AAPM 64th Annual Meeting and Exhibition
WE-H-201-0: Ultrasound Performance Assessment and Quality Control

Ultrasound Elastography, Quantitative Ultrasound, and QIBA Initiatives

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Conflicts of interest

- Equipment loan and technical support from Siemens Healthineers and GE Healthcare
- Consultant for Siemens Healthineers
- Leadership roles in the Quantitative Imaging Biomarkers Alliance of the Radiological Society of North America
- Member of American Institute of Ultrasound in Medicine
- Consultant to the Society of Abdominal Radiology

Disclaimers

- This presentation does not represent the views or positions of ’ University of Wisconsin-Madison
- The author and his institution do not endorse any of the discussed technologies or devices. These are referenced just as examples

Learning outcomes

Explain the physical principles behind Shear Wave Elastography (SWE) and Pulse-Echo Quantitative Ultrasound (PEQUS)

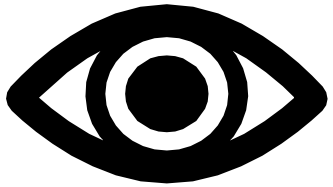
List QA/QC tests reported in the literature and by professional organizations

Identify ongoing efforts to standardize the use of SWE and PEQUS as sources of biomarkers for diffuse liver disease

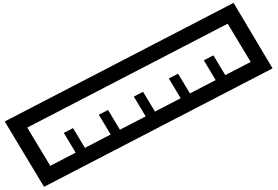
Quantitative imaging

"The extraction of quantifiable features from medical images for the assessment of normal or the severity, degree of change, or status of a disease, injury, or chronic condition relative to normal" https://www.rsna.org/QIBA.aspx

Visual Assessment



Quantitative Analysis



Biomarker

"Objective characteristic derived from an in vivo image […] as an indicator of normal biological processes, pathogenic processes, or a response to a therapeutic intervention"

Kessler et al. Statistical methods in medical research. 201; 24(1):9-26
Raunig et al. Statistical methods in medical research. 2015; 24(1):27-67

Quantitative imaging in ultrasound

Distance measurements

Blood flow velocity, volume blood flow

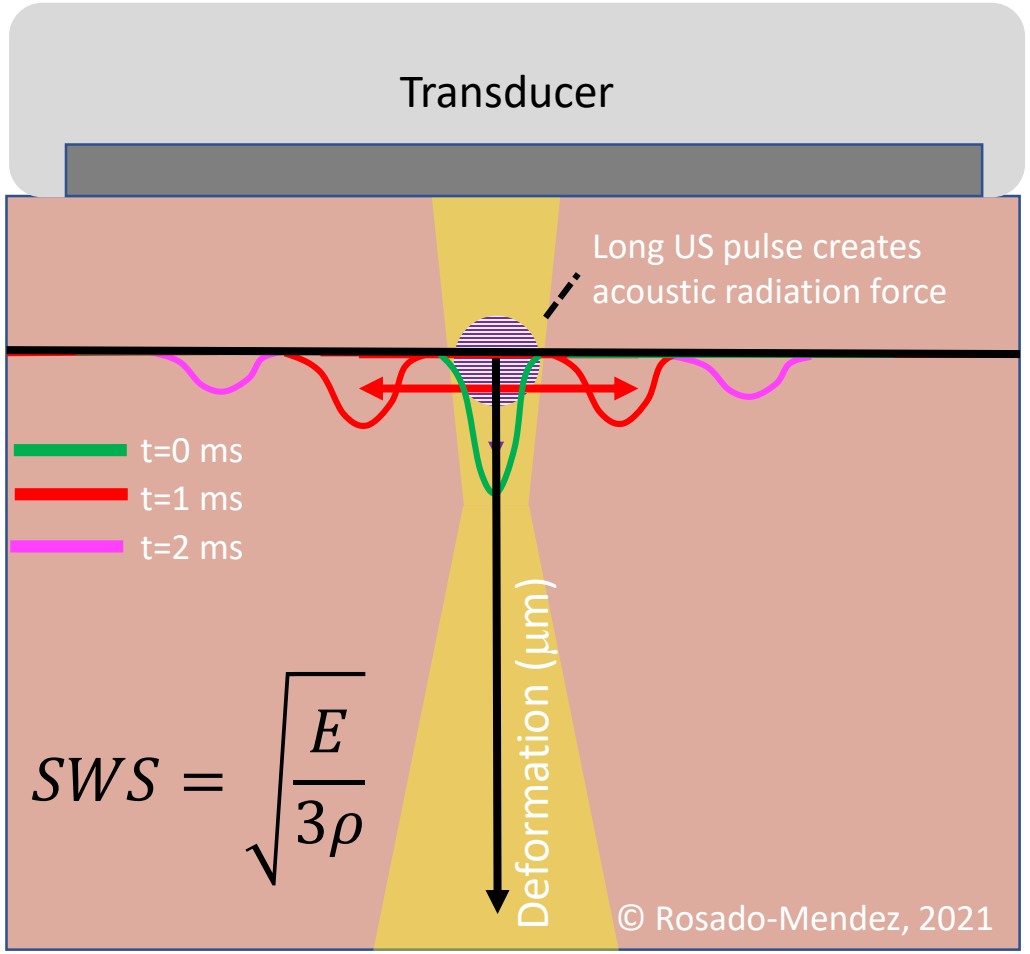
Contrast medium enhancement and uptake dynamics

