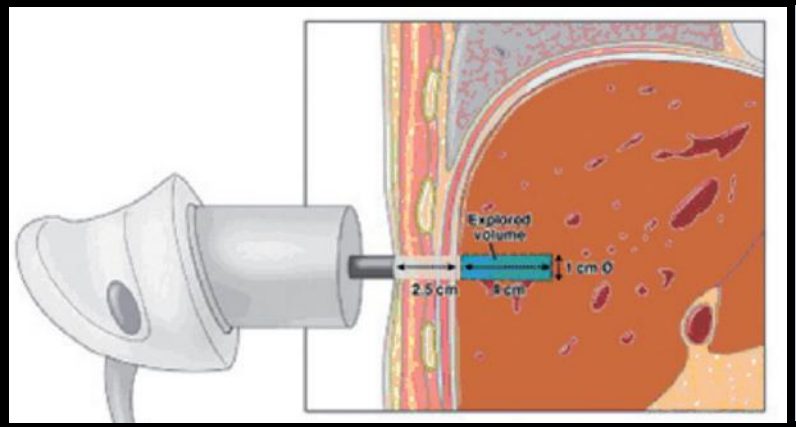


# How to diagnose fibrosis/cirrhosis?






2D shear wave elastography



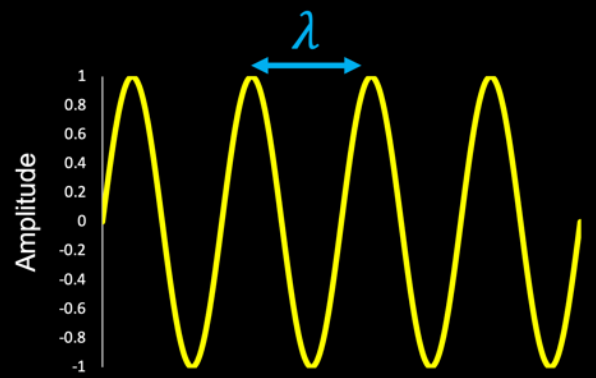

- 1/2000 liver
- 6 cm depth

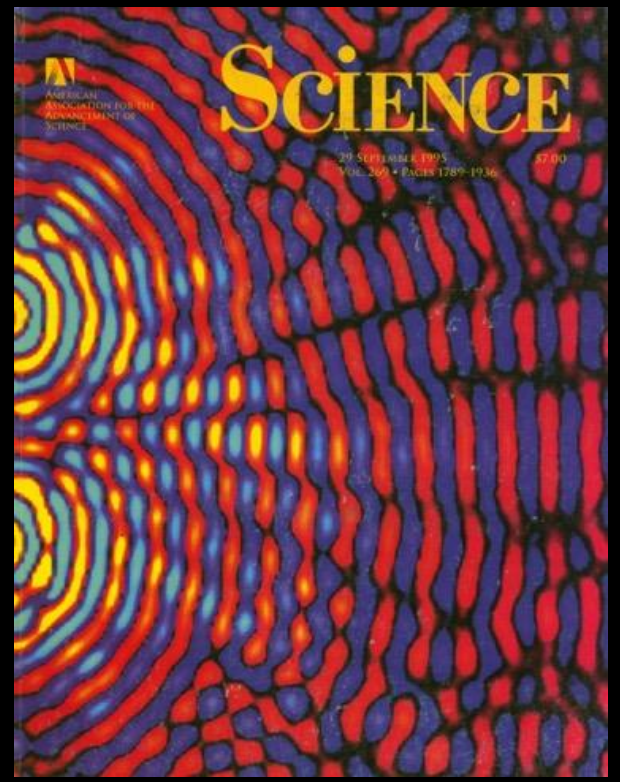
Transient elastography (“Fibroscan”)

www.fibroscan.com

- Patient factors: obesity, ascites
- No images for guidance
- Limited sampling

# Magnetic Resonance Elastography (MRE)

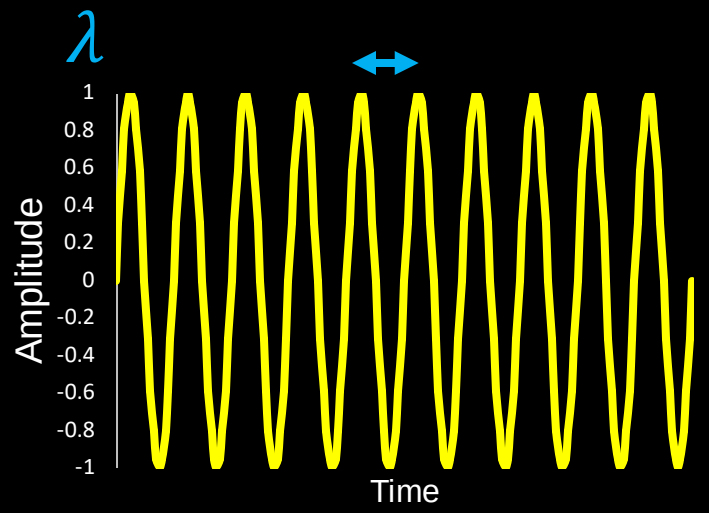


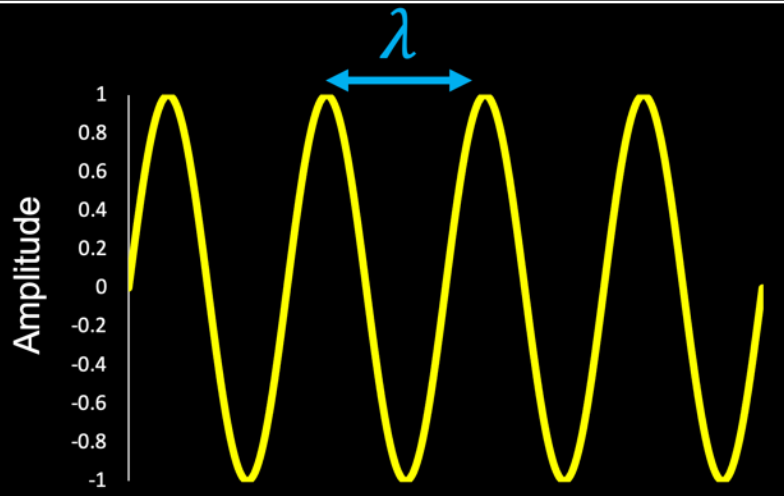

- Mechanical waves → measure shear modulus (shear stiffness) of tissues?
- 1995 Mayo group (Ehman et al)
- FDA approval – 2009 (GE), Siemens (2012), Philips (2014)

Muthupillai et al Science 269:1854-1857 (1995)

