Diagnostic Ultrasound Imaging QA/QC Hands-on Workshop

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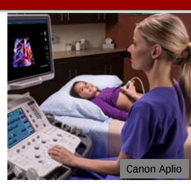
Learning Objectives

- Define common elements of a QA program for diagnostic ultrasound imaging that meet ACR ultrasound lab accreditation requirements
- Identify QC tools, phantoms, and software for testing diagnostic ultrasound systems a
- Describe/(participate in) the use of these devices on general purpose ultrasound scanners as well as on a whole breast screening ultrasound system.

Today's most common Radiology/Echocardiology systems



- Small-mid-size scan console.
- Linear, curvilinear, phased array transducers, supported by hardware or software beam formers, in the console or in the probe, real-time 2D images.
  - Many 2019 + systems apply "synthetic transmit focus"
- 3D imaging capabilities via motorized translation of the array or via a 2D array.
- Very good gray-scale performance, Doppler, shear wave, contrast agents

Information From US Accreditation Bodies

- Ultrasound Accreditation Program Requirements, Am College of Radiology, http://www.acraccreditation.org
- ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Real Time Ultrasound Equipment. http://www.acr.org/~/media/ACR/Documents/PGTS/standards/MonitorUSEquipment.pdf
- AIUM 1998, American Institute of Ultrasound in Medicine, Routine Quality Assurance for Diagnostic Ultrasound Equipment. http://aium.s3.amazonaws.com/resourceLibrary/rqa.pdf

Annual Surveys, Routine QA (ACR)

- Annual surveys: required
  - Physical and and mechanical inspection; sterility
  - Image display performance
  - Image Uniformity
    - Element "dropout" and other sources on non-uniformity
  - System sensitivity and/or penetration capability
  - Geometric measurement accuracy (during program initiation)
- 6-month Routine QC: optional
  - Same items as on annual survey
- http://www.acraccreditation.org/Modalities/Ultrasound

Physical and Mechanical Inspection, ACR

- Console
  - Air filters
  - Lights, indicators
  - Wheels, wheel locks
  - Proper cleaning (are procedures in place?)
  - Viewing monitor, keyboard clean
  - Other safety issues

Before

Air filters on back of console

After

Image Display (Scanner and PACS)

- Gain and sensitivity adjustments done using system monitor
- Intrepretation most often done on a PACS workstation.
- Important that there is agreement between image features viewable on PACS and the features seen on the system monitor.
- Problems have arisen when the 2 do not agree
  - Apparent echo-free masses (cysts) could be overgained by the sonographer and appear to have subtle echo signals on PACs
  - Sonographers sometimes run over to the PACs room to check their images!

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Recommend: SMPTE, TG18 Gray Scale Test Pattern

- Available on most scanners
- 0% to 100% gray bar pattern
- Squares for detecting geometric distortion
- Are all gray transitions visible?
- Is the 0-5% transition visible?
- Is the 95-100% transition visible?

TG18: Q=0+14 I=1 | Q=128+14 I=129 | Q=255-14 I=254

UW-Madison System Worksheet, page 2 of Report for each scanner

General Machine Cleanliness:

Keyboard and knobs clean?	☒Yes	☐No
Monitors Clean?	☒Yes	☐No
Air Filters clean?	☐Yes	☒No

Mechanical and Electrical:

Wheels fastened securely and rotate easily?	☒Yes	☐No
Wheel locks work well?	☒Yes	☐No
Accessories fixed securely?	☒Yes	☐No
Cords attached securely?	☒Yes	☐No

PACS Workstation-System Monitor

Contrast and Brightness between scanner and workstation:
☐1 poor ☐2 ☐3 average ☒4 ☐5 excellent

Assessment made from Both 1 & 2 below:
Generate a gray bar pattern. Save it to PACS.
Number of gray levels seen on the system monitor 15+
Number of gray levels seen on the PACS 15+
*Gray bar visualization:
With "patient" registered, push "exam utilities;" push "test pattern."
Record an image and compare to the workstation
Count the number of gray levels seen in the room and on the PACS monitor.
SMPTE Pattern: 0-5% transition: seen on system monitor: NO seen on PACS: YES
95-100% transition: seen on system monitor: YES seen on PACS: YES