Shear wave elastography

Pulse-echo quantitative ultrasound

Shear wave elastography

- Ultrasound-based technique used to quantify tissue stiffness non-invasively
- The transverse or shear waves are remotely induced by acoustic radiation force fields created by long, intense ultrasound (compression) pulses
- The shear wave speed (SWS) is used as a biomarker of tissue stiffness, e.g., assessment of liver fibrosis
- Commercial implementations from major vendors
- **QA/QC guidelines from ACR-AAPM**



Shear Wave Speed

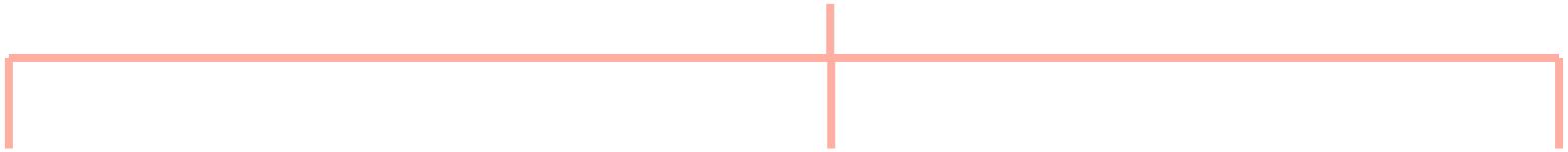
$$SWS = \sqrt{\frac{E}{3\rho}}$$

E: Young's modulus (kPa)

Shiina et al. Ultrasound in medicine & biology. 2015;41(5):1126-47
Ferraioli et al. Ultrasound in medicine & biology. 2015;41(5):1161-79

Pulse-echo quantitative ultrasound

Quantification of **acoustic properties** of tissue describing the physical interactions that ultrasound waves undertake as they propagate through tissue and generate echoes, using “raw” (unprocessed) echo signals produced by commercial scanners