# Elastography – ”Palpation with MRI”

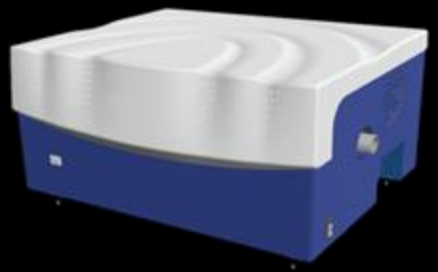



- Low elasticity (soft tissues)
- Shorter wavelength
- Lower velocity

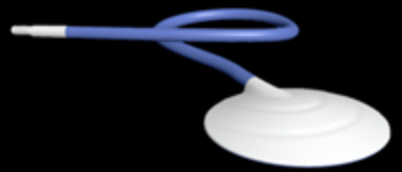



- High elasticity (stiff tissues)
- Longer wavelength
- Greater velocity

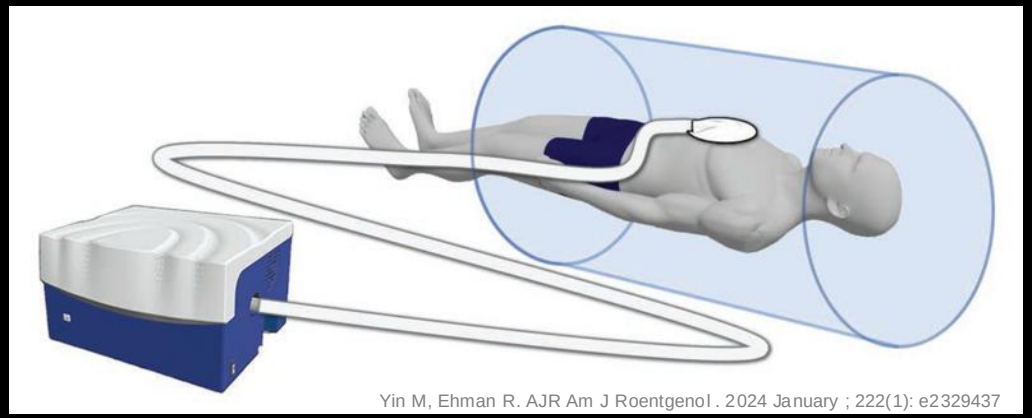
# Commercial MRE system



Active Driver – longitudinal waves



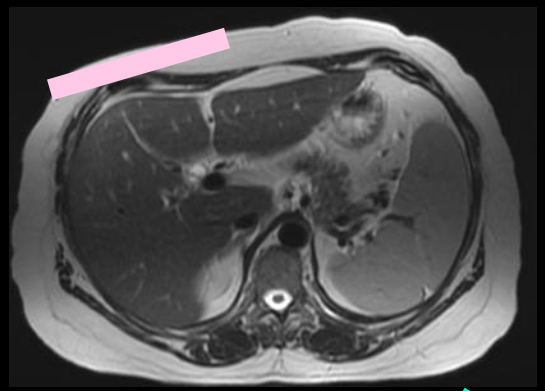
Passive Driver – acoustic vibration

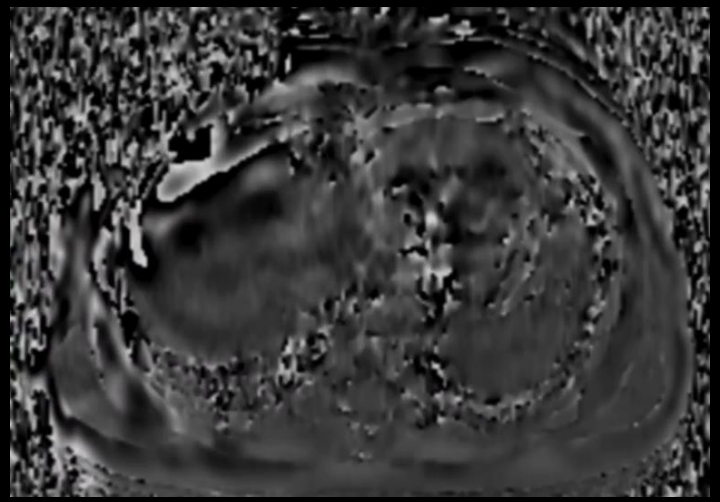


Yin M, Ehman R. AJR Am J Roentgenol . 2024 January ; 222(1): e2329437

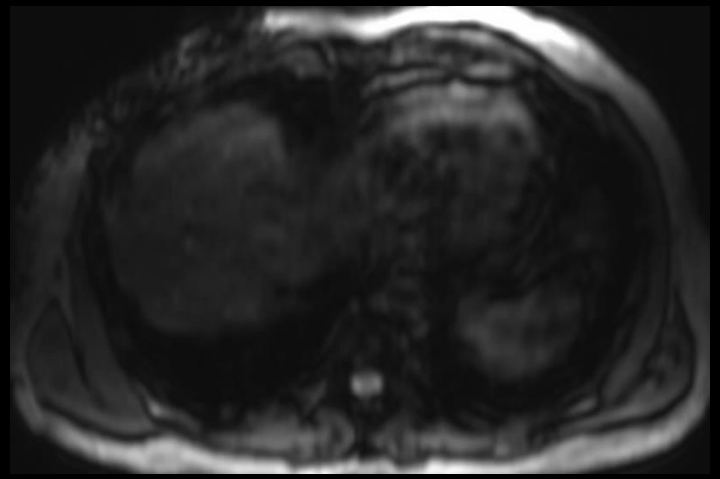
Longitudinal waves (~60 Hz) converted within tissues to shear waves