Generate a gray bar pattern. Save it to PACS.
Number of gray levels seen on the system monitor 15+
Number of gray levels seen on the PACS 15+

SMPTE Pattern: 0-5% transition:
system monitor: NO
PACS monitor: YES

SMPTE Pattern: 95-100% transition:
system monitor: YES
PACS monitor: YES

Routine QA: Transducers

- Check all transducers on the system
  - (most facilities have many interchangeable probes that float among systems; a systematic approach to evaluate all probes should be in place.
- Transducer Inspection Delaminations
  - Frayed cables
  - Proper cleaning

www.providian.com

Tests using phantoms. Current materials:

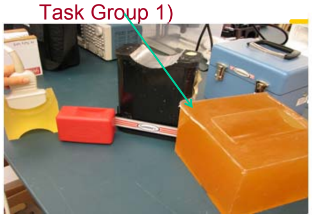
- Water-based gels
  - Advantages:
    - Speed of sound = 1540 m/s
    - Attenuation ~ proportional to frequency (specific attenuation expressed as 0.5 or 0.7 dB/cm-MHz)
    - Backscatter
  - Disadvantages:
    - Subject to desiccation (?)
    - Must be kept in containers
    - Requires scanning window

Tests using phantoms. Current materials:

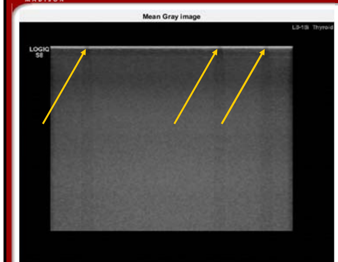
- Solid, non-water-based materials (urethane)
- Advantages:
  - Not subject to desiccation
  - No need for scanning window; possibility for soft, deformable scanning window
  - Produce tissue-like backscatter
- Disadvantages:
  - C= 1430-1450 m/s
  - Attenuation ~ proportional to $f^{1.6}$
  - Surface easily damaged if not cleaned regularly to remove gels

Uniformity tests with curvilinear arrays

- Solution: Use a phantom having concave or easily deformable windows (Goodsitt et al, AAPM Ultrasound Task Group 1)



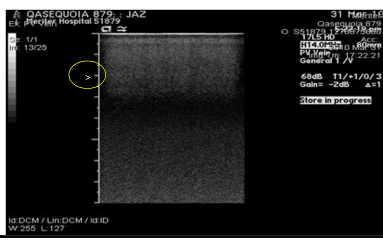
Check for non-uniformities caused by element dropout



- Most frequent fault seen in QA testing
- Image a phantom using good coupling
- Search for "shadows" emanating from the transducer
- Common in new and old probes!
- (This transducer has 3 obvious areas of dropout.)

Recommended Testing Technique

- Use a single (shallow) transmit focal distance (if system has user set transmit focus controls)



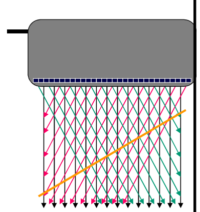
Recommended Testing Technique

- Use a single (shallow) transmit focal distance
- Use persistence; translate transducer to reduce effects of speckle.

Recommended Testing Technique

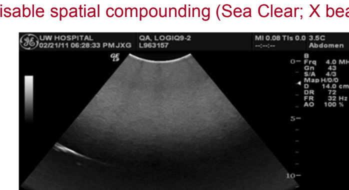
- Use a single (shallow) transmit focal distance
- Use persistence; translate transducer to reduce effects of speckle.

This transducer has significant element dropout.

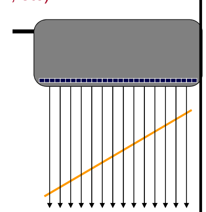


Recommended Testing Technique

- Use a single (shallow) transmit focal distance
- Use persistence; translate transducer to reduce effects of speckle.
- Disable spatial compounding (Sea Clear; X beam, etc)



Dropout areas are easily seen with proper technique.