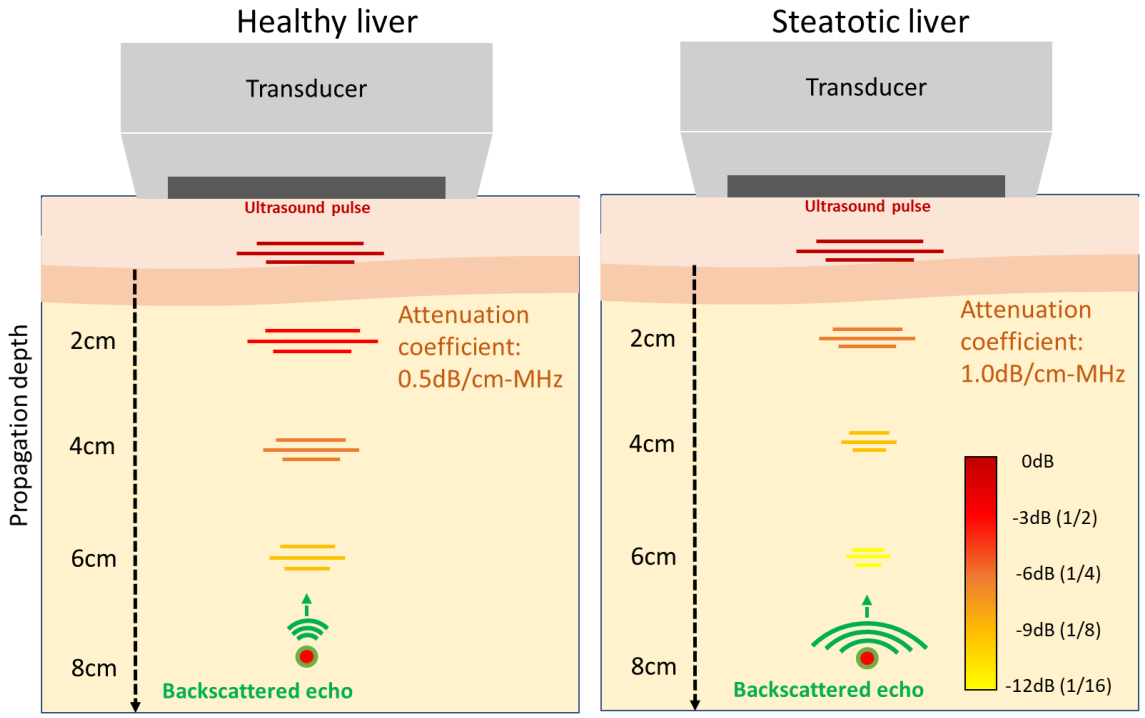
Attenuation coefficient

Backscatter coefficient

Speed of sound

Attenuation

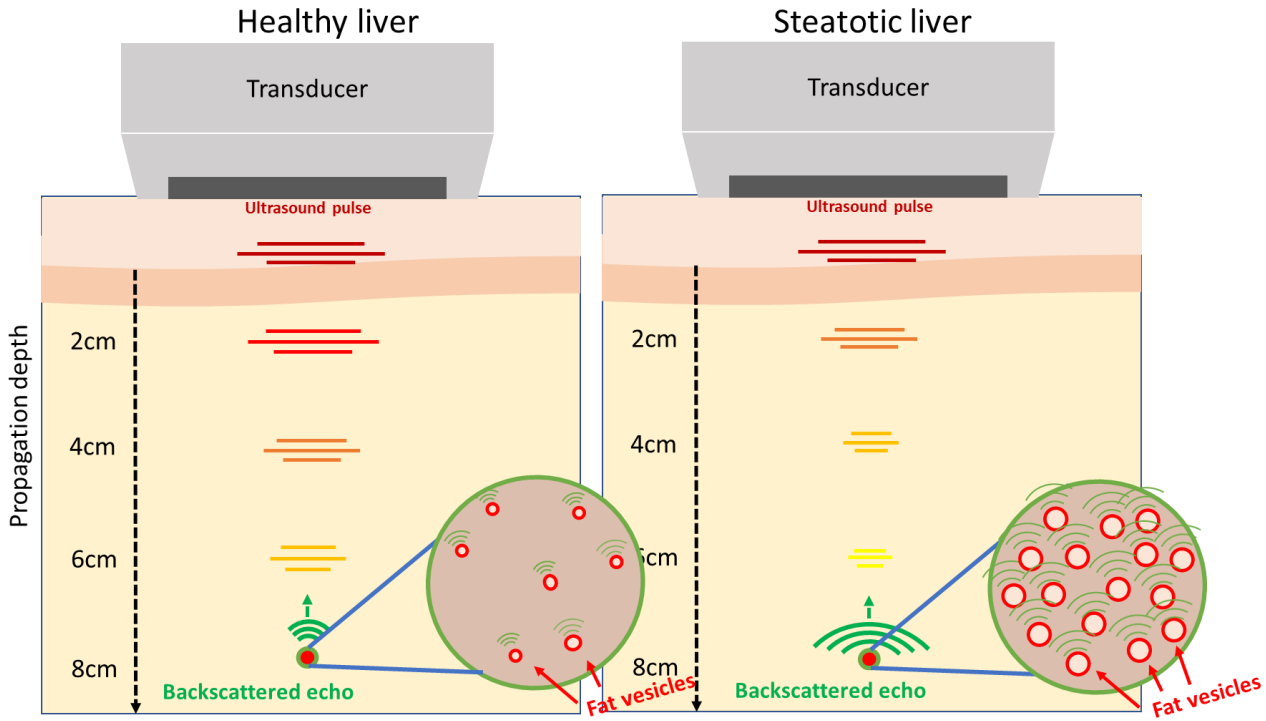
- **Attenuation**: exponential energy loss of the ultrasound wave as it travels through tissue and back to the transducer
- **Biomarker**: **Attenuation coefficient**
  - Rate of energy loss per unit distance
  - Depends on biochemical composition of tissue
  - Increases approximately proportionally with frequency in abdominal applications
  - Units: **dB/cm-MHz**
- **>6 commercial implementations**
- **No QA/QC guidelines**



Ozturk et al. Ultrasound in Medicine & Biology. 2018 ;44(12):2461-75