# Example output images



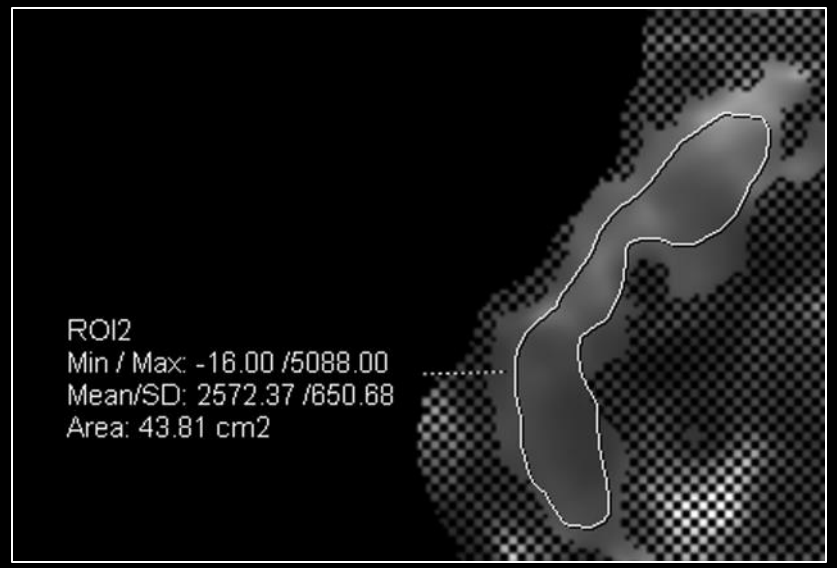


Phase images x 4



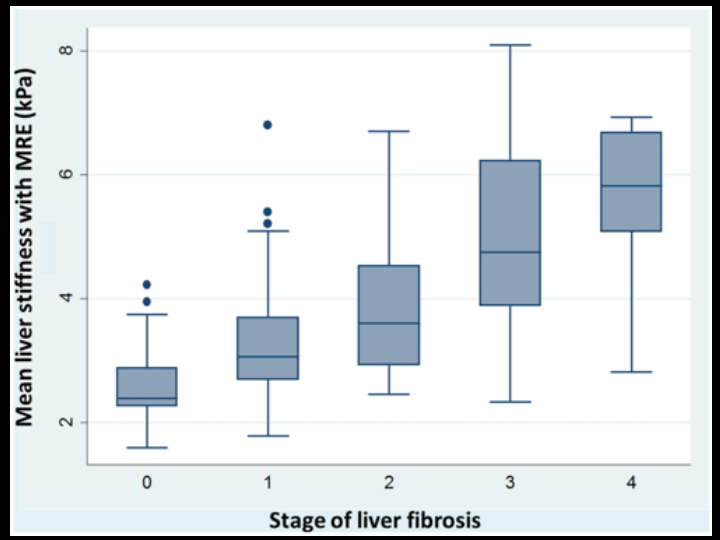
Magnitude images x 4

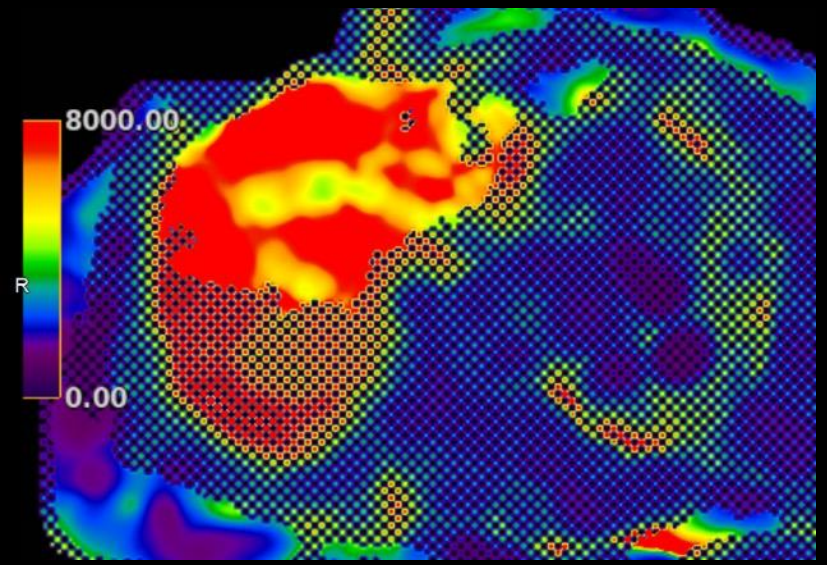
# Results




| Mean liver stiffness | Fibrosis stage |
|---|---|
| < 2.5 kPa | Normal |
| 2.5 to 3.0 kPa | Normal or inflammation |
| 3.0 to 3.5 kPa | Stage 1–2 fibrosis |
| 3.5 to 4.0 kPa | Stage 2–3 fibrosis |
| 4.0 to 5.0 kPa | Stage 3–4 fibrosis |
| > 5.0 kPa | Stage 4 fibrosis or cirrhosis |

Abdom Radiol (NY) . 2022 January ; 47(1): 94–114



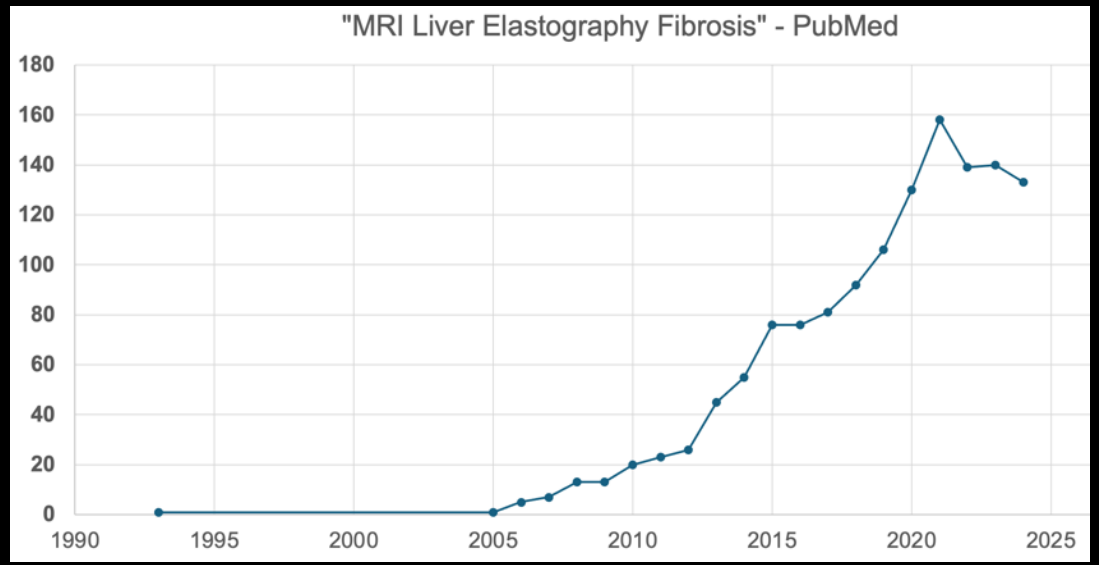




Weighted mean of 4 slices calculated:

- “Significant” fibrosis = ≥ F2
- “Advanced” fibrosis = ≥ F3
- Cirrhosis = F4

# How well does MRE perform?

- Extensive literature: >500 studies
- High +ve and –ve predictive values
- Generally outperforms transient elastography, shear wave US, T1 mapping, DWI, IVIM…. [1]



