

Novel PULSE-ECHO QUANTITATIVE ULTI BIOMARKERS Ultrasound Biomarkers

Quantitative
Imaging
Biomarkers
Alliance®

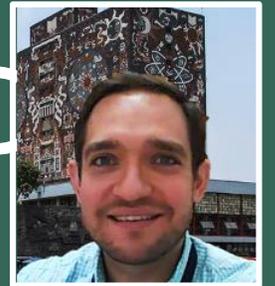


The association for medical ultrasound
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AMERICAN INSTITUTE OF ULTRASOUND IN MEDICINE

ACOUSTIC ATTENUATION COUSTIC ATTENUATION



LABORATORIO DE
ULTRASONIDO
MÉDICO



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DISCLOSURES

- I am co-chair of the AIUM/QIBA Pulse-Echo Quantitative Ultrasound Biomarker Committee
- There is no financial conflict of interest to report



LEARNING OBJECTIVES LEARNING GOALS

After this presentation, attendees will be able to:

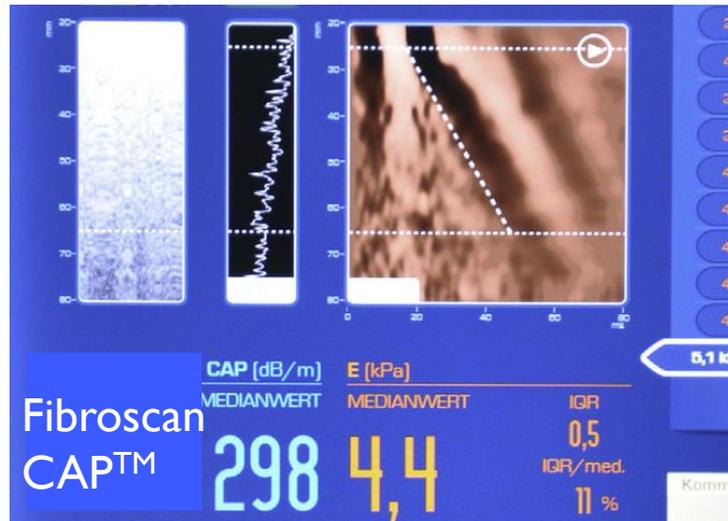
- Identify current commercial implementations of acoustic attenuation
- Describe the terminology and physical principles of acoustic attenuation
- Understand the technical aspects of *in vivo* attenuation estimation
- Identify sources of error (bias, variance, confounders)



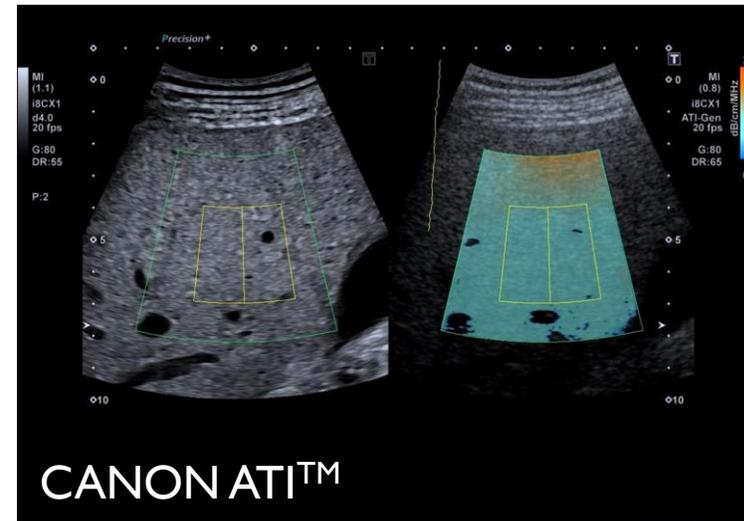
ATTENUATION IN ULTRASOUND SYSTEMS IUM / QIBA PEQUS BIOMARKER COMMITTEE



www.fibroscan.com



Berzigotti et al. Digestive and liver disease. 2018 ;50(2):107-12



<https://us.medical.canon/products/ultrasound/aplio-i-series/technology/>



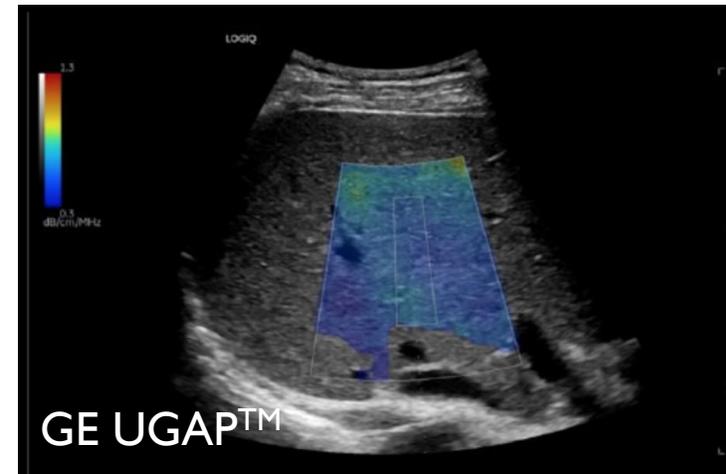
global.medical.canon



www.hitachi-medical-systems.eu



<https://www.hitachi-medical.com.sg/solutions/radiology/>



<https://www.gehealthcare.com/products/ultrasound/logiq/logiq-e10>



www.gehealthcare.com

ACOUSTIC ATTENUATION IN CLINICAL STUDIES

- **Attenuation:** Loss of acoustic power W of the ultrasound pulse with depth z within tissue

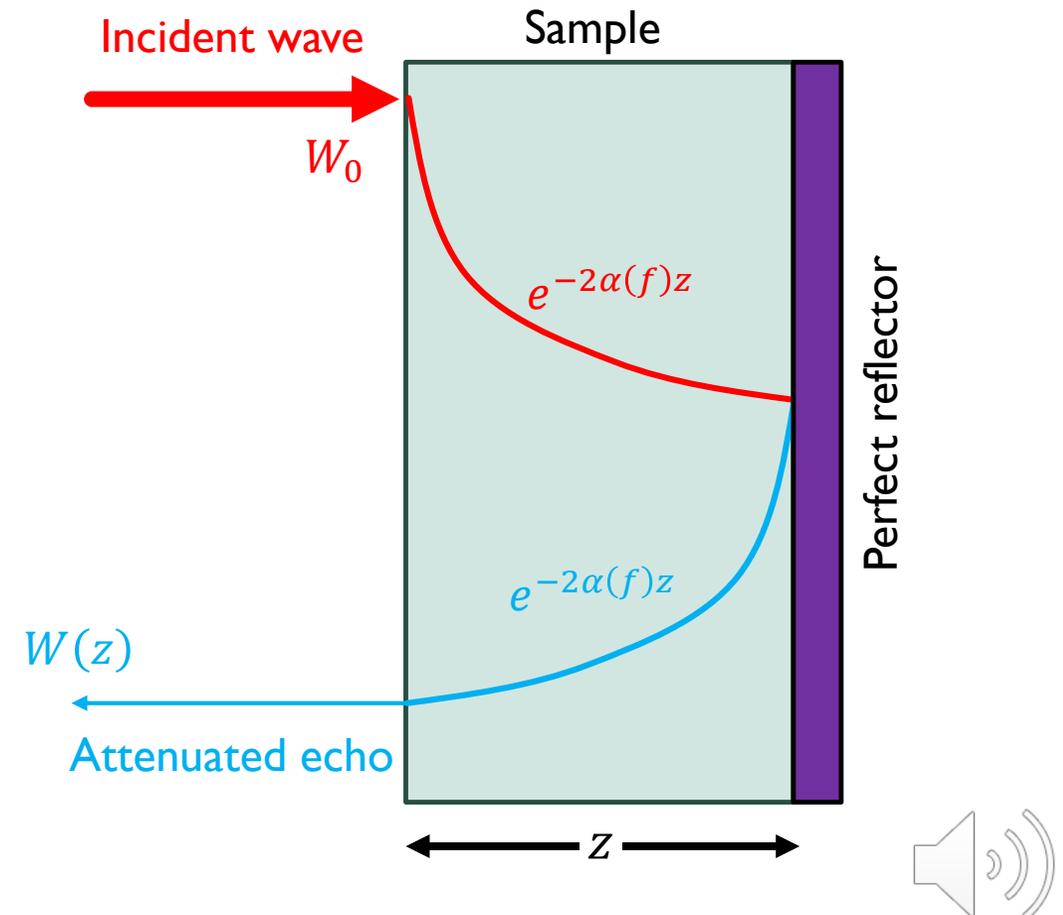
$$W(z) = W_0 e^{-2\alpha(f)z}$$

- **Attenuation coefficient α [dB cm⁻¹]:** rate of amplitude loss per unit path length