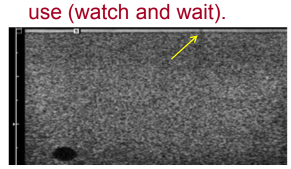
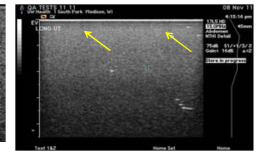
Transducer worksheet part of UW Report

Instructions, uniformity ratings (UW-Madison; differs slightly from AAPM):
1=uniform
2=minor inhomogeneity (no more than 2 minor dips)
3=Significant inhomogeneities; transducer is functional, but consider replacing
4=Immediate repair or replacement recommended
Data table (1 line for each transducer)

Transducer ID/Serial Number	Cables/ cracks/ delaminate		Uniformity, dropout		Sensitivity (Depth of Penetration) (MHz/cm)	Geometric Accuracy H: cm/actual cm V: cm/actual cm	Conclusions and recommendations
	OK	No	OK	No			
C1-5 79635YP9	☒	☐	☒	☐	5MHz/ H5MHz/	H: V:	Uniformity Rating 1 DOP ≈ to previous results ☒ Yes ☐ No Click here to enter comments.

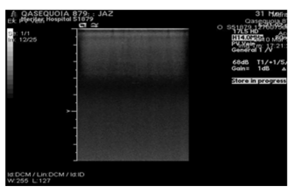
Transducer Recommendations

- Rating of "2": 1 or 2 minor defects seen. Continue to use (watch and wait).

Transducer Recommendations

- Rating of "3": Significant inhomogeneities; transducer is functional, but look to replace it ASAP.

Transducer Recommendations

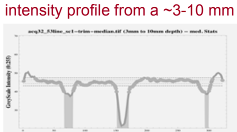
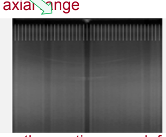
- Rating of "4": Immediate repair or replacement recommended.


The left half of the array is faulty, with numerous dropout areas.


There is a single, large dropout areas in the middle of the array.

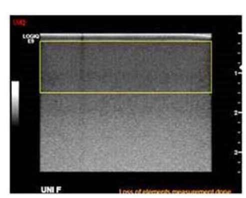
Objective Criteria being developed

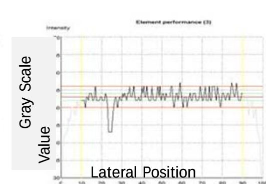
- IEC 62736 Ultrasonics (2016) – Pulse-echo scanners – Simple methods for periodic testing to verify stability of an imaging system's elementary performance
- AAPM Ultrasound Subcommittee Task Group
  - Record a cine loop while translating the transducer ⊥ to the image plane.
  - Compute the **'median'** image for this (~100) image loop
  - Plot a lateral intensity profile from a ~3-10 mm axial range



Median image

- A dip >3dB and more than 2 elements wide is worth counting as a defect of possible concern. (IEC 62736)

Image Uniformity(Automated QC Software)


Median Image

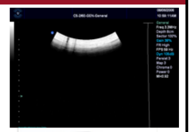


UltraiQ

Dip magnitude and width analyzed in uniformity assessment

Developments in Probe Testing Space: FDA "Marketing Clearance of Dx US systems & Transducers"

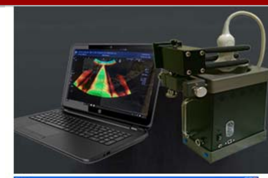
- Guidance Document, 6/27/2019
- "Manufacturers should implement tests of a transducer when it is activated by the sonographer "
- "Tests should be accessible to competent operators, service personnel"
- Machine sequences through each channel measuring the signal while the transducer is "in air."
- "Reports should identify for operators regions in an image that could be compromised"
- "Tests should be available when operators suspect a probe may be failing."