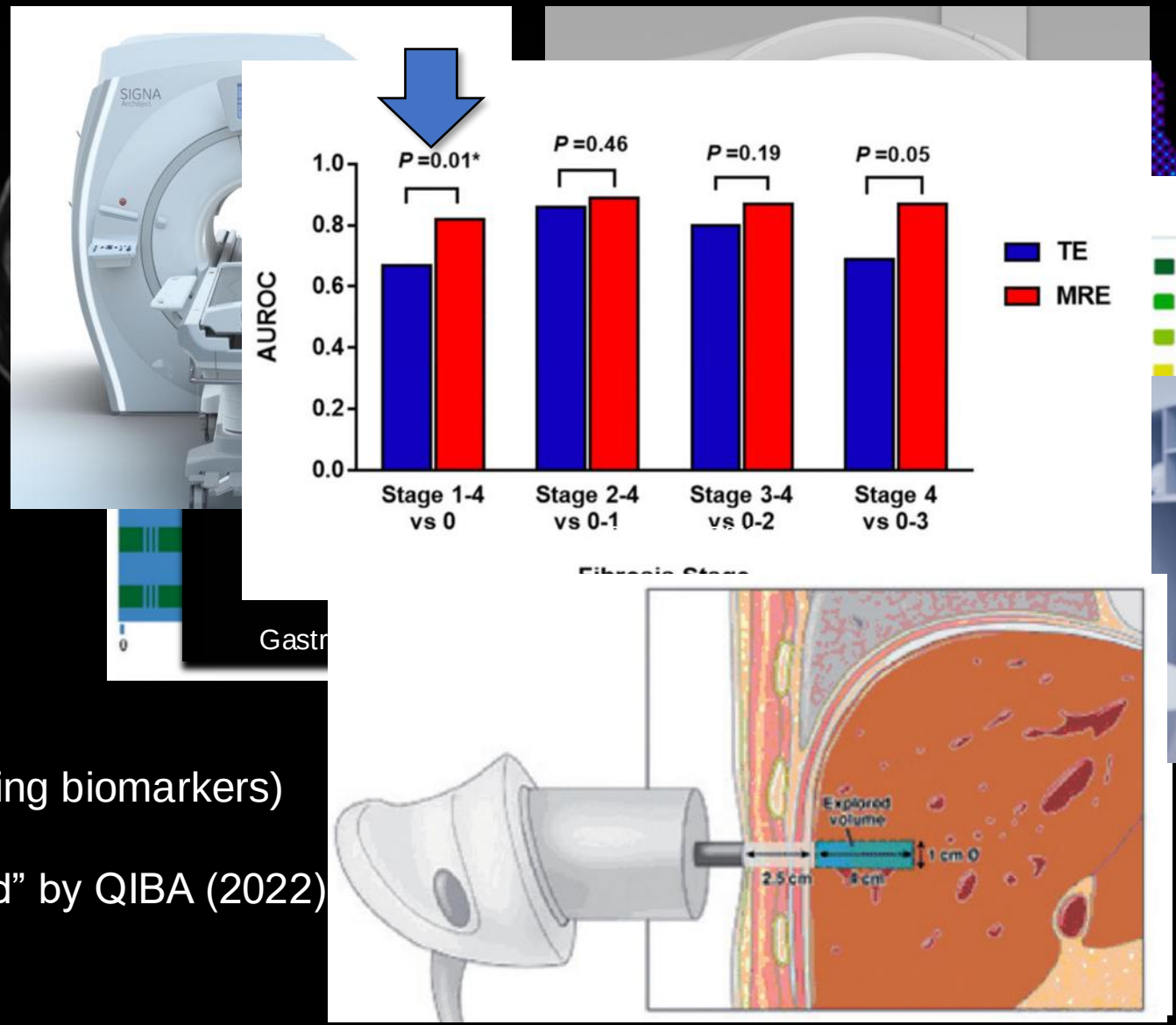

| Fibrosis Stage | Optimal cut-off (kPa) | AUROC (95% CI) | Sensitivity | Specificity |
|---|---|---|---|---|
| Any Fibrosis (≥Stage 1) | 3.45 | 0.84 (0.76–0.92) | 0.73 | 0.79 |
| Significant Fibrosis (≥Stage 2) | 3.66 | 0.88 (0.84–0.91) | 0.79 | 0.81 |
| Advanced Fibrosis (≥Stage 3) | 4.11 | 0.93 (0.90–0.95) | 0.85 | 0.85 |
| Cirrhosis (Stage 4) | 4.71 | 0.92 (0.90–0.94) | 0.91 | 0.81 |

Singh et al. Clin Gastroenterol Hepatol. 2015 Mar;13(3):440-451

1. Yin M, Ehman R. AJR Am J Roentgenol . 2024 January ; 222(1): e2329437

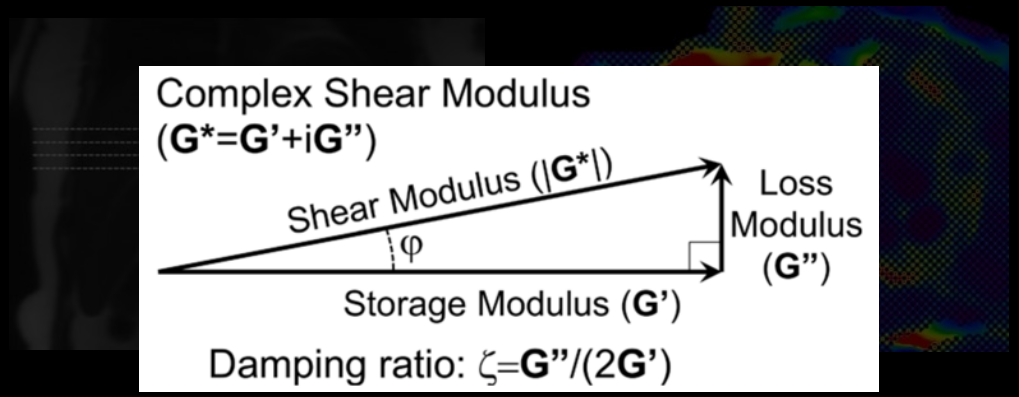
# Advantages of MRE

1. Very low technical failure rate (c.5%)
2. Limited impact of obesity (cf TE/ARFI)
3. Minimal impact of ascites
4. Superior performance to TE or ARFI
5. Common thresholds regardless of aetiology
6. No impact from steatosis (cf. TE/ARFI)
7. Ability to demonstrate geographic fibrosis
8. Cross vendor compatibility (unlike other imaging biomarkers)
9. The first MRI biomarker “technically confirmed” by QIBA (2022)



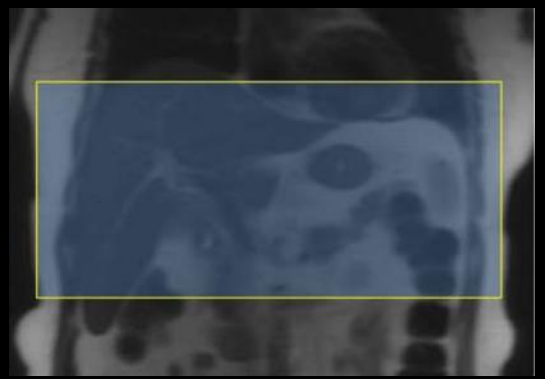
# Future directions?

# “3D” MRE



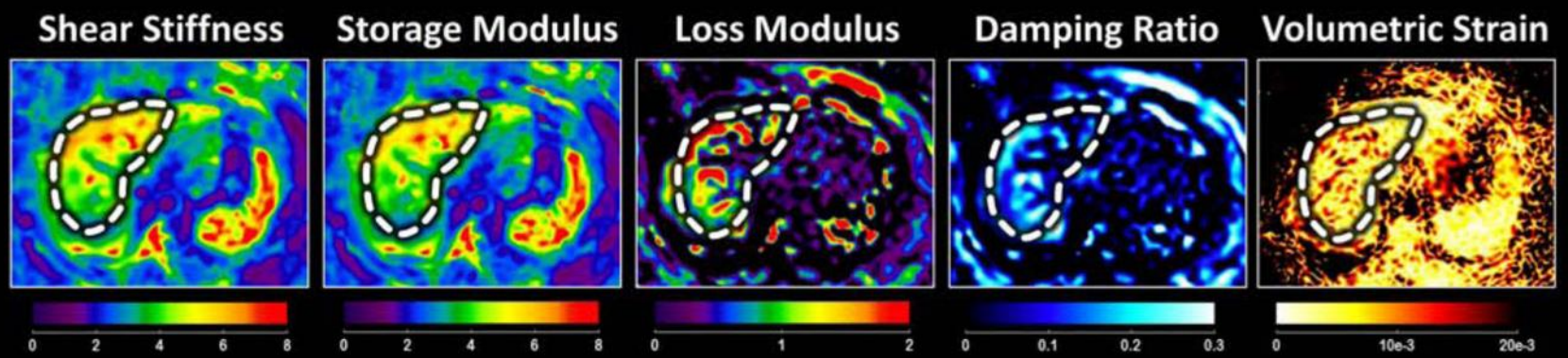

2D MRE

3D MRE



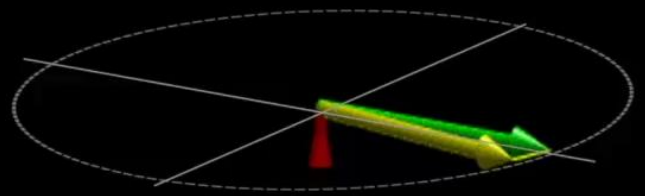
3D MRE = motion encoding all 3 axes:

- Conventional MRE = 2D
- Volumetric acquisition
- Single direction of motion encoding
- Potential for discriminating:
- Solitary metric: ”complex shear modulus (stiffness)”
  - Inflammation vs fibrosis
- Simple but confounders:
  - Fibrosis vs congestion
  - Inflammation
  - Prediction of portal HTN
  - Biliary obstruction, cholestasis
- Currently research only
  - Venous congestion (eg. cardiac)