$$\alpha(f) = 4.343[\mu_{abs}(f) + \mu_{scat}(f)]$$

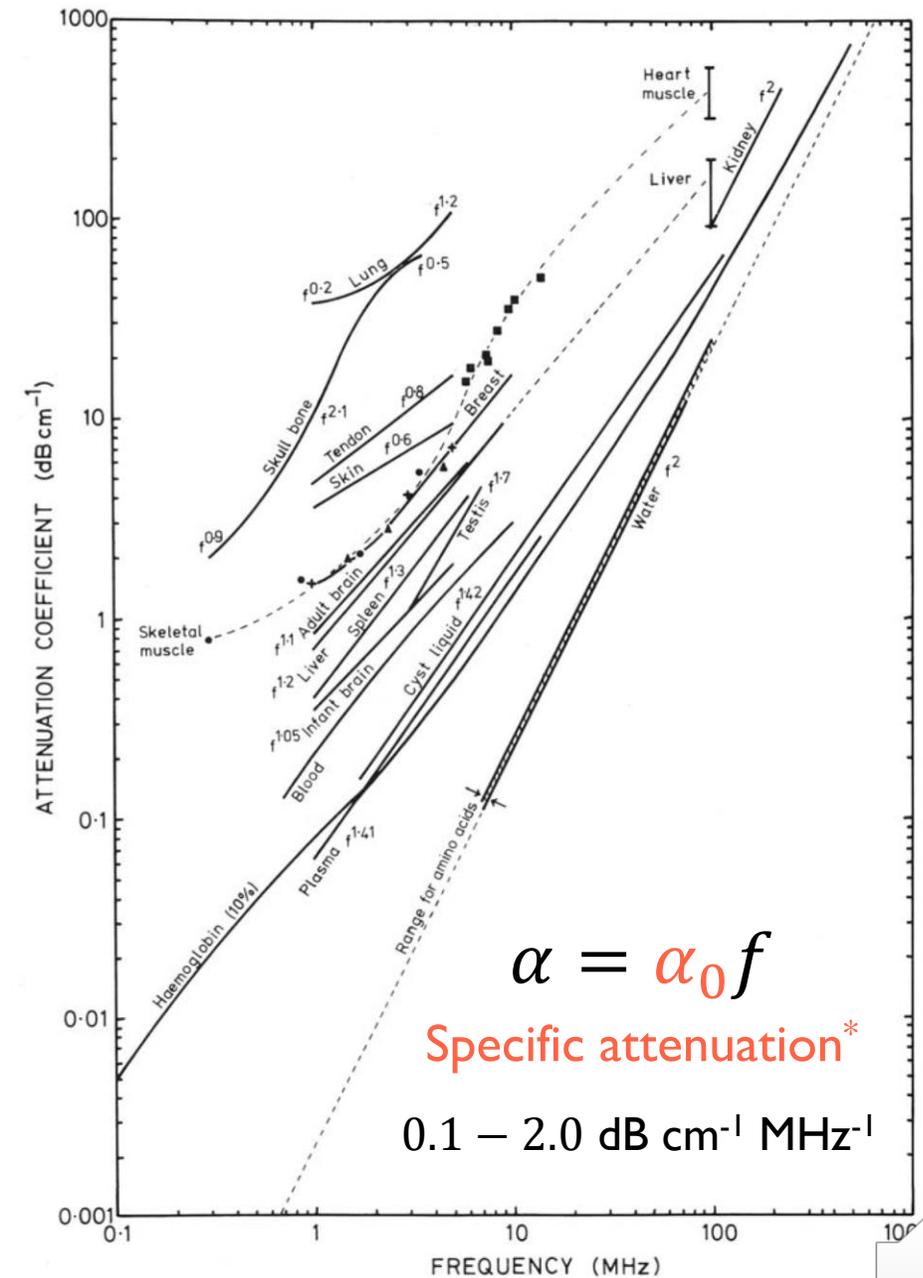
μ = Interaction cross section per unit volume [cm⁻¹]

f = frequency

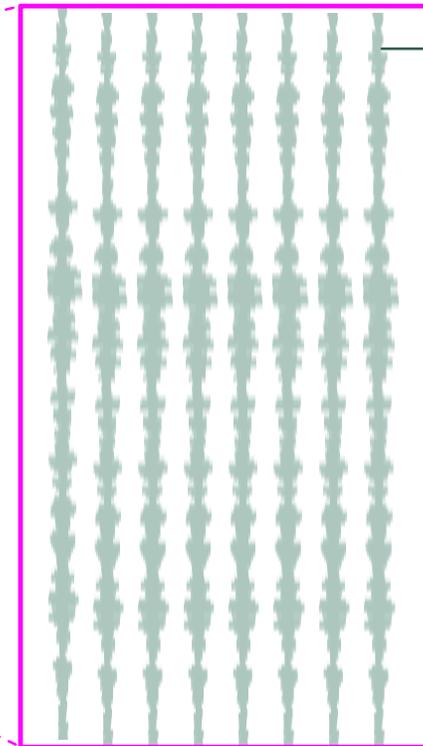
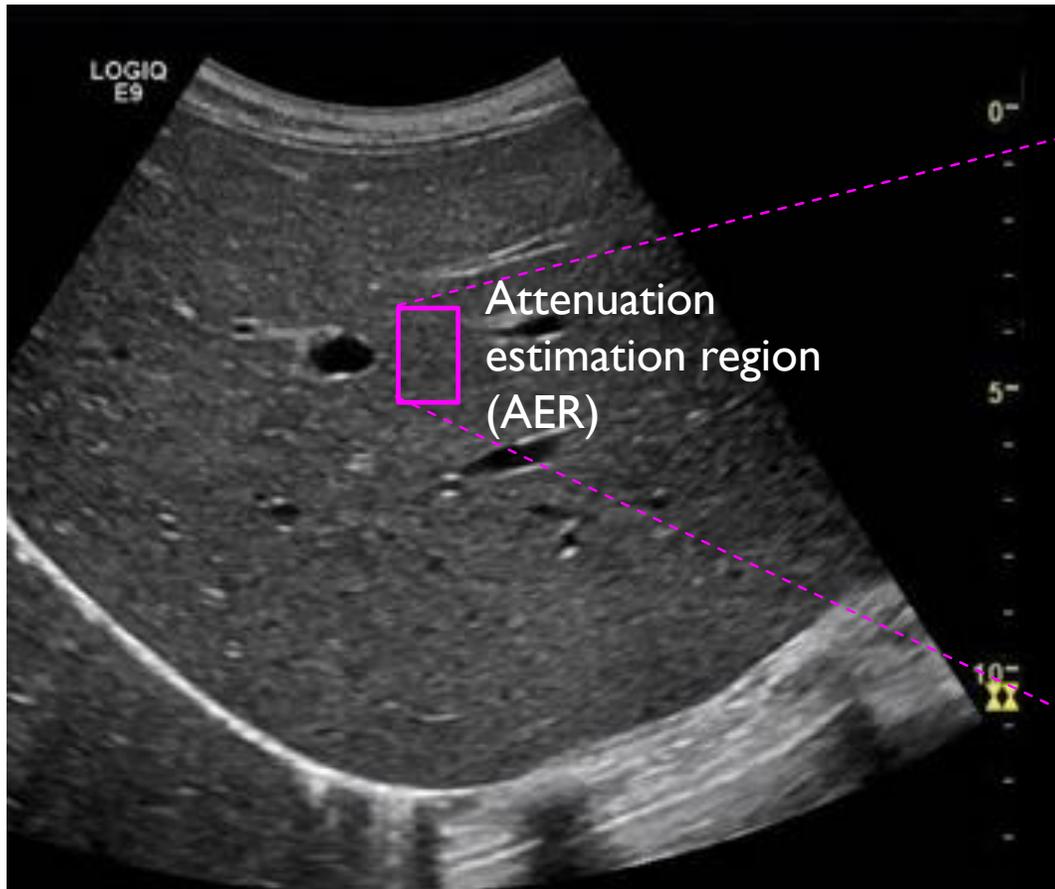


MECHANISMS OF ATTENUATION

- **Absorption (85-90%):** Inelastic interactions resulting in transformation of acoustic energy into heat
- **Scattering (10-15%):** Elastic interactions resulting in a change in direction and frequency content of the ultrasound wave



IN VIVO ESTIMATION PHYSICS OF ATTENUATION (CONT...)



