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Medical Physics 2.0
Ultrasound 2.0

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Overview

- Ultrasound Perspectives (Paul Carson, PhD)
- Ultrasound 1.0 (Zheng Feng Lu, PhD)
- Ultrasound 2.0:
  How will *clinical* medical physics support future ultrasound practices?
  - Performance testing
  - Optimization of image quality and exam protocols
  - Clinical innovation
  - Education of physicians, sonographers, residents, medical students, patients
- Clinical implementation

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Role of ultrasound in future clinical imaging practices

- Strengths of ultrasound:
  image quality, Doppler modes, real-time, portable, safety record, low cost

  → *Very wide range of clinical applications*
  - adjunct to physical exam, vascular access for interventional radiology procedures, screening, primary diagnosis, guidance of biopsy & fluid aspiration, guidance of ablation (e.g. RF, ETOH), thermal ablation (MRgFUS, HIFU), facilitate soft tissue healing, targeted drug delivery


Philips Healthcare

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Role of ultrasound in future clinical imaging practices

- Who is using ultrasound?
  Radiology, Cardiology, Anesthesiology, Obstetrics & Gynecology, Urology, Gastroenterology & Hepatology, Hospital Internal Medicine, …

- The future…
  - Continued expansion in clinical applications and exam volumes is expected
  - Increased diversification in user base?

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Ultrasound Perspectives

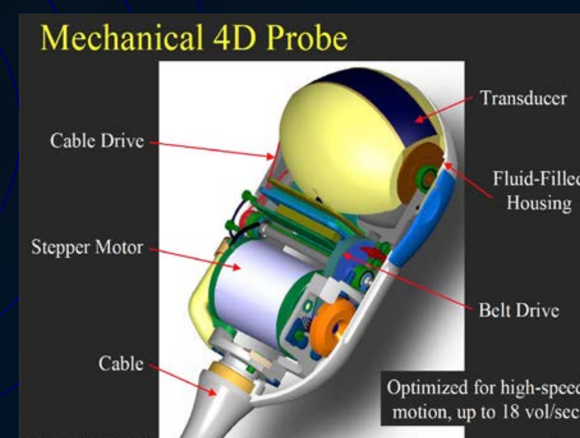
PL Carson, PhD

1. **Perspectives from the past and present**
   1. Innovations in newer current medical ultrasound systems
   2. Physics successes and failures
2. **A perspective, from the more distant future, of potential use in shaping planning by medical physics**
   1. Ubiquitous in personal experience e- personal tricorders
   2. Power, readout and internal processing of neural and other implants
   3. Localized drug delivery and activation
   4. Resolving of deep, even transcranial, 200 micron vessels
   5. Medical physicists' opportunities