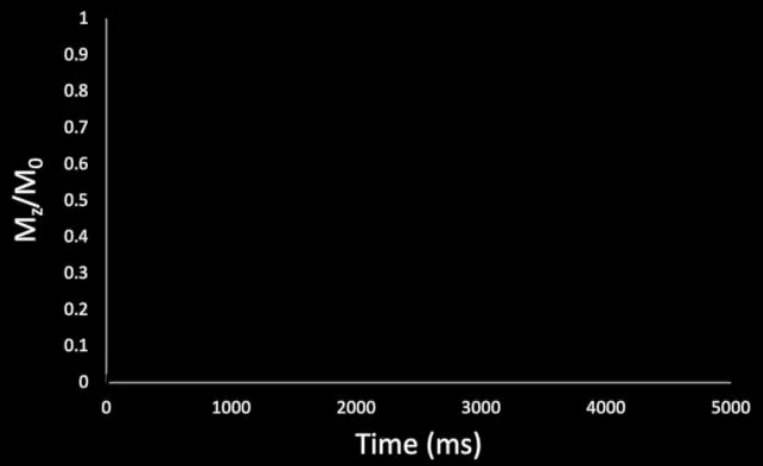



Magn Reson Imaging Clin N Am . 2020 August ; 28(3): 331–340

# T1 mapping



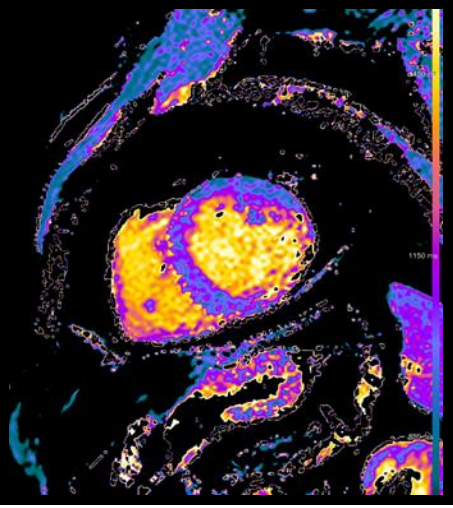
Courtesy Prof.Martin Graves, CUH




| Tissue | T1 (msec) |
|---|---|
| Water/CSF | 4000 |
| Gray matter | 900 |
| Muscle | 900 |
| Liver | 500 |
| Fat | 250 |
| Tendon | 400 |
| Proteins | 250 |
| Ice | 5000 |

Questions & Answers in MRI. https://mri-q.com/why-is-t1--t2.html#/

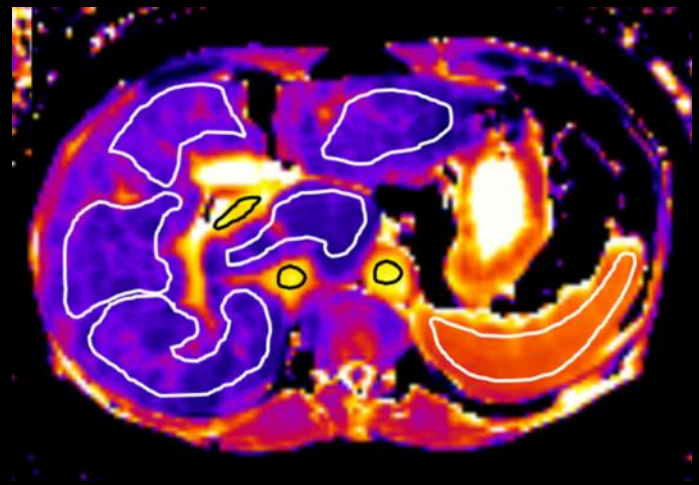
- T1 = recovery of longitudinal relaxation (time to 63% recovery)
- An inherent physical property of tissues (cf density etc)
- Water = long T1
- Myocardial fibrosis – shown to increase T1
- Role in assessment of liver fibrosis? Without new hardware?

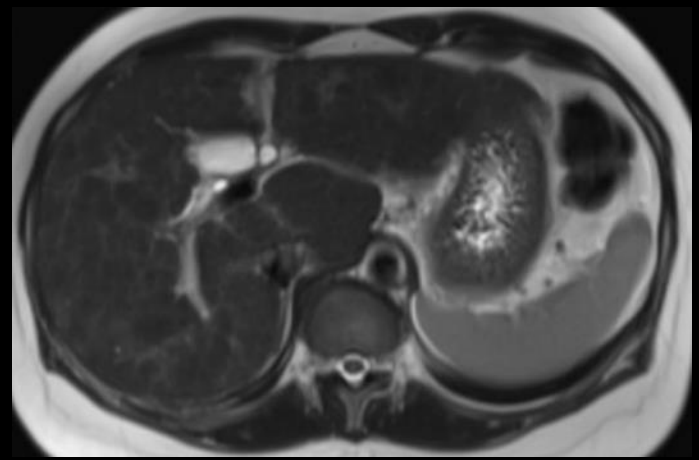


# T1 mapping

- T1 shown to increase with liver fibrosis….but why?
- Fibrosis → ↑ Extracellular space → $H_20$ accumulation

- BUT confounded by:
  - Inflammation ($H_2O$), protein/matrix deposition (increases T1)
  - Fat (increases T1)
  - Iron (reduces T1)
  - Haematocrit
  - Blood oxygenation…





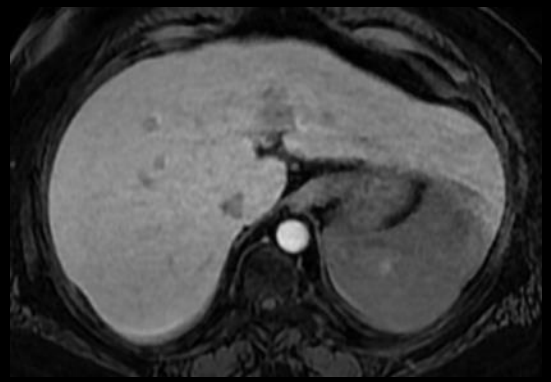
Obmann et al. European Radiology (2021) 31:4308–4318

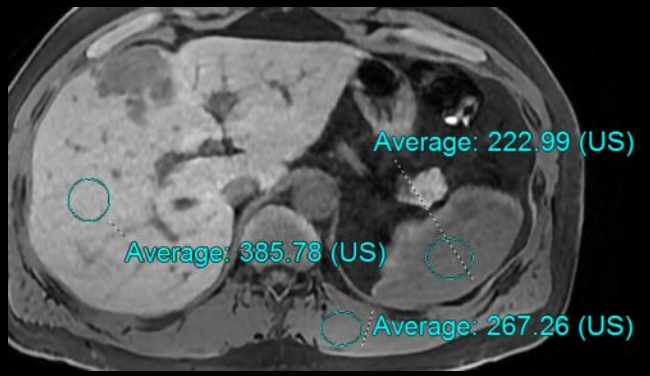
- "Corrected" – cT1 – accounts for iron but not all of above, esp. fat

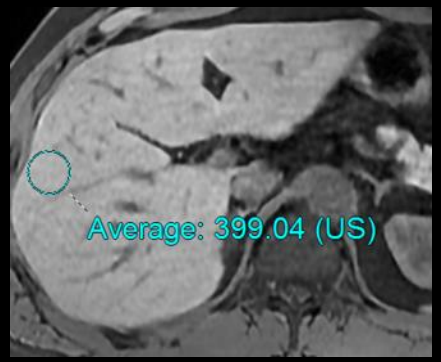
# Gadoxetic acid (Primovist) uptake

$$RLE = \frac{SI_{\text{Liver enh HBP}} - SI_{\text{Liver unenh}}}{SI_{\text{Liver unenh}}} \times 100$$