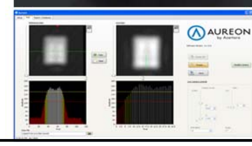


Aureon by Acertara

System that tests ultrasound transducers when driven by the scanner

- 2D matrix receiver captures energy profile of transducer following each transmit pulse
- All 1-D and 2-D transducers from any manufacturer
- All operating modes, including ARFI and shear wave imaging
- Assesses lens stability over time
- Potential to calculate acoustic dose





Other ways to test transducers: Sonora FirstCall 2000

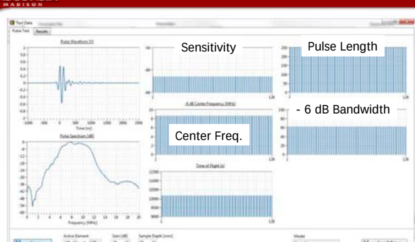
- FirstCall 2000 is an "early" probe diagnostic tool
- Echo from a curved or planar target in water is detected with each element
- Each element is tested for:
  - Sensitivity
  - Capacitance
  - Pulse duration
  - Center frequency
  - Bandwidth

System developed by Wayne Moore and Colleagues in ~2001.
After acquisition of the First Call system by a different manufacturer, probe adapters, etc., no longer available.

Transducer Tester Resurgence: ProbeHunter.com

European company (Sweden) that has built and now markets an extended version of a probe tester (similar in many respects to the original Sonora) but with:
- 256 channels
- capabilities for testing newer US transducers
- adapters for nearly every make and model scanner and transducer

Transducer Tester Resurgence: Atlas by ACERTARA



http://www.acertaralabs.com

Design goal of ATLAS:
- "replicate the results of legacy test systems"

Annual Surveys, Routine QA (ACR)

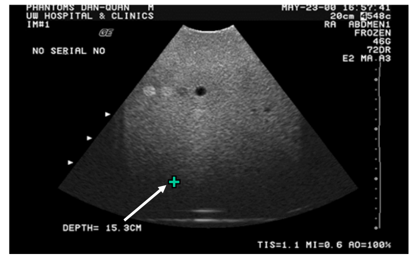
- Annual surveys: <u>required</u>
  - Physical and and mechanical inspection; sterility
  - Image display performance
  - Image Uniformity
    - Element "dropout" and other sources on non-uniformity
  - **<u>System sensitivity and/or penetration capability</u>**
  - Geometric measurement accuracy (during program initiation)
- 6-month Routine QC: <u>optional</u>
  - Same items as on annual survey
- http://www.acraccreditation.org/Modalities/Ultrasound

Sensitivity, Maximum Depth of Penetration

- Considered by many as a good overall check of the integrity of the system
- FOV set to match the phantom height or the maximum visualization depth of the transducer
- Output power (MI) at max
- Transmit focus at deepest settings
- Gains, TGC for visualization to the maximum distance possible

Maximum "Relative" Depth of Penetration

How far can you see the speckle pattern in the material?



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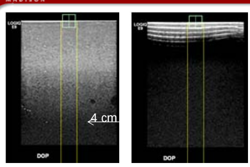
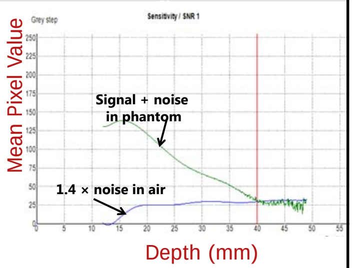
DOP testing: Objective methods are becoming available





Compute mean pixel value vs. depth for phantom (signal+noise).

Do the same for "air" image (noise) acquired using the same settings.