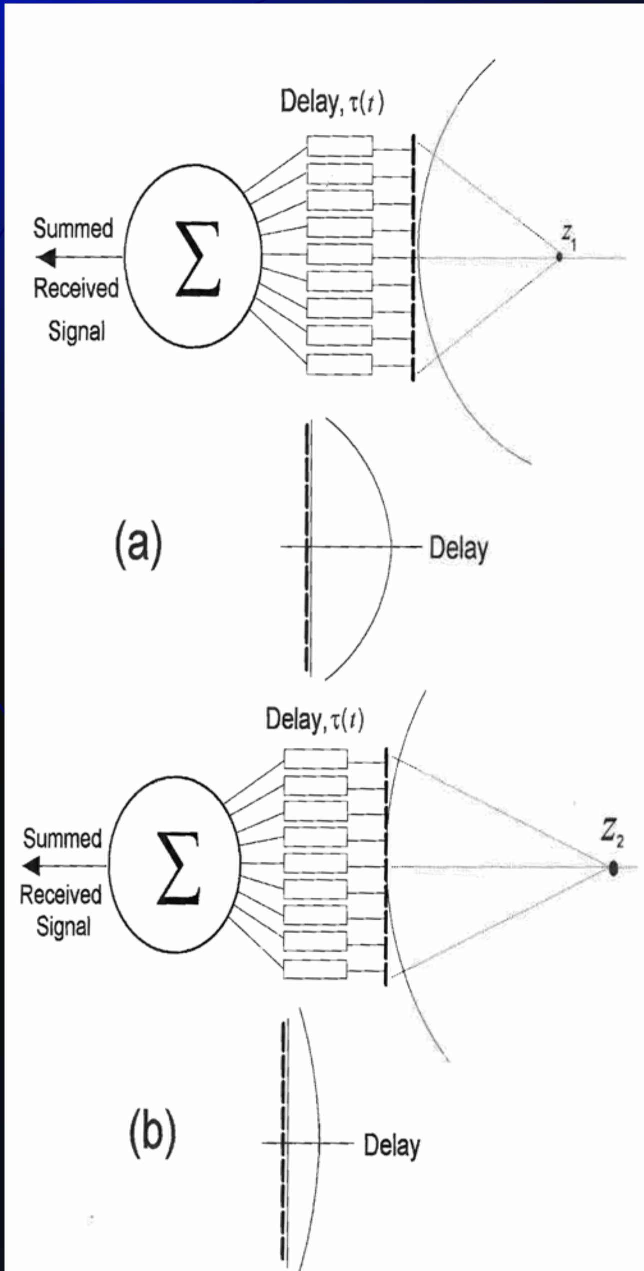
Innovations in newer current systems

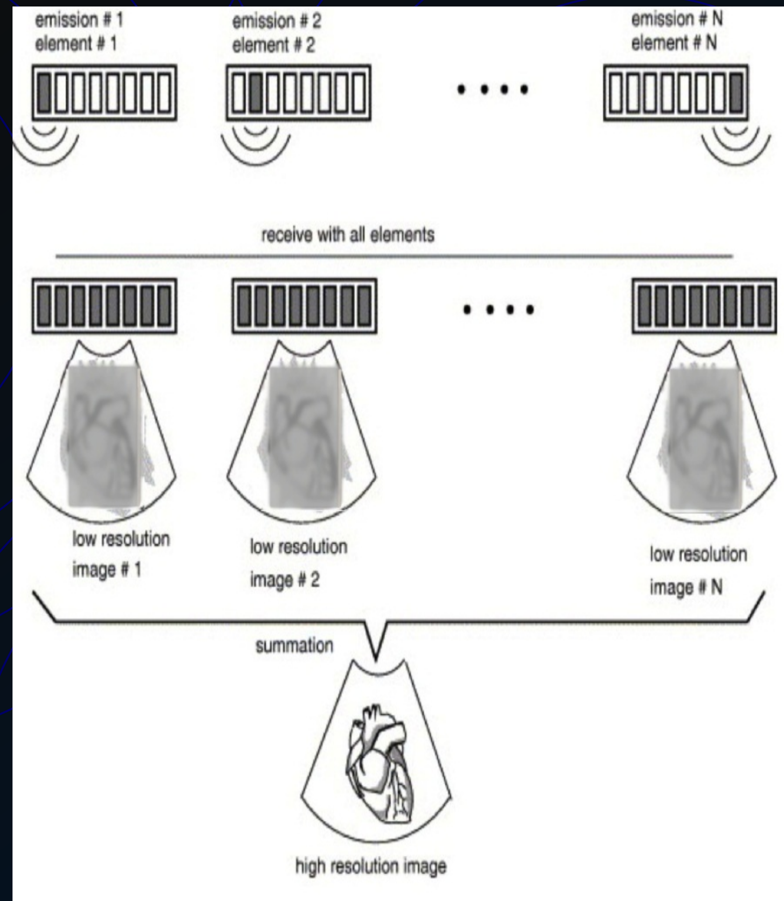
- 1. Software beam formers
- 2. Shear wave speed imaging (elastography)
- 3. 4D color flow contrast and non-contrast imaging
- 4. Aberration correction

D Wildes,
AIUM 05



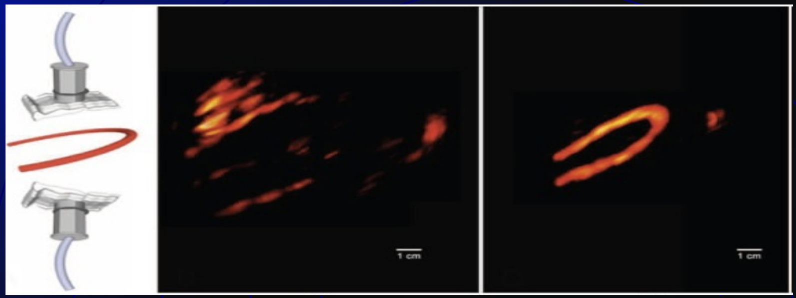
Synthetic aperture imaging





Adapted from Cobbold, Foundations of Biomedical Ultrasound, Oxford Press, 2007, p 34.