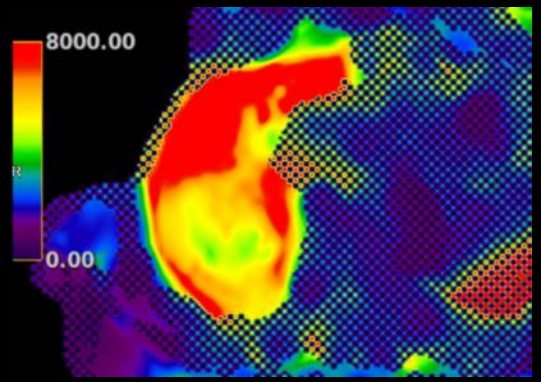
Poetter-Lang et al. Abdominal Radiology (2020) 45:3532–3544






Relative liver enhancement

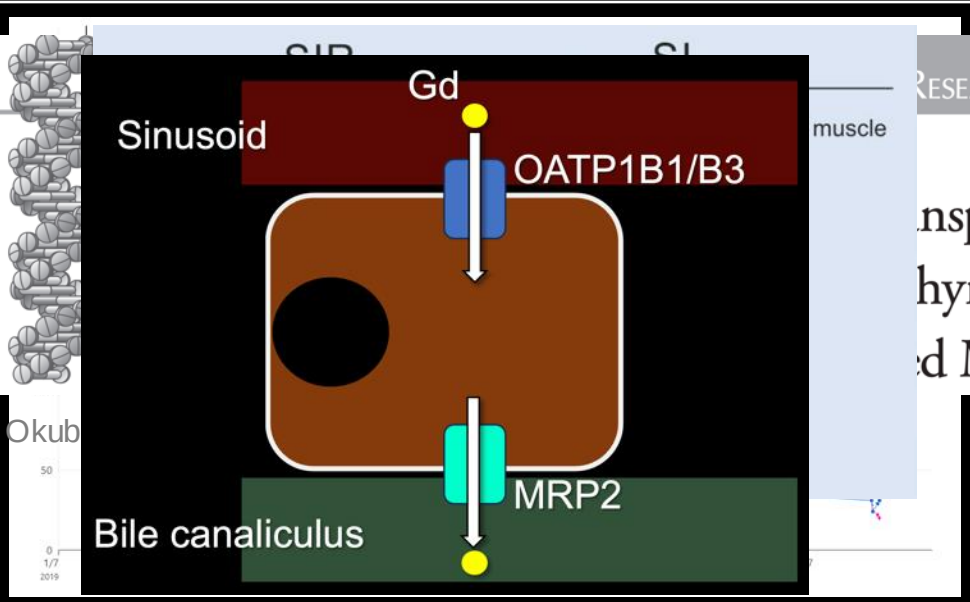


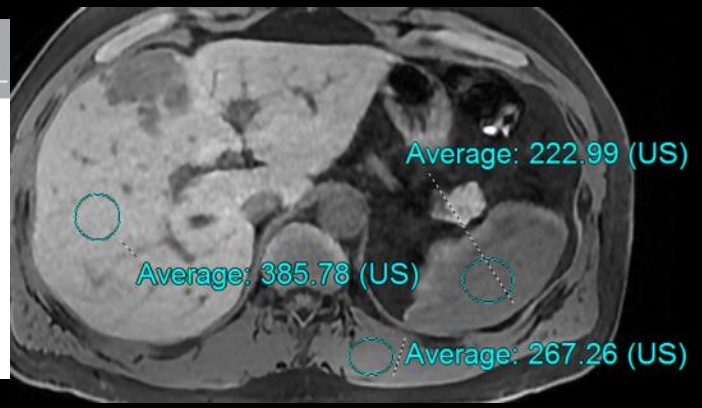

## Cirrhosis:

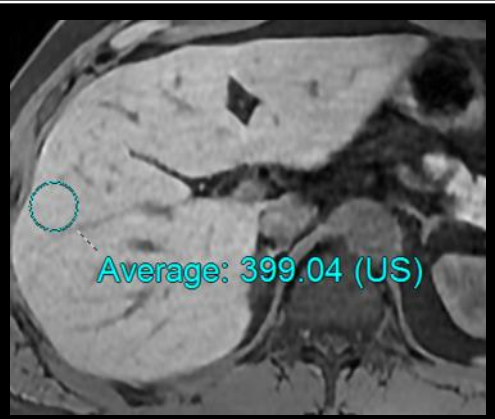
- Decreased no. hepatocytes
- Increased fibrosis
  - Reduced enhancement in HPB phase?

- No need for specialist hardware/software
- AUC of RLE = c 0.83 for  cirrhosis

# Confounders/Issues




T1w - Pre Gadoxetate – 20 mins

1. Inflammation → reduced function, oedema
2. Cholestasis → reduced excretion
3. Transporter proteins up/downregulated → complex
4. Enhancement reflects <u>function</u> - not just structural changes - function not the same in all cirrhotic livers
5. Which enhancement ratio to use?
6. Vendor, field strength
7. Genetic polymorphisms in transporter proteins

# Quantitative analysis: Summary

Comparison of Magnetic Resonance Elastography and Gadoxetate Disodium–Enhanced Magnetic Resonance Imaging for the Evaluation of Hepatic Fibrosis

*Ye Ra Choi, MD,* Jeong Min Lee, MD,*† Jeong Hee Yoon, MD,* Joon Koo Han, MD,*† and Byung Ihn Choi, MD*†*

Invest Radiol 2013;48: 607-613

QIBA Profile: MRE of the Liver – 2023

Quantitative Imaging Biomarkers Alliance

QIBA Profile:

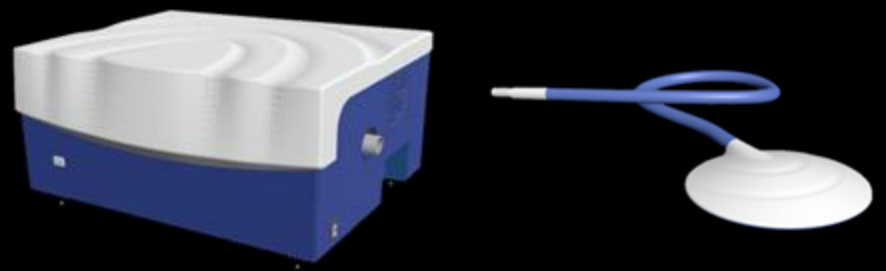
Magnetic Resonance Elastography of the Liver

5

Stage: 3: Clinically Feasible
November 7, 2023

MRE outperforms [1]:

- US methods (TE/ARFI)
- T1 mapping
- Gadoxetate-enhancement methods
- Other MR methods (DWI, IVIM)
- Serum-based methods



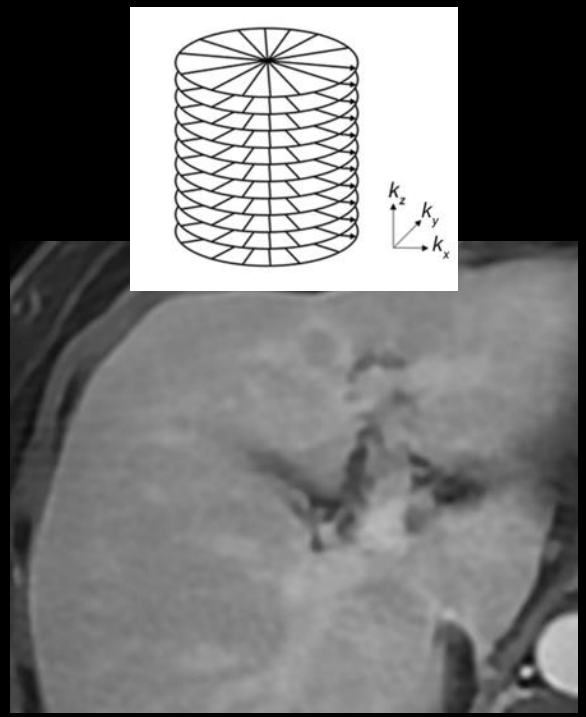
But: hardware costs (c. £60K)