Depth where (signal + noise) equals 1.4 x (noise) =DOP (IEC 62736, 2016)

UltraiQ

UW Report Transducer worksheet (page 3)

Transducer ID/Serial Number	Cables/ cracks/ delaminate		Uniformity, dropout		Sensitivity (Depth of Penetration) (MHz/cm)	Geometric Accuracy H: cm/actual cm V: cm/actual cm	Conclusions and recommendations
	OK	No	OK	No			
C1-5 79635YP9	☒	☐	☒	☐	5MHz/13.71cm H5MHz/10.6 cm ------------------ S-N: 5MHz/13.8 cm H5MHz/10.3 cm	H: V:	Uniformity Rating 1 DOP ≈ to previous results ☒ Yes ☐ No Click here to enter comments.

Distance Measurement Accuracy: Vertical

Measure leading edge to leading edge

- Actual 8.0 cm
- Measure 7.94 cm
- error 0.75%
- Acceptable

*Action: >1.5mm or 1.5%

*Defect: >2mm 0r 2%

*Goodsitt M M *et al* 1998 Real-time B-mode ultrasound quality control test procedures. Report of AAPM Ultrasound Task Group No. 1 *Med. Phys.* **25** 1385

Routine QA (ACR General US Program)

- Distance Measurement Accuracy tests
  - Necessary? ("Scanner is a transducer tied to a computer.")
  - ACR lists as optional
  - May be important for specific uses
    - Images registered from 3-D data sets
    - Workstation measurements
    - Radiation seed implants

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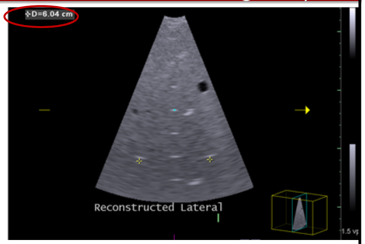
Routine QA (ACR General US Program)

- Distance Measurement Accuracy tests
  - Required in the mechanically scanned direction



Actual: 6.0 cm
Measured: 6.04 cm
Error: <0.7%

UW Report Transducer worksheet (page 3)

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L9-6	☐	☐	☐	☐		H: V:	Uniformity Rating __ DOP ≈ to previous results ☐ Yes ☐ No Click here to enter comments.
etc., for each probe	☐	☐	☐	☐		H: V:	

ACR submission for "Annual Survey" (model)

Equipment Evaluation Tests

Test	Pass/Fail	Comments
1. Physical and Mechanical Inspection	*Pass*	Air filters needed cleaning
2. Image Uniformity and Artifact Survey	5 Probes pass 0 probes fail	The C1-6 (s/n 23456) and the L3-7 (s/n 65432) were rated "2." (see p 3) All others are "1".
3. Geometric Accuracy (Optional)	5 Probes pass 0 probes fail	All 5 transducers tested exhibited excellent geometric accuracy
4. System Sensitivity	5 Probes pass 0 probes fail	Tested using both visual assessment and S/N assessments. Results are consistent with similar probes
5. Scanner Electronic Image Display Performance	*Pass*	The 0-5% transition of the TG18 test patters was not visible on the scanner monitor; it was seen on the PACs system. Please consider having the manufacturer recalibrate the scanner monitor.
6. Primary Interpretation Display Performance (Optional)	*Pass*	
7. Contrast Resolution (Optional)	_ Probes pass _ probes fail	Optional; Not tested
8. Spatial Resolution (Optional)	_ Probes pass _ probes fail	Optional; Not tested

Were all clinically used transducers tested?

Spatial Resolution?

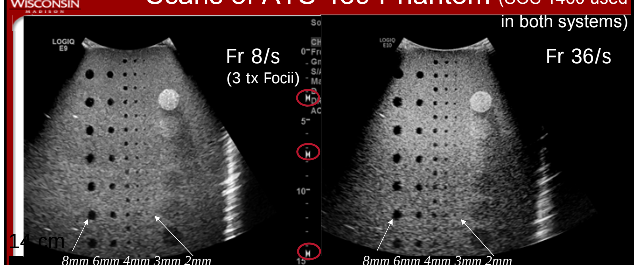
- Not done routinely
  - 2 image sets, each taken with a different speed of sound assumption in the beam former
  - Targets not agreed on universally
    - Anechoic objects get fuzzy with poorer resolution
    - Line targets get wider
  - Requires standardized gain settings to make meaningful
  - Enhance using computational methods to measure point spread function width? (UltraIQ)

Image of a phantom is useful for qualitative comparisons!