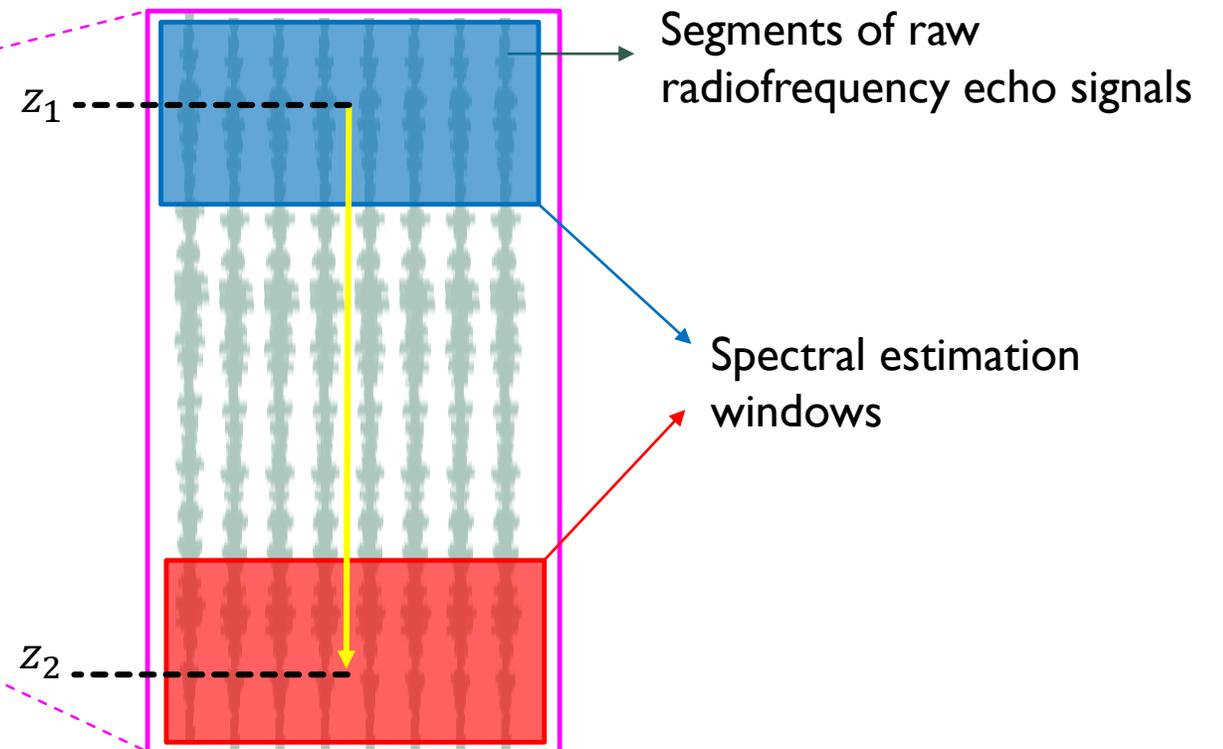
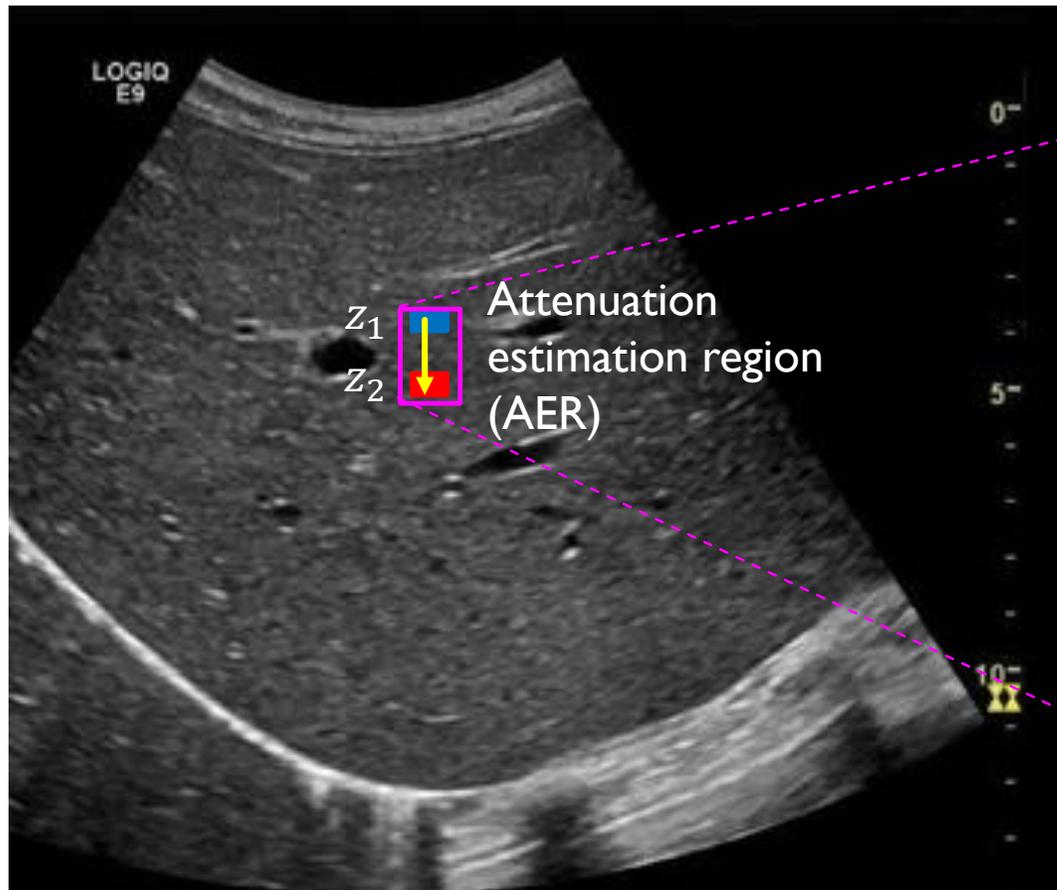
Segments of raw radiofrequency echo signals

Smaller AER:

↓
Better resolution
Higher variance
Higher bias



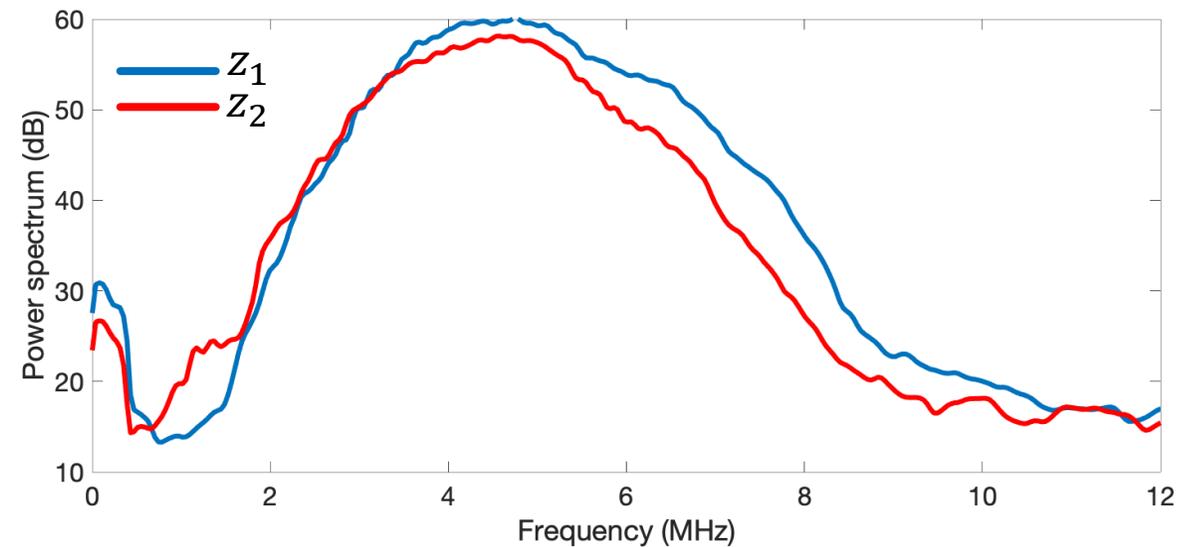
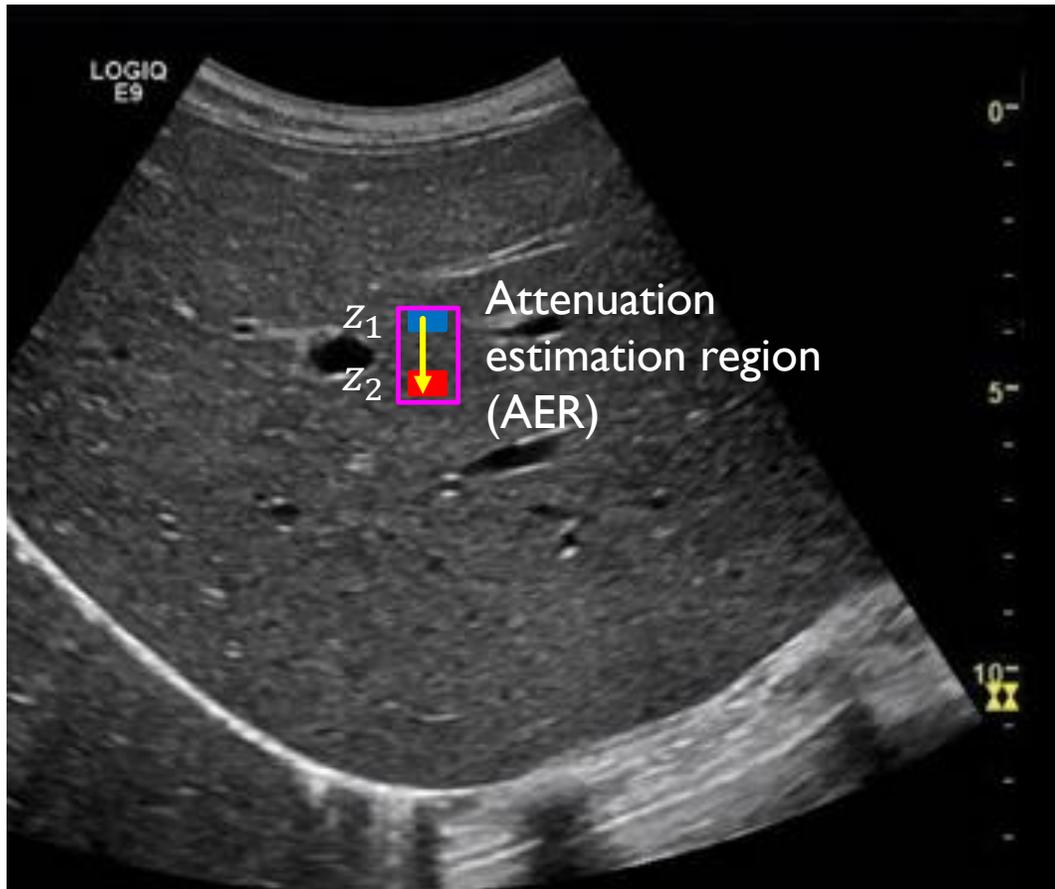
IN VIVO ESTIMATION PHYSICS OF ATTENUATION (CONT...)



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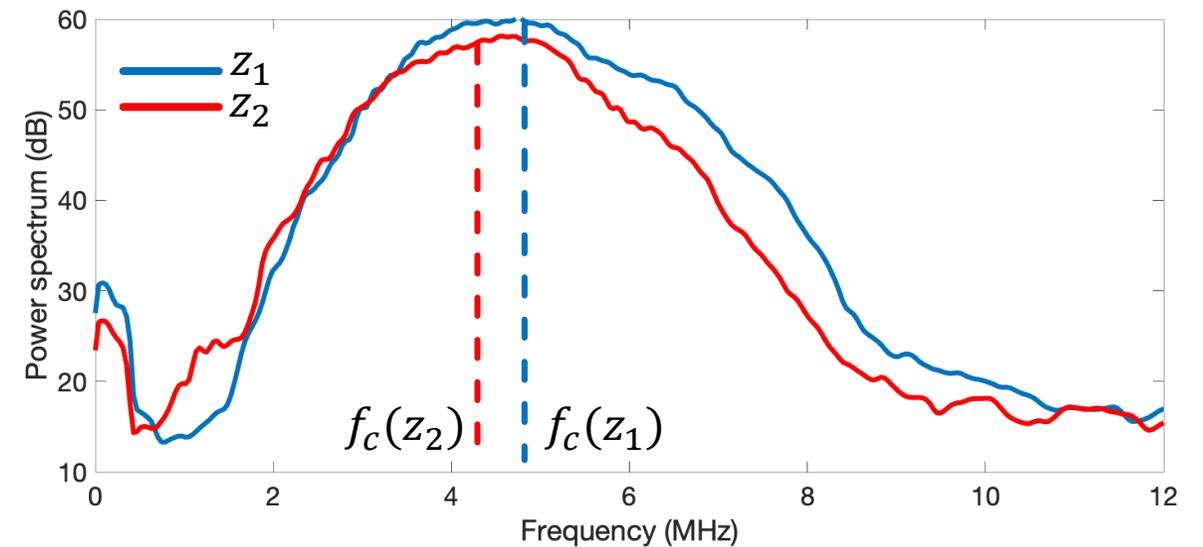
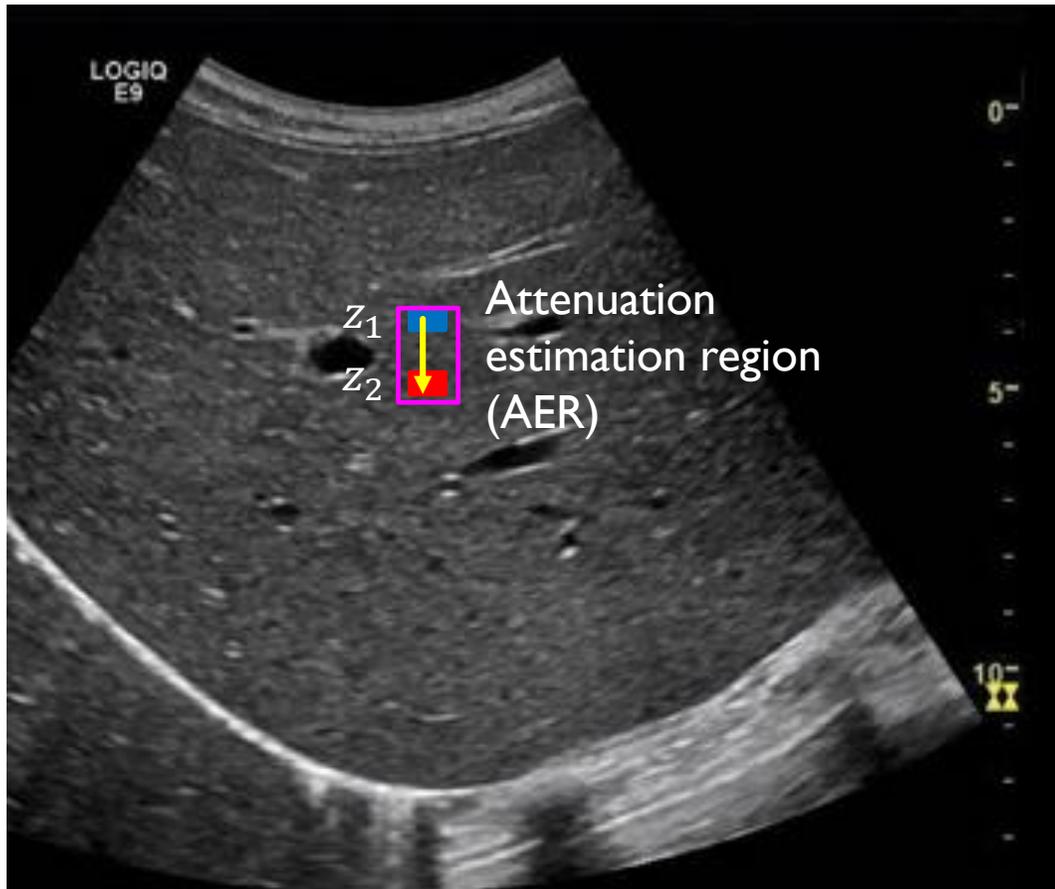
IN VIVO ESTIMATION PHYSICS OF ATTENUATION (CONT...)