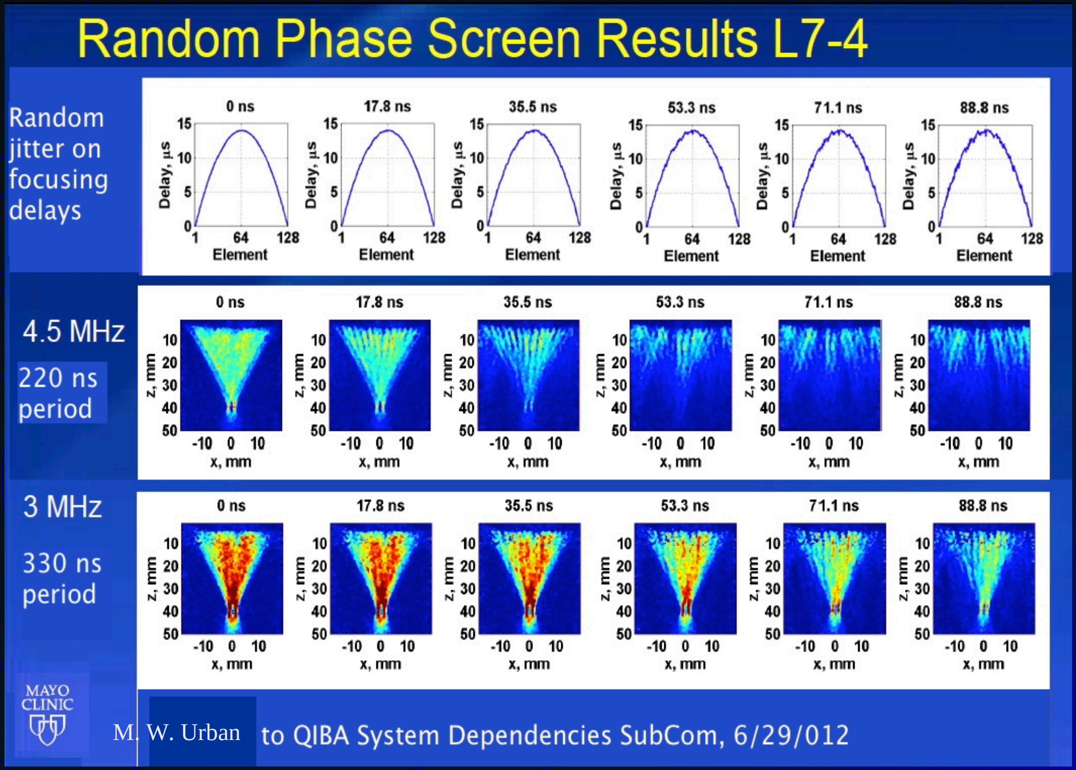
← JA Jensen, et al., Ultrasonics, Suppl. 2006, pp e5ff.



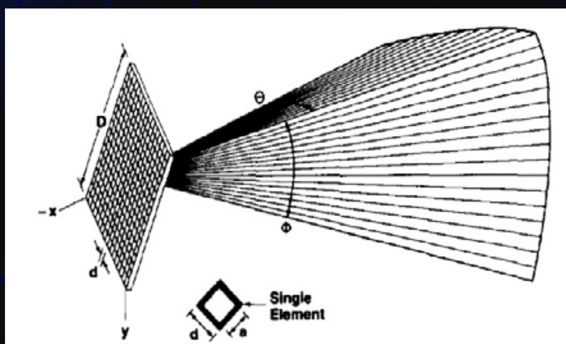
Lindsey & Smith, "Pitch-catch phase aberration correction of multiple isoplanatic patches for 3-D transcranial US," IEEE TUFFC, 60, 463, 2013 (Ultras. Imaging, Jan: 35-54, 2014).