Conventional

Spatial Compounding

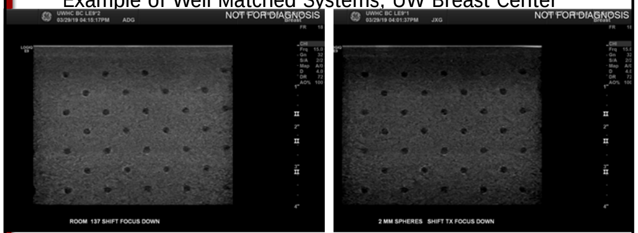
Scans of ATS 439 Phantom (SOS 1460 used in both systems)



Traditional Beam Former *Synthetic TX Focus*

Breast Center Acceptance Tests, including a Gammex 408 Phantom

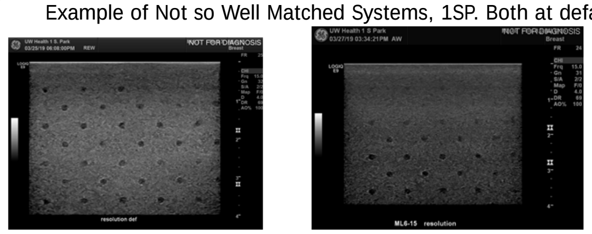
Example of Well Matched Systems, UW Breast Center



Rom 137, Breast Center

Rm 139, Breast Center

Example of Not so Well Matched Systems, 1SP. Both at defaul



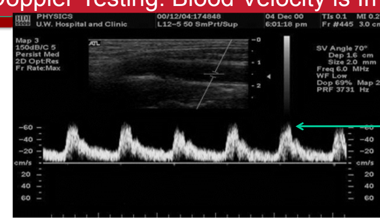
Rm 1, 1 SP

Rm 3, 1 SP

Beyond "Routine QC:" Important Areas for Medical Physics Involvement

- Tests of Presets using more advanced phantom testing
  - Example: breast imaging using multi-row transducers
- Doppler evaluations
  - Velocity accuracy
  - Volume flow, (QIBA)
  - Directional Discrimination; gate accuracy, etc.
- Elasticity, shear wave (SW) imaging
  - QIBA work on SW velocity in liver (advanced stages)

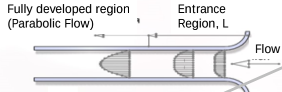
Doppler Testing: Blood Velocity is Important!



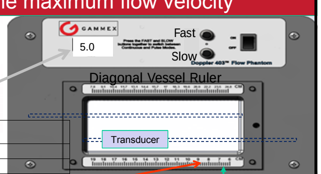
Common Carotid Artery
60 cm/s

Consensus criteria used to diagnose stenosis of the internal carotid artery based on blood velocity measurements. ICA blood velocities of less than 125 cm/s are considered normal, as are ratios of the velocity in the internal carotid artery to that in the common carotid artery of less than 2. Specific values of these Doppler spectrum-based parameters are associated with different degrees of stenosis. (From http://www.slideshare.net/shaffar75/doppler-ultrasound-of-carotid-arteries)

Gammex 403 Flow Phantom: uses a calibrated volume flow meter Estimates are made of the maximum flow velocity



Phantom Display (ml/s)	System Display (ml/min)	Average Vmean	Peak Velocity at Parabolic Flow Vmax	Entry Length to achieve Parabolic Flow
1	60	5.1	10.2	1.76
2	120	10.2	20.4	3.51
3	180	15.3	30.6	5.27
4	240	20.4	40.7	7.03
5	300	25.5	50.9	8.79
6	360	30.6	61.1	10.54
7	420	35.7	71.3	12.30
8	480	40.7	81.5	14.06
9	540	45.8	91.7	15.81
10	600	50.9	101.9	17.57
11	660	56.0	112.0	19.33