Ferraioli et al. Journal of Ultrasound in Medicine. 2021; 40(7):1325-32
Fetzer, Rosado-Mendez, et al. Radiology, in press

Backscatter

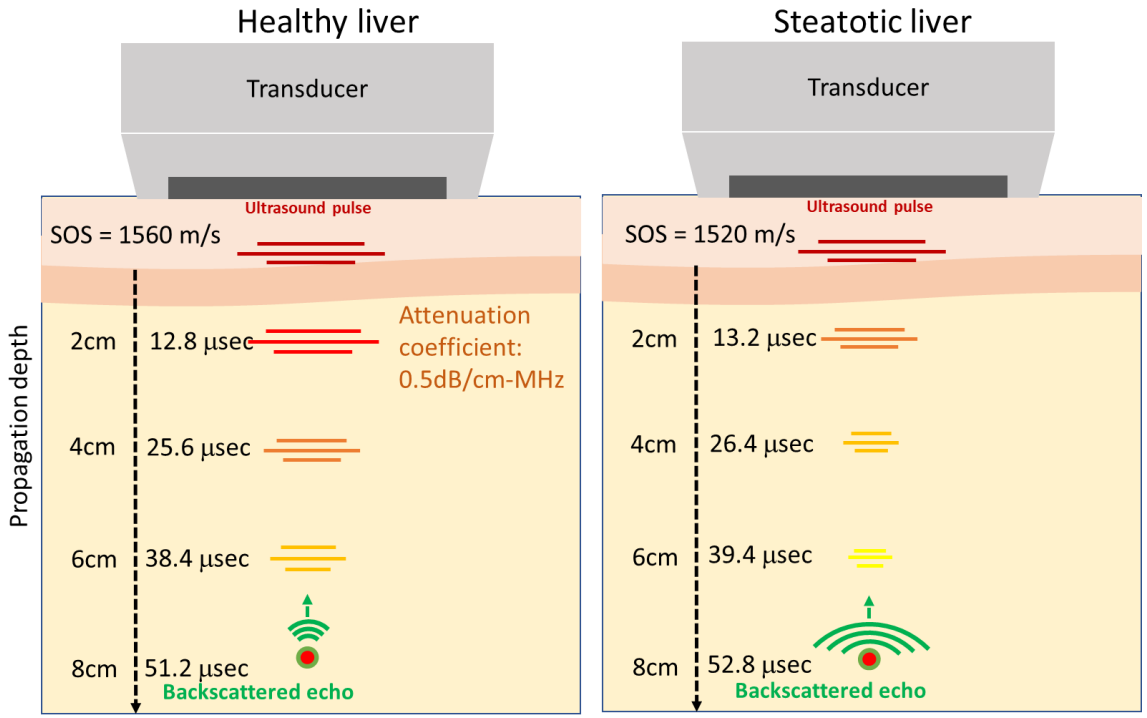
- **<u>Backscatter</u>:** Deflection of a fraction of the ultrasound energy back to the transducer
- **Biomarker**: **Backscatter coefficient**
  - Quantitative assessment of parenchymal echogenicity
  - Complicated dependence on frequency (f^0–f^4)
  - Depends on tissue microscopic heterogeneity of density and compressibility
  - Units: **1/cm-Sr**
- **One related commercial implementation**
- **<u>No QA/QC guidelines</u>**