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IN VIVO ESTIMATION PHYSICS OF ATTENUATION Spectral Shift Method (CONT.)



$$\alpha_0 = C - \frac{m_{f_c}}{4B^2}$$

C → Calibration constant
 m_{f_c} → Slope of center frequency vs. depth
 B → Width of Gaussian model fitted to the power spectrum

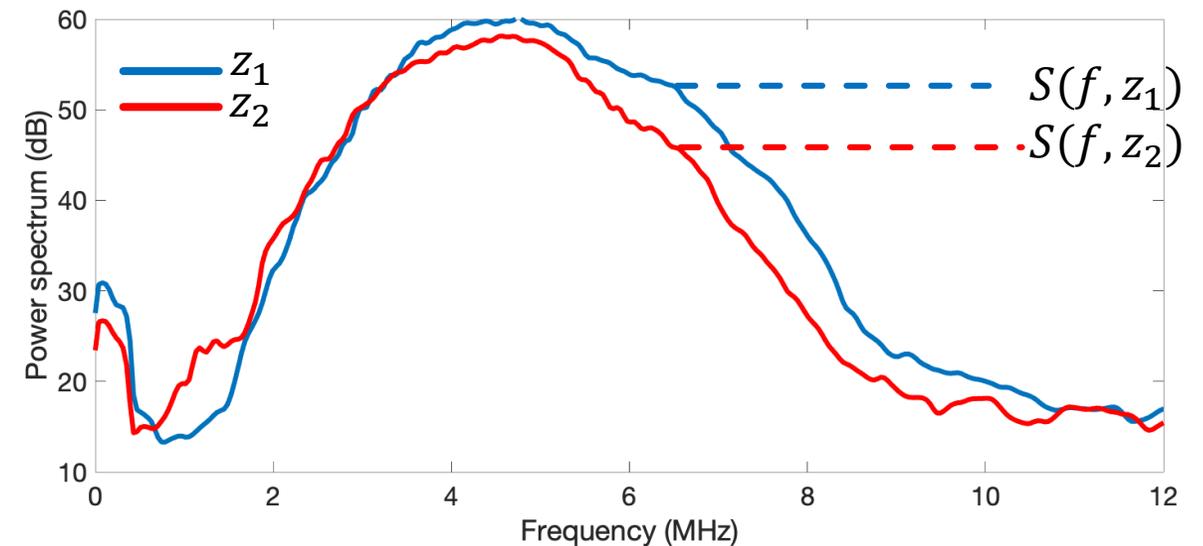
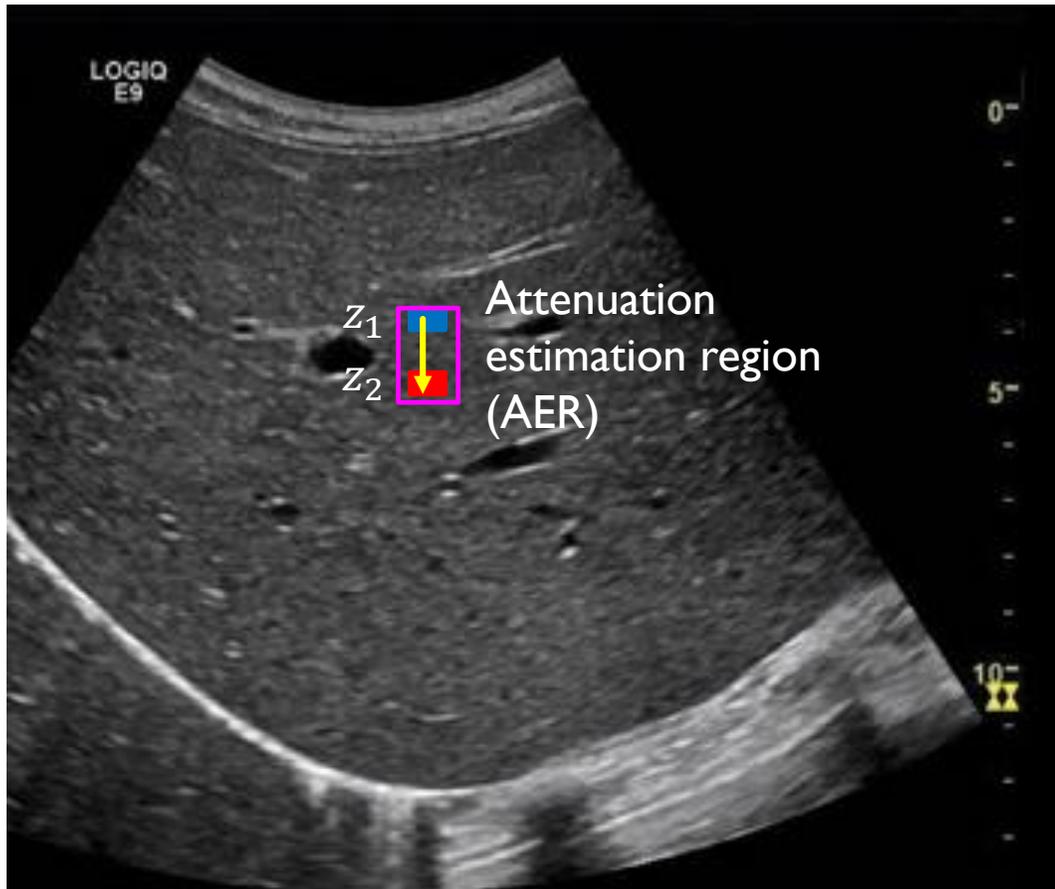
CAUTION

Tissue scattering properties must be constant within AER



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IN VIVO ESTIMATION PHYSICS OF ATTENUATION (CONT.) Spectral Difference Method



$$\alpha(f) = Cf - 0.25m_s(f) \rightarrow \text{Slope of log power at frequency } f \text{ vs. depth}$$

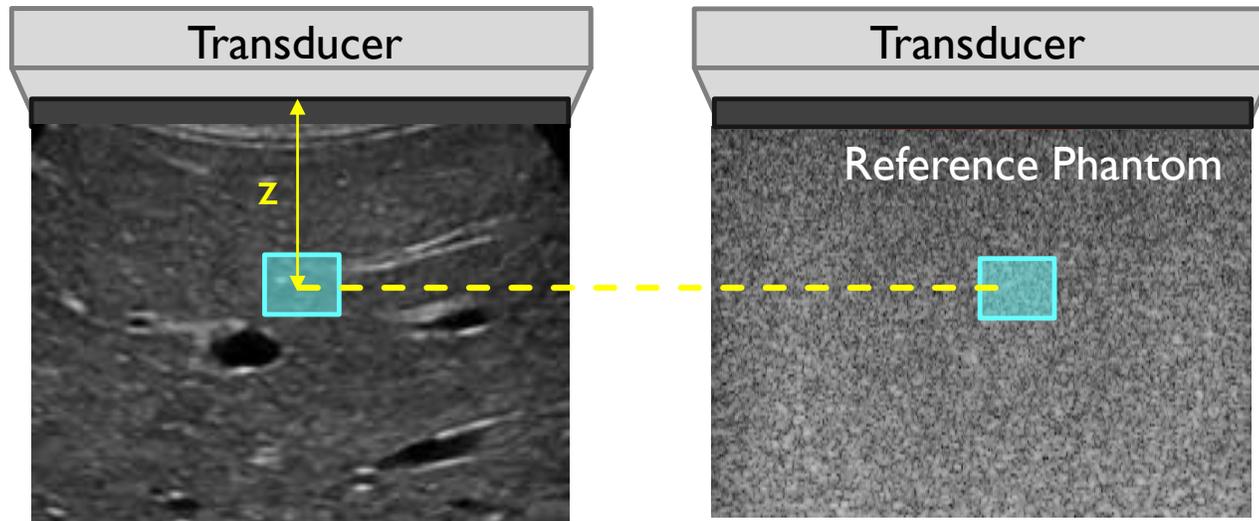
$$\alpha_0 \left\{ \begin{array}{l} \text{Average over bandwidth of } \alpha(f)/f \\ \text{Slope of linear fit to } \alpha \text{ vs. frequency} \end{array} \right.$$