Aberration correction

Beam pretty good up to rms phase noise of 0.1 τ

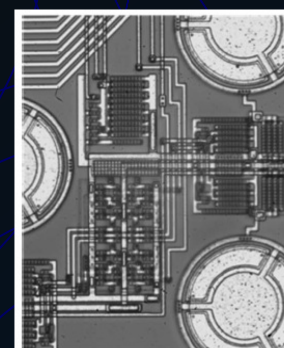


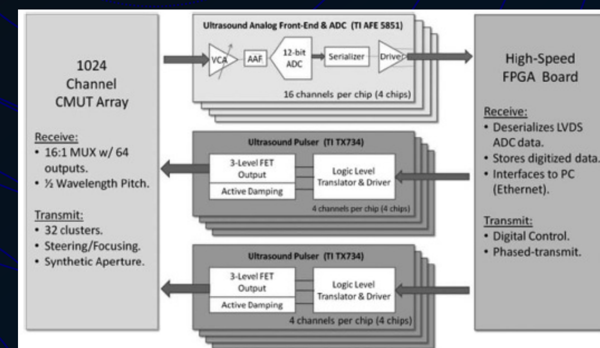
Perspective from the more distant future



Smith, S.W., et al., IEEE Trans,. Ultras. Ferroel. Freq. Contr., 38, 1991, 100-108

Lemmerhirt, D., et al., A 32 x 32 capacitive micromachined ultrasonic transducer array manufactured in standard CMOS. *IEEE Trans.Ultras, Ferroel. Freq. Contr., 59*, 1521-1536, 2012





I. High end medical future
   a. Full 2D arrays – evolution is here **…electronic 4D imaging**
   b. Aberration correction
   c. Super resolution
II. High performance US simple in the future, thus ubiquitous
III. Medical physicists can serve broad spectrum of society

Ultrasound 1.0

ZF Lu, PhD

1. System performance

- Introduction
- Ultrasound phantoms
- Ultrasound image quality metrics

2. System implementation

- Efficacy and sensitivity of current ultrasound QA/QC

3. Testing paradigm

- Survey of voluntary ultrasound accreditation programs
- Survey of available standards for diagnostic ultrasound

Various Levels of QC Testing

	Testing Time and Methods	Testing Frequency	Testing Personnel
Level 1	•Quick check; •no special tool needed;	Daily or weekly or monthly	By **ultrasound system users** and overseen by medical physicists
Level 2	Quick QC tests with a simple phantom;	Quarterly or semi-annually	By **ultrasound system users** and overseen by medical physicists
Level 3	Comprehensive QC tests with phantoms;	Annual or every two years	By medical physicists

Ultrasound Phantoms

Tissue-mimicking

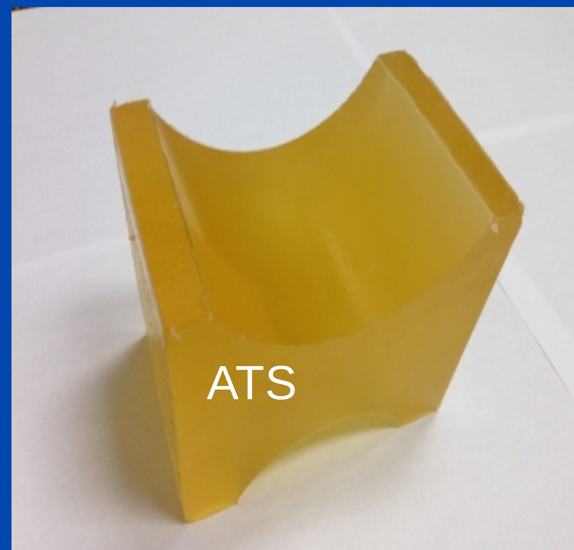
- Speed of sound propagation
- Attenuation coefficient
- Backscatter coefficient (echogenicity)
- Built-in targets
- Ultrasound elastography properties

Water-based versus rubber-based

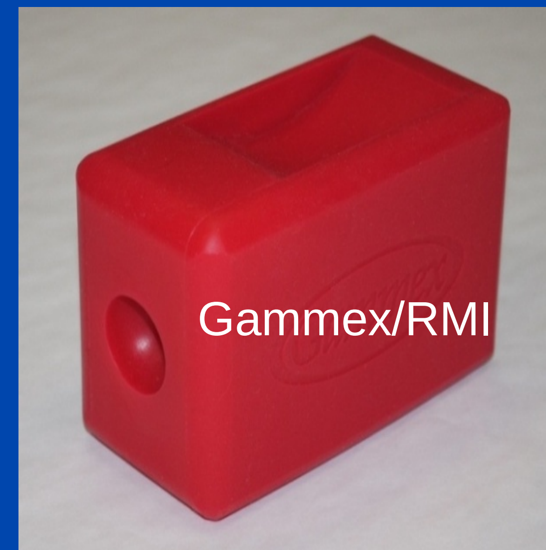
- Caution about phantom desiccation
- Caution about sound speed effect