Cloutier et al. Insights into Imaging. 2021;12(1):1-20
Ozturk et al. Ultrasound in Medicine & Biology. 2018 ;44(12):2461-75
Fetzer, Rosado-Mendez, et al. Radiology, in press

Speed of sound

- **<u>Speed of sound</u>:** Velocity of propagation of ultrasound waves in tissue
- **Biomarker: Speed of sound**
  - Inversely related to tissue mass density and compressibility
  - Approximately frequency independent (within abdominal imaging frequency range)
  - Units: **m/sec**
- **Not the same as shear wave speed!**
- Three commercial implementation
- **<u>No QA/QC guidelines</u>**



Ormachea & Parker. Ultrasound in Medicine & Biology. 2022; in press
Fetzer, Rosado-Mendez, et al. Radiology, in press
Ferraioli et al. Journal of Ultrasound in Medicine. 2021; 40(7):1325-32

ACR-AAPM Guidelines

ACR–AAPM TECHNICAL STANDARD FOR DIAGNOSTIC MEDICAL PHYSICS PERFORMANCE MONITORING OF REAL-TIME ULTRASOUND EQUIPMENT (www.acr.org)

ACCEPTANCE TESTS

Frequency: upon arrival, software update, transducer replacement,…

- **Scanners and transducers** (physical inspection, port inspection, geometric accuracy, sensitivity, spatial resolution, contrast resolution, display fidelity)
- **Doppler** (Doppler sensitivity, velocity accuracy, directional discrimination, angle correction, spatial registration, volume flow accuracy
- **Elastography functionality**

PERIODIC QUALITY CONTROL

Frequency: at least monthly

- Physical and mechanical inspection
- Image uniformity and artifact evaluation
- Fidelity of image display
- Port functionality

PERFORMANCE TESTING

Frequency: yearly

- Monthly QC tests
- Evaluation of QC program
- System sensitivity*
- Geometric accuracy*
- Contrast resolution*
- Spatial resolution
- Fidelity of display
- Doppler functionality
- **Elastography functionality**