CAUTION

Tissue scattering properties must be constant within AER



CALIBRATION: REFERENCE PHANTOM METHOD (RPM) HOW TO MEASURE IT? – EX VIVO



- Phantom design:
 - ✓ Fully developed speckle
 - ✓ Similar attenuation and sound speed
 - ✓ Known attenuation $\alpha_{0,Ref}$ and backscatter coefficients σ_{Ref}
- The goal is to compensate for:
 - $G(f, z)$: gain setting
 - $D(f, z)$: diffraction and focusing
- Calibration constant C :
 - Reference attenuation $\alpha_{0,Ref}$

$$S_{sample}(f, z) = \cancel{D(f, z)} \cancel{G(f, z)} \sigma_{sample}(f, z) e^{-4\alpha_{0,sample} f z}$$

$$S_{Ref}(f, z) = \cancel{D(f, z)} \cancel{G(f, z)} \sigma_{Ref}(f, z) e^{-4\alpha_{0,Ref} f z}$$



FACTORS AFFECTING ACCURACY AND PRECISION

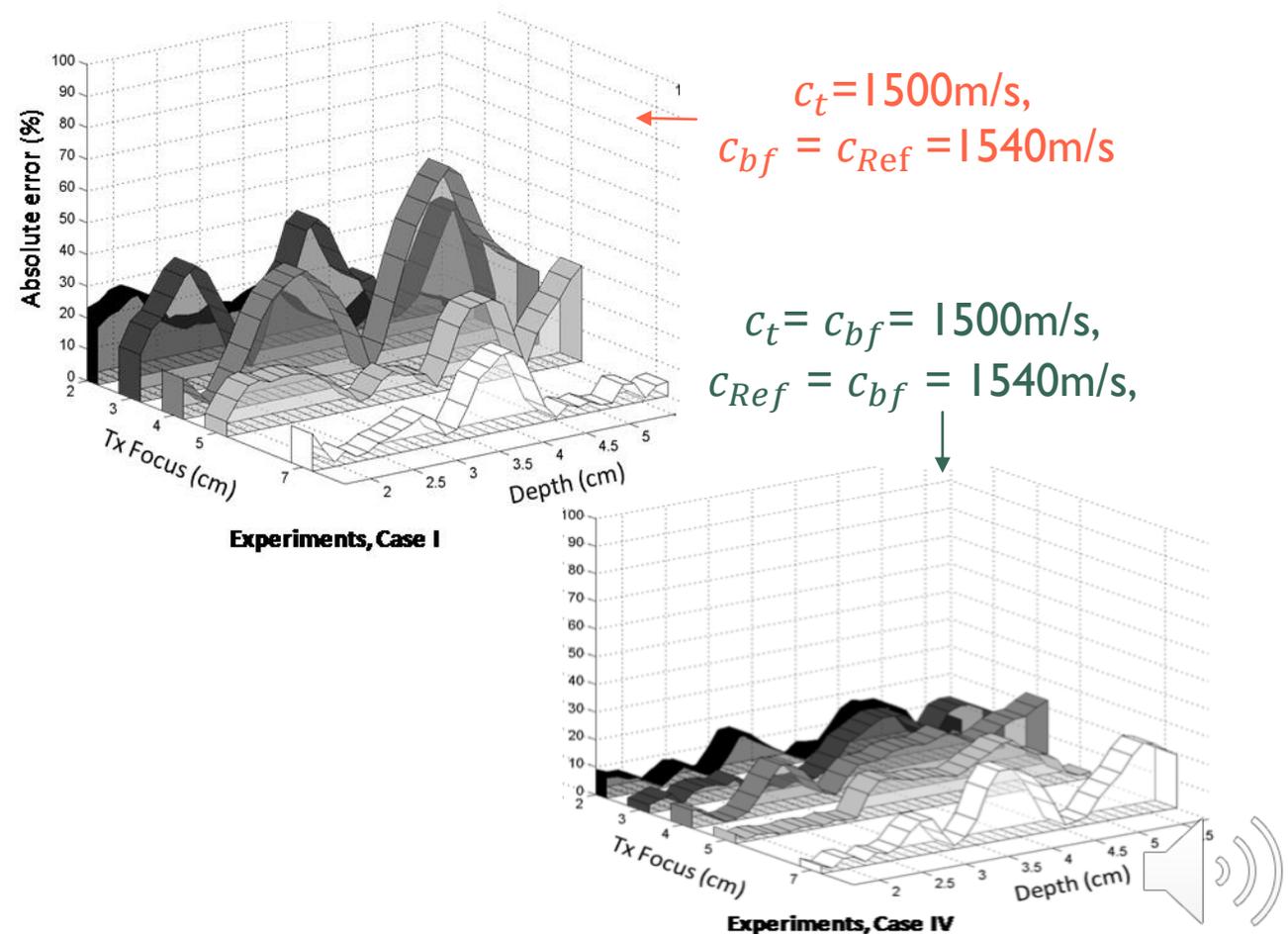
- Physical
 - Sound speed mismatch
 - Nonlinear wave propagation
- Biological
 - Fasting and hydration status



SOUND SPEED MISMATCH HOW TO MEASURE IT? – IN VIVO

- If the tissue sound speed c_t is very different from the scanner's beamformer sound speed c_{bf} :
 - Displayed distances do not correspond to actual distances in the tissue
 - Spatial resolution is degraded because of flawed focusing

- In the RPM, if the reference phantom sound speed c_{Ref} is very different from c_t
 - Focusing compensation is flawed



NONLINEAR WAVE PROPAGATION NOW TO MEASURE IT – IN VIVO (CONT...)

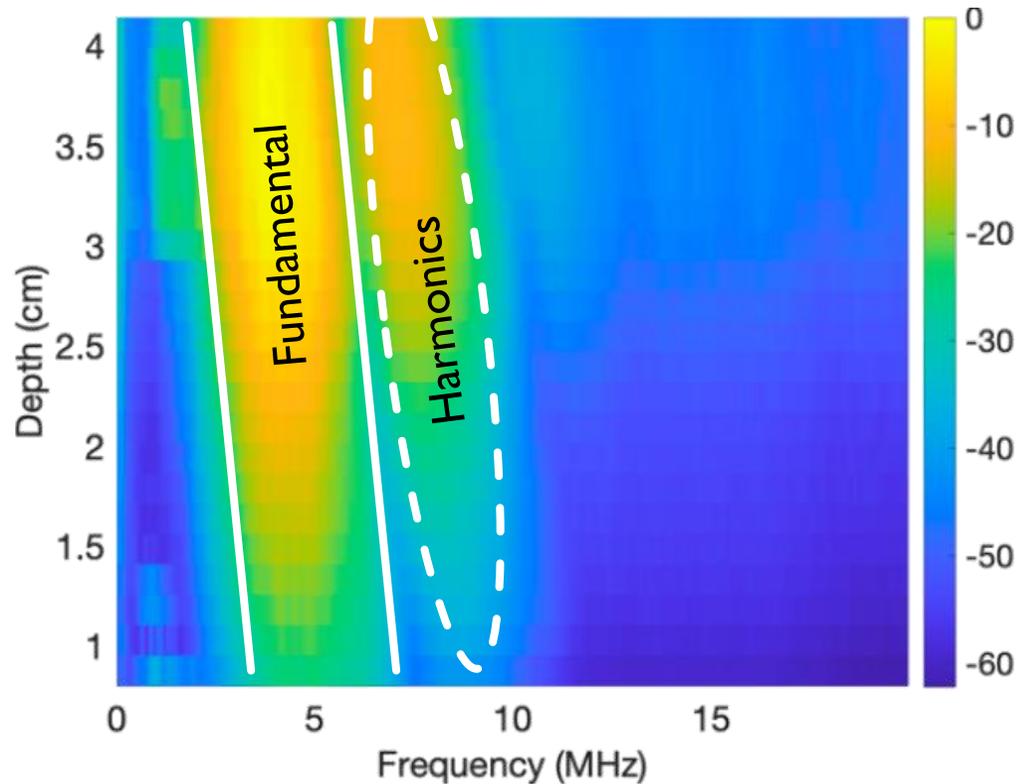
- At moderate and high ultrasound amplitudes, the relationship between changes in pressure and density becomes nonlinear
- Effects of nonlinear propagation include:
 - Generation of harmonics
 - Excess attenuation
- The propensity of a medium to show nonlinear propagation is quantified by the B/A parameter
 - Ratio of second order/first order terms in Taylor's series expansion of pressure vs. density