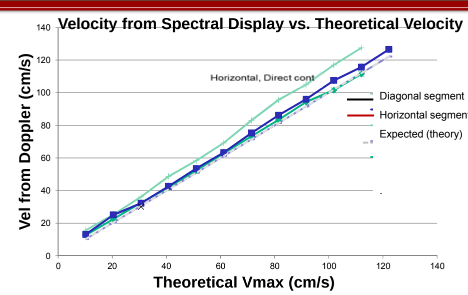
Horizontal Vessel Ruler

$$v_{mean} = \frac{Q}{Area} = \frac{Q}{\pi D^2/4}$$

$$v_{max} = 2\, v_{mean}$$

$$L = 0.06\, D\, Re$$

Doppler 403 Flow Phantom, Siemens S2000



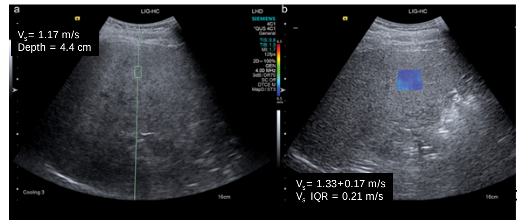
Liver Tissue Stiffness

"And on the basis of shear wave measurements, the liver exhibits a stiffness of 13.4 kilopascals."

- Strain and shear wave imaging is built into most radiology machines.
- Important area of medical physics involvement
  - Support testing
  - Radiology resident education
  - QIBA work

Tissue Stiffness: Shear Wave Speed

- One of the major growing applications of the technology is for assessing the liver, detecting fibrosis, etc.



Kennedy et al., Quantitative Elastography Methods in Liver Disease: Current evidence and Future directions, Radiology 286: No 3 – March 2018.

QIBA Effort: Shear Wave Speed in Liver

QIBA Profile* ***Ultrasound Measurement of Shear Wave Speed for Estimation of Liver Fibrosis.*** If successful, shear wave assessments might be used for:

- patient treatment decisions
- monitor progression, response to treatment

QIBA Profile: Places requirements on:

- Acquisition Devices,
- Technologists, Radiologists, training, actions
- **Image Data Acquisition**, Image Data Reconstruction,
- Image QA and Image Analysis.

*Currently in draft form only. Committee heads: Brian Garra, MD, Tim Hall, Ph.D., Andrej Milkowski, MS.

QIBA Effort: Shear Wave Speed in Liver

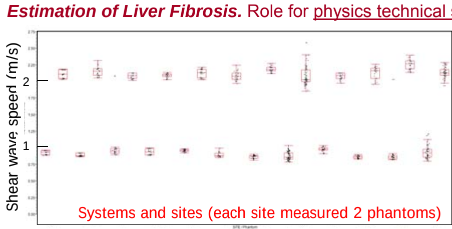
QIBA Profile* ***Ultrasound Measurement of Shear Wave Speed for Estimation of Liver Fibrosis.*** Role for physics technical support

- Standard QA tests listed by AIUM and ACR
- In-house SWE phantom testing is an important component.
- Elastic phantoms, ~2 m/s and ~ 0.9 m/s (using ultrasound based SWE)
- Standard properties of QA phantoms
  - 0.5 ± 0.1 dB/cm-MHz
  - SOS 1540 ± 30 m/s
- Procedure for verifying phantom stability

*Currently in draft form only. Committee heads: Brian Garra, MD, Tim Hall, Ph.D., Andrej Milkowski, MS. Phantom courtesy of CIRS Inc.

QIBA Effort: Shear Wave Speed in Liver

QIBA Profile* ***Ultrasound Measurement of Shear Wave Speed for Estimation of Liver Fibrosis.*** Role for physics technical support



Tim Hall et.al., RSNA/QIBA: Shear wave speed as a biomarker for liver fibrosis staging. IEEE Ultrasonics Symposium Proceedings, 2013.

Thanks to Equipment Suppliers, AAPM Volunteers

Room Lay out