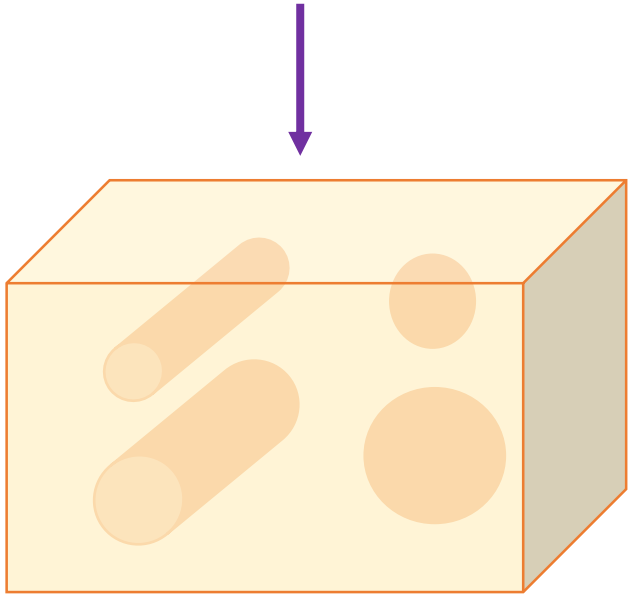
Target / Contrast-detail

Measurement accuracy and precision

https://www.acr.org/-/media/ACR/Files/Practice-Parameters/us-equip.pdf?la=en

Phantoms

Target/Contrast-detail



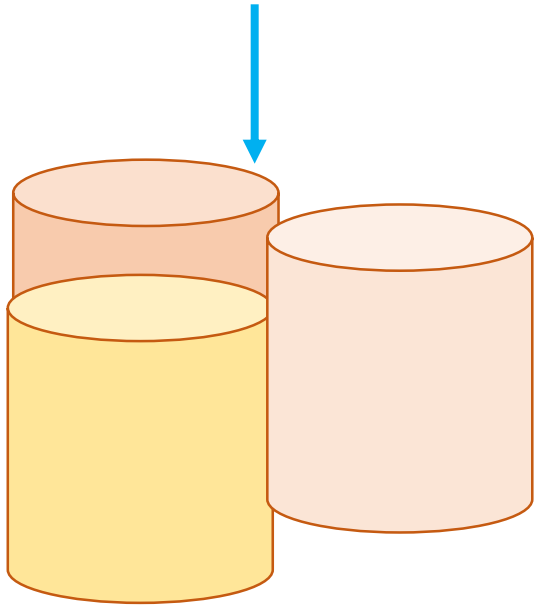
Cylindrical/spherical inclusions stiffer/softer than background

Attenuation: 0.5-0.7 dB/cm-MHz
Speed of sound= 1540m/s
Background: 3 – 30 kPa*
Inclusions: 3-200 kPa*
*Depending on application

Young's modulus (kPA)

Cournane et al. Ultrasound. 2012;20(1):16-23

Global characterization



Homogeneous samples with varying stiffness

Research examples: Al-Mutairi et al., UMB 2021;47(9):2749-58
Commercial examples: CIRS model 049, 049A

Commercial examples: CIRS Model 039
www.cirsinc.com

Examples of performance testing

Z. Long et al. J Appl Cl Med Phys 2018
doi.org/10.1002/acm2.12310

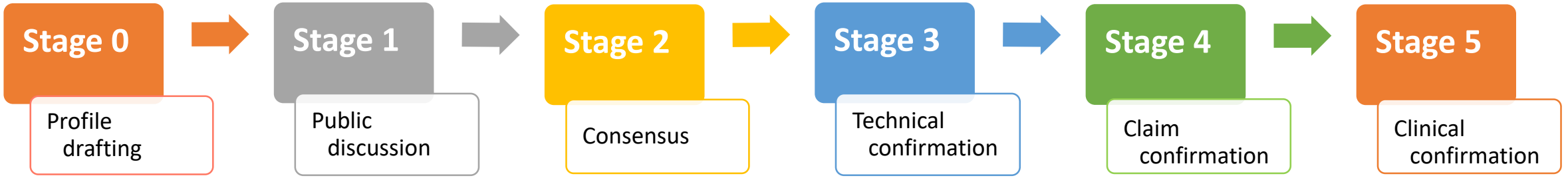
Acceptance testing of scanners with SWE

- Tests on homogeneous phantoms
  - Max System deviation from group mean
  - Inter-observer coefficient of variation
  - Intra-observer coefficient of variation
  - Effects of coupling medium
- Tests on target phantom
  - Comparison with a different vendor
  - Soft (8 kPa) and hard (45 kPa) targets in 25 kPa background
  - Sizes: 10.40, 6.49, and 4.05 mm diameter
  - Transaxial and longitudinal measurements