Human tissue type	α [dB/cm] @ 1 MHz	B/A
Adipose	0.29	10.0
Blood	0.20	7.1
Brain	0.60	7.1
Kidney	1.0	7.4
Liver	0.50	6.6
Cardiac muscle	0.52	7.1
Skeletal muscle	0.74	6.6
Skin	0.35	7.9
Fatty	0.40	8.5

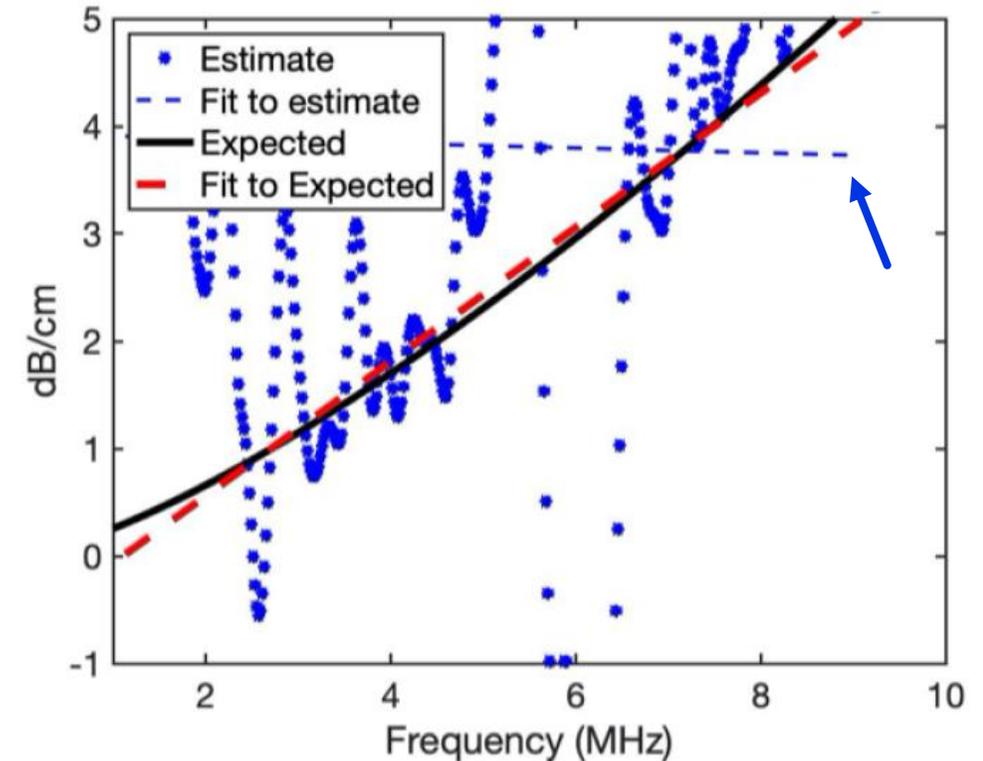


NONLINEAR WAVE PROPAGATION (CONT...)OW TO MEASURE IT? – IN VIVO (CONT...)

Distribution of spectral power with depth



Attenuation coefficient with RPM



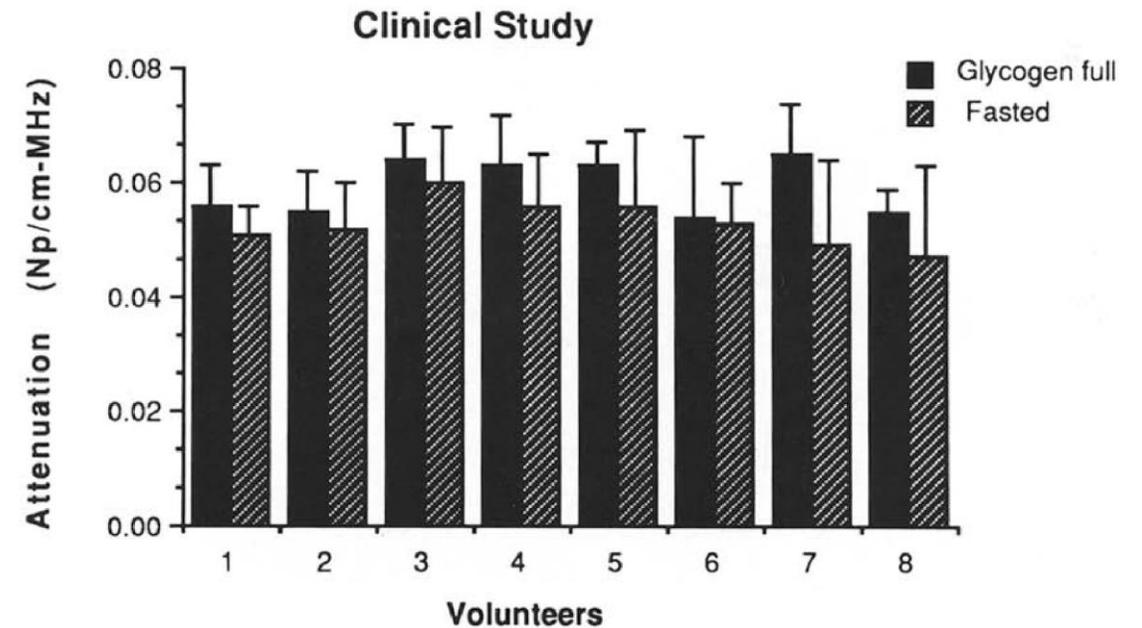
B/A sample = 9.8-11.1, B/A reference = 6

Tx Power=100% (MI=0.6) ,TX focus= 5cm, z=4cm



FASTING AND HYDRATION

- Glycogen is a highly absorptive biomolecule that is polymerized from glucose by liver cells and stored in the liver
- The content of glycogen varies typically from 1% to 4% in normal adults
- As glycogen concentration increases, water content tends to raise to maintain the density of the liver