More Ultrasound Phantoms

E Madsen, AIUM



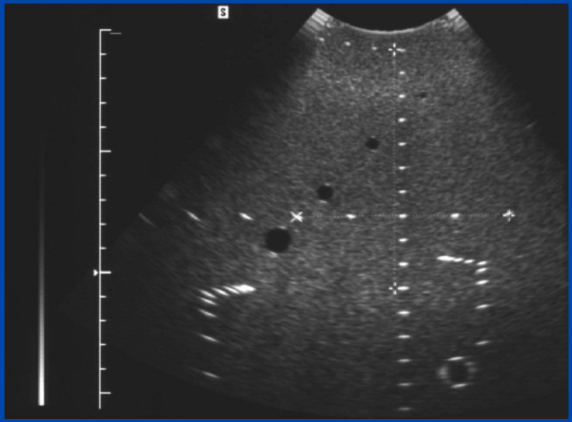
ATS



Gammex/RMI

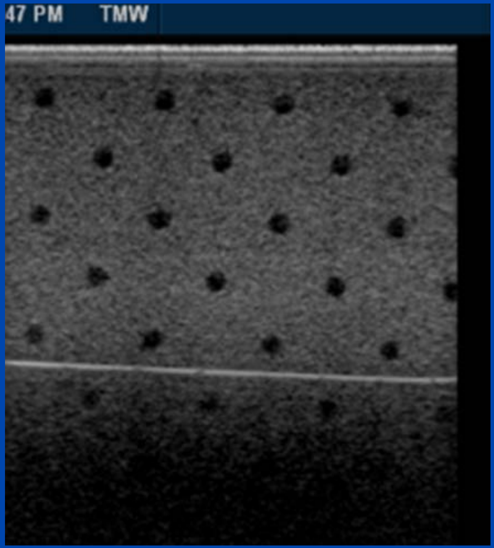
DM King, et al, Phys. Med. Biol. 55, N557-N570, 2010

Current Image Quality Metrics



B-Mode

- Image geometry
- Maximum depth of penetration (system sensitivity)
- Image uniformity and artifact survey
- Ring down
- Lesion detectability with a spherical lesion phantom
- Spatial resolution (axial, lateral, elevational)
- Contrast resolution

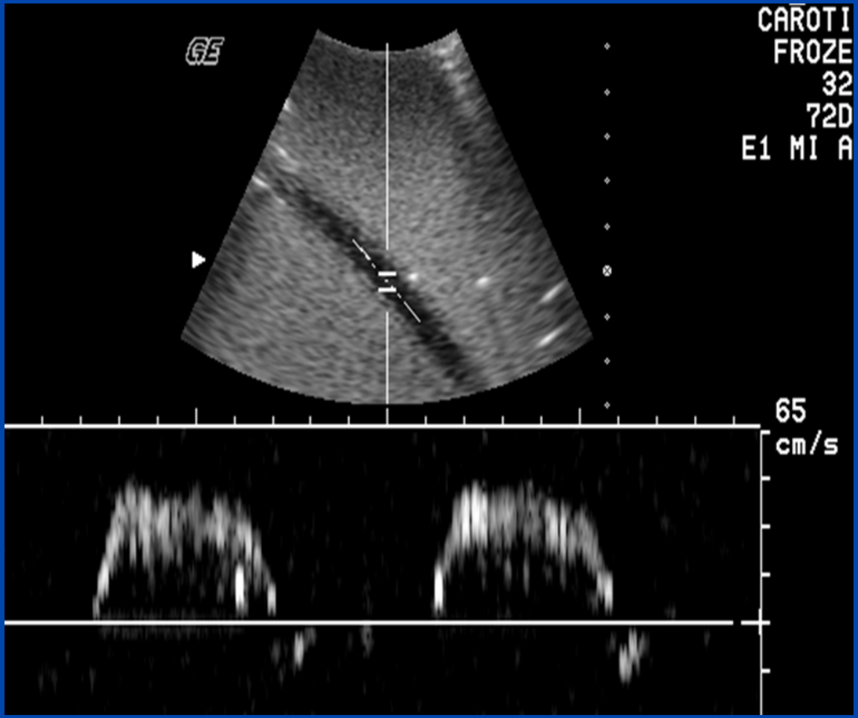


Common approaches are mainly visual & qualitative