RSNA Quantitative Imaging Biomarkers Alliance

Mission: "Improve the value and practicality of quantitative imaging biomarkers by reducing variability across devices, sites, patients, and time"

QIBA profiles: live documents describing claims of expected levels of bias and precision in the quantification of the biomarker for an intended application, as well as actions to conform with the claims



qibawiki.rsna.org

Shear wave speed profile

- **Goal:** Help achieve useful levels of performance for the shear wave speed as a biomarker for liver fibrosis
- **Status: Stage 2 (Consensus)**
- Claims:
  1. Technical performance (within-subject coefficient of variation)
  2. Cross-sectional (95% confidence interval)
  3. Longitudinal (same system, same site)
  4. Longitudinal (different system, same site)
  5. Longitudinal (different system, different site)
- Checklists with activities required for conformance

Periodic Quality Assurance*
QA specified in ACR, AIUM or other accreditation guidelines
Recommendation – SWS measurement consistency Annual measurements of SWS on a QIBA elastic phantom should be within ±5% of the expected values from Verasonics testing
Confirmation that each operator meets staff qualification criteria
Recommendation - Confirmation of SWS phantom acoustic and mechanical properties at independent site if a weight change >0.5% during a period of 6 months has occurred

*Activities assigned to Quality Assurance manager

QIBA profile: Ultrasound Measurement of Shear Wave Speed for Estimation of Liver Fibrosis Version 04_25_2022
https://qibawiki.rsna.org/images/1/1b/QIBA_US_SWS_Profile_04.25.2022-clean_version.pdf

PEQUS profile

- **Goal:** Help achieve useful levels of performance for attenuation, backscatter coefficient, and speed of sound, as a biomarkers for liver steatosis
- **Status: Stage 0 (Profile drafting)**

1. Single-biomarker measurement level

2. Single-biomarker predictor level

3. Multiple-biomarker predictor level

Fetzer, Rosado-Mendez, et al., "Pulse-Echo Quantitative Ultrasound biomarkers for liver steatosis: towards technical standardization," Radiology, in press

Strategy

First draft of profile

Phantom specifications

We are here

Round-robin, multisite phantom study

Revision of claims and profile refinement

Stage 1

Summary

- Shear wave elastography and pulse-echo quantitative ultrasound provide quantitative information related to tissue elasticity/stiffness and acoustic properties, respectively
- The "ACR-AAPM *Technical standard for diagnostic medical physics performance monitoring of real-time ultrasound equipment"* includes performance tests for elastography as part of acceptance and annual performance testing. No guidelines exist for pulse-echo quantitative ultrasound (***yet***)
- The RSNA Quantitative Imaging Biomarkers Alliance works towards reducing bias and variability of quantitative imaging biomarkers by standardizing measurements and evaluating sources of error
  - ✓ The shear wave speed biomarker committee has produced a profile (consensus stage, 2/5) describing activities required to conform with claimed levels of performance of the SWS as a biomarker for liver fibrosis. These activities include periodic QA
  - ✓ The PEQUS profile is still in the drafting stage (0/5) and will contain performance claims for attenuation, backscatter coefficient, and speed of sound as biomarkers for liver steatosis

Acknowledgements

<u>Leadership and members of:</u>

QIBA ultrasound coordinating committee

QIBA SWS biomarker committee

AIUM/QIBA PEQUS biomarker committee

Industry partners

Thank you for your attention

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