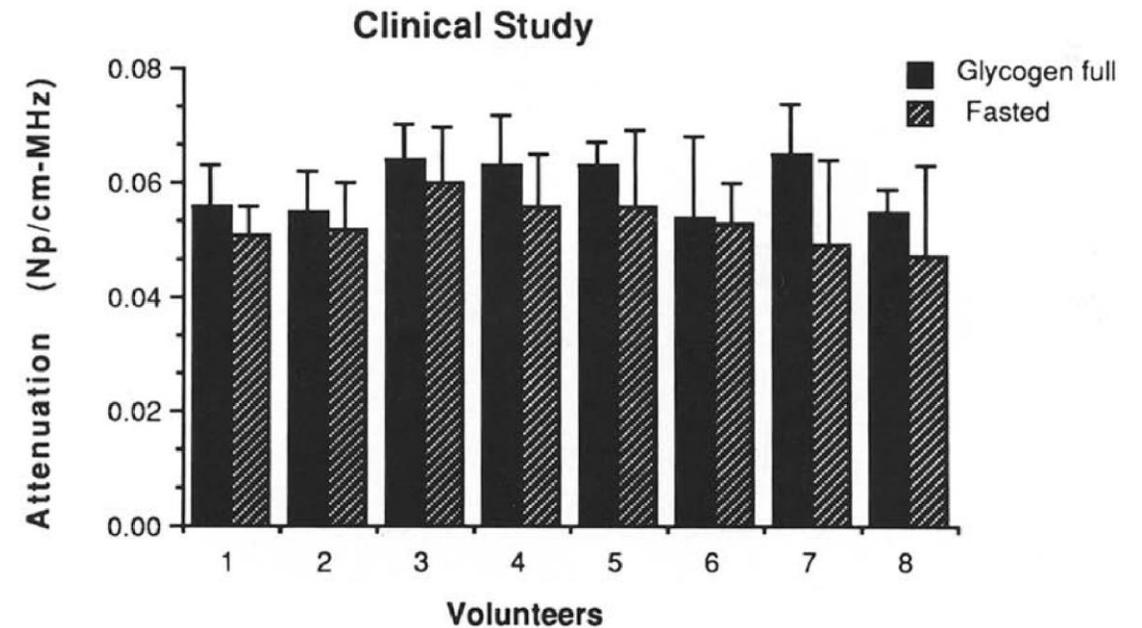
Glycogen full: High carbohydrate, low-fat meals for 2 days
 Fasted: Fasting or light meal for 18 hours



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Fasting and hydration status can confound liver fat assessment using attenuation

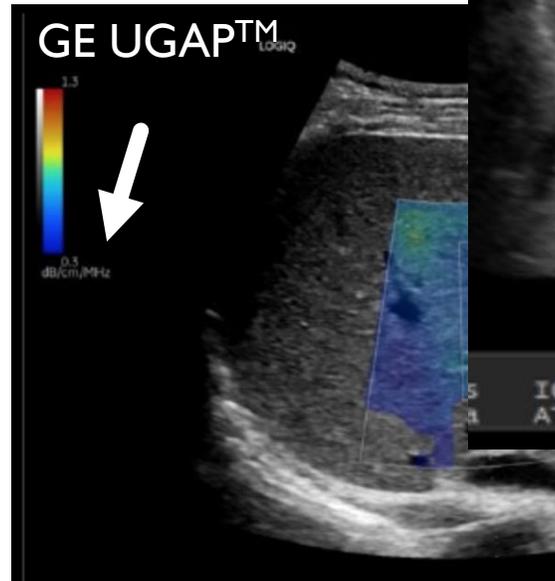
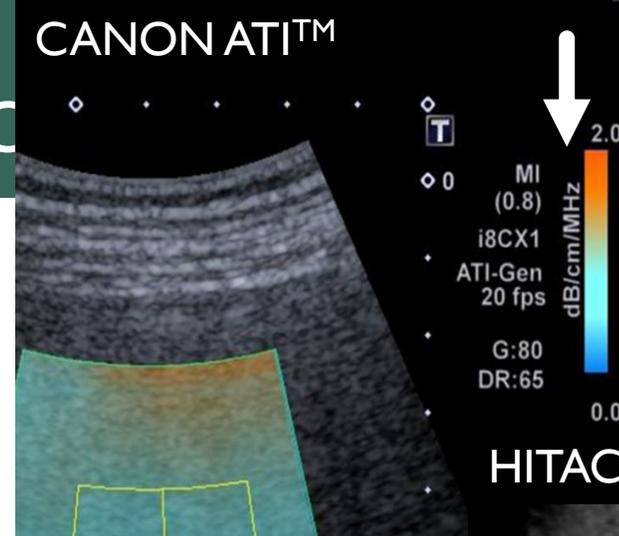


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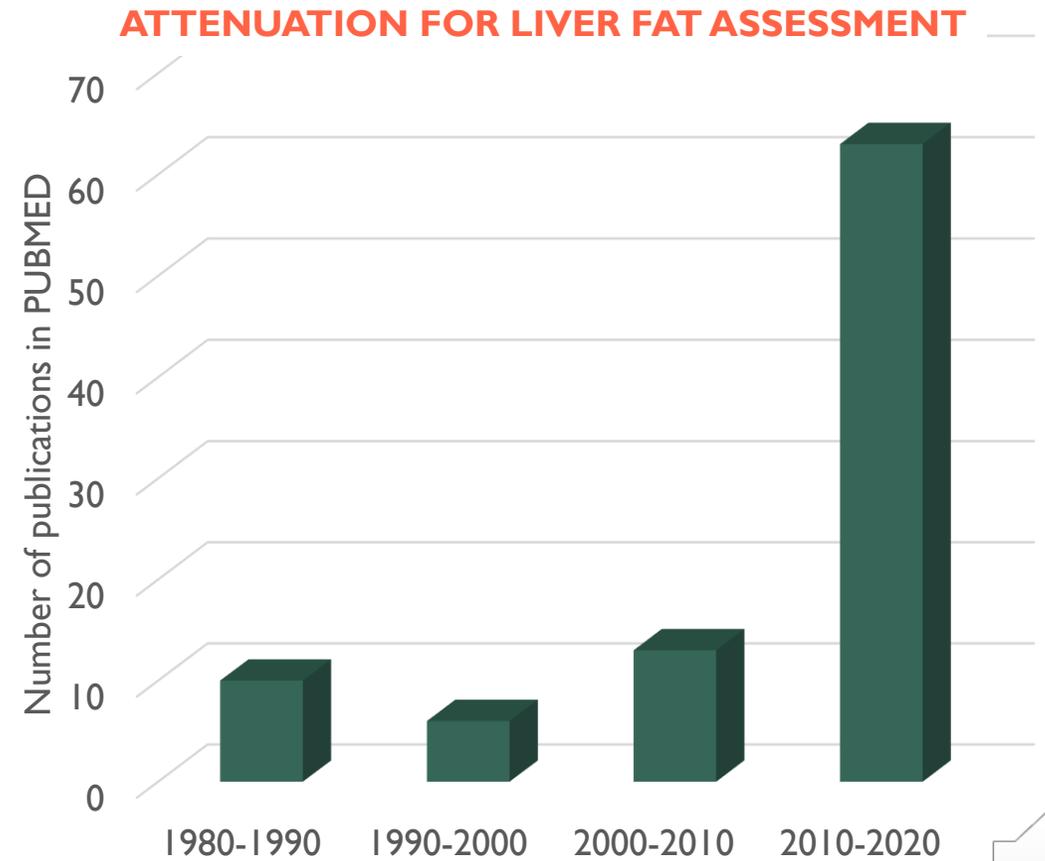
SUMMARY SOURCES OF VARIABILITY – SCANNERS

- Acoustic attenuation is one of various pulse-echo quantitative ultrasound features being translated into clinical use, with a focus on liver fat assessment
- It includes contributions of absorption and scattering and increases approximately linearly with frequency
 - The constant of proportionality is the specific attenuation [$\text{dB cm}^{-1} \text{MHz}^{-1}$]
 - This possibly corresponds to the ATI, ATT, and UGAP features in Canon, Hitachi, and GE scanners



SUMMARY (CONT...) SOURCES OF ERROR – SCATTERER CONCENTRATION

- There are various methods to estimate attenuation *in vivo*
 - The most common ones evaluate changes in the shape of the power spectrum of echo signals
 - A calibration is required to remove system-dependent effects such as focusing and gain
- Many factors can affect the accuracy and precision of attenuation estimates
 - They can reduce the utility of attenuation as a quantitative imaging biomarker
 - Standardization is needed to reduce bias and variance



Search words: "ultrasound" AND "attenuation" AND "liver" AND "fat"



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Attenuation / Backscatter / Sound speed



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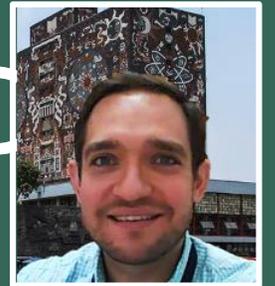


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