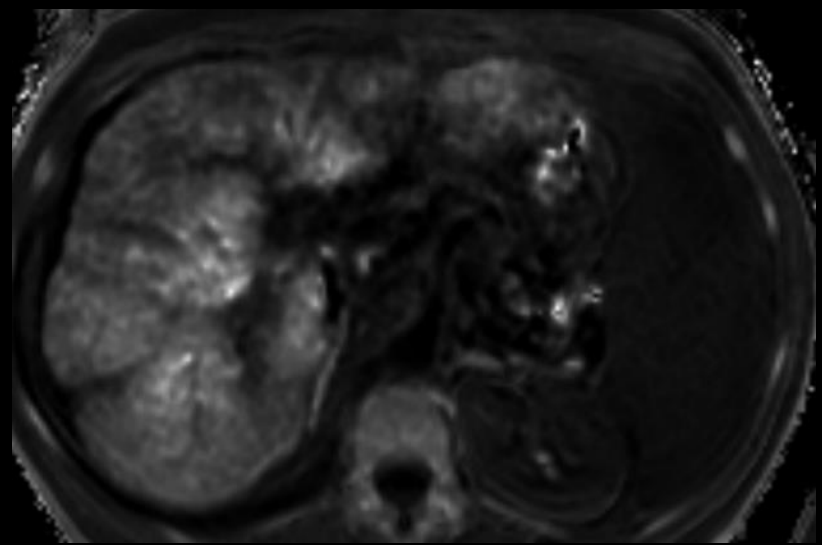
1. Yin M, Ehman RL. AJR. 2024 Jan;222(1):e2329437

# Summing up

# Getting the basics right

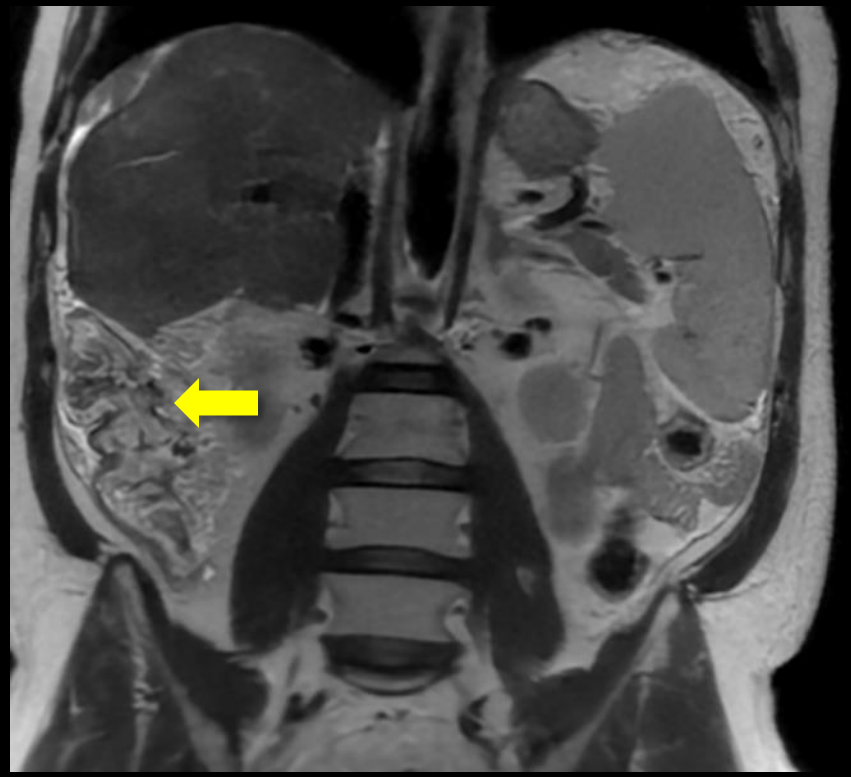
- Image optimization!
- Consider delayed FB sequence & fat/iron quant as routine
- Have a backup protocol for difficult patients

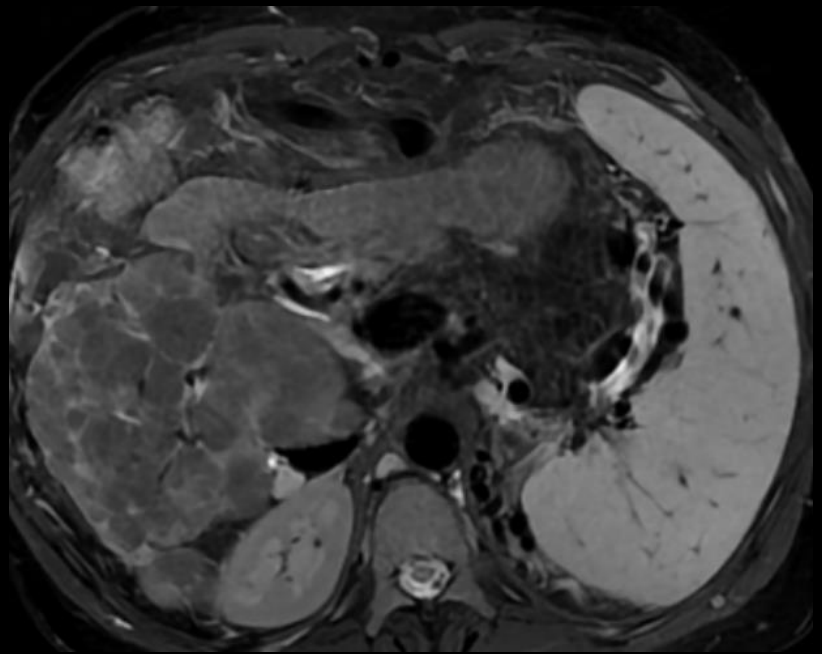



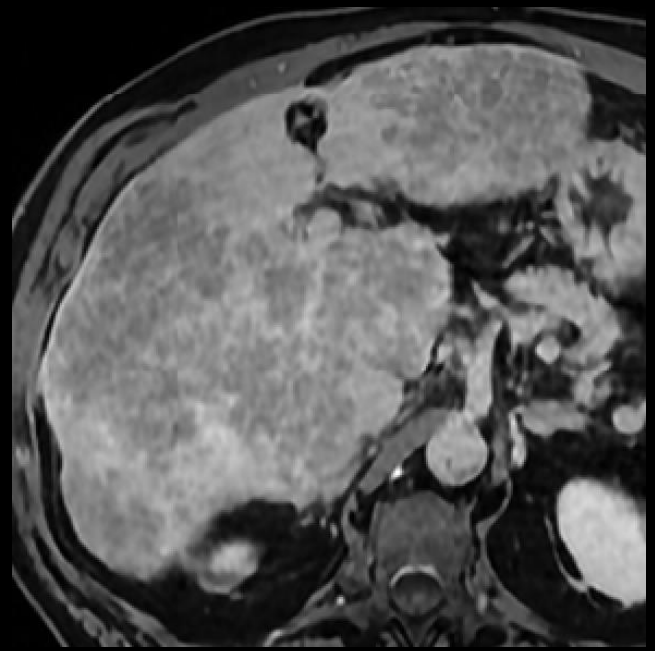



# Qualitative evaluation

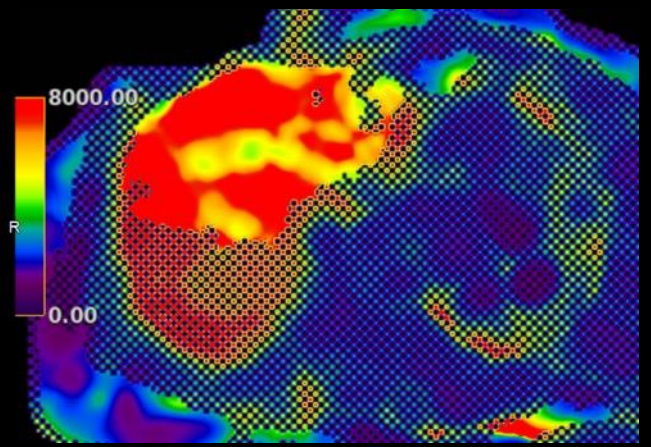
- Morphologic changes
- Can be subtle
- Ancillary features

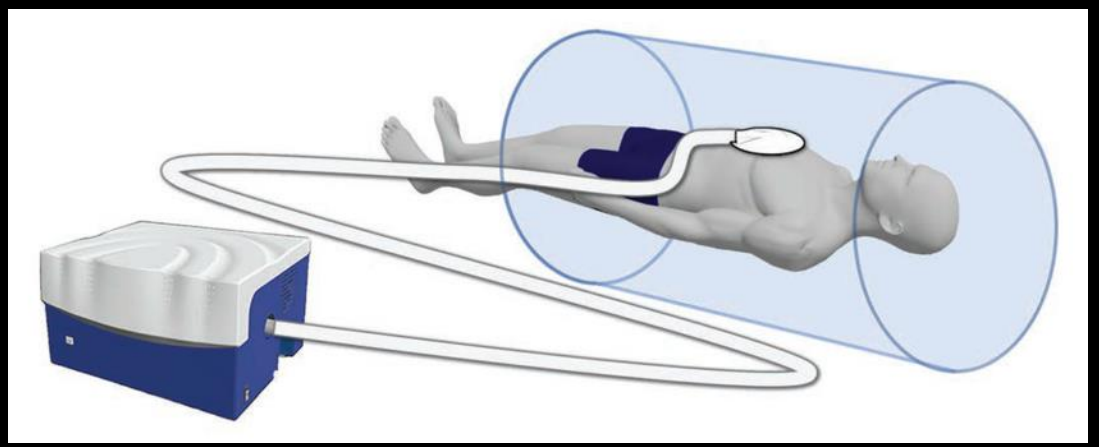






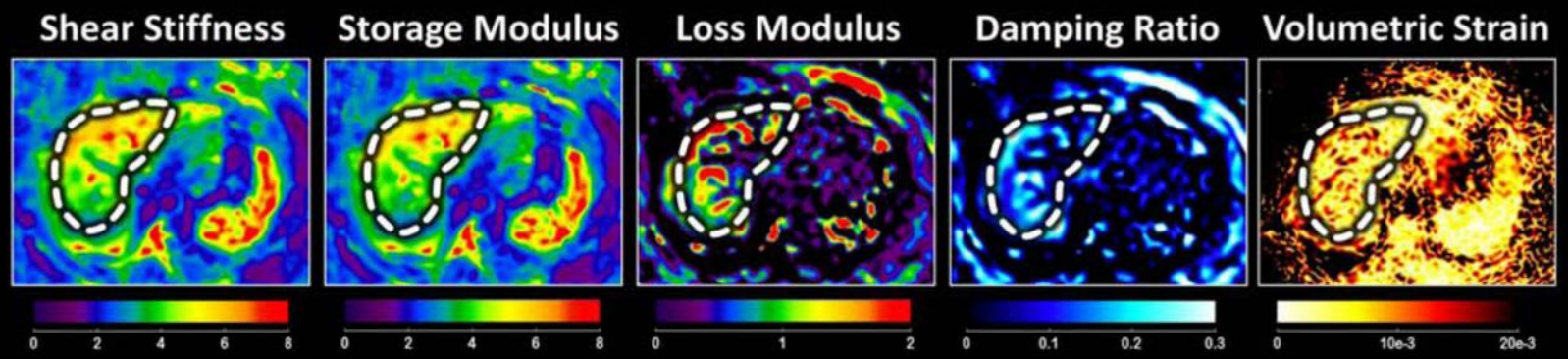
# Principles & practice of elastography

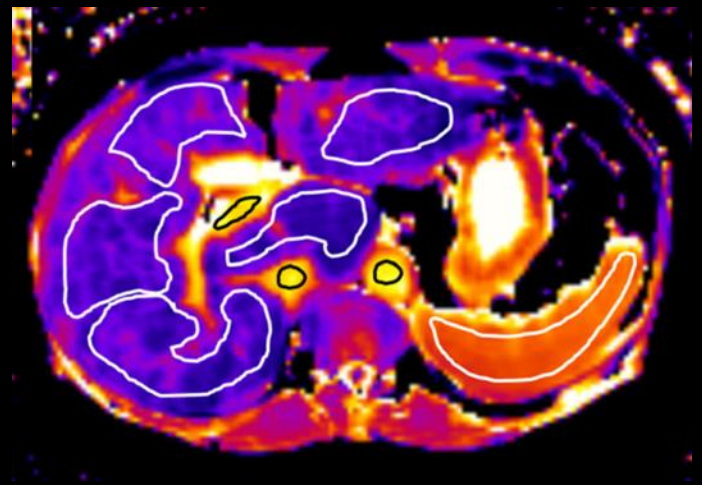


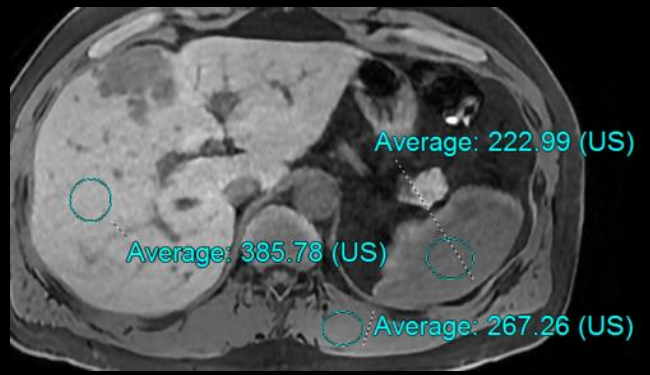
- Not difficult!
- Performs better than any other quantitative technique

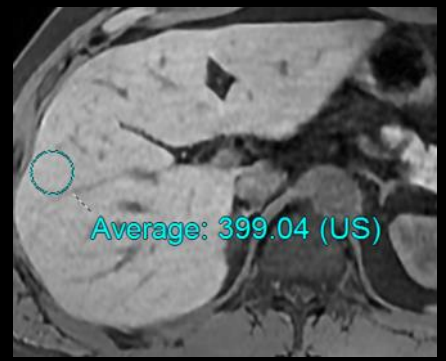
# Future directions



- <u>3D MRE</u>
- T1 mapping?
- Gadoxetate/functional imaging?



# Please get in touch if any questions/comments!


david.bowden4@nhs.net

Further reading: to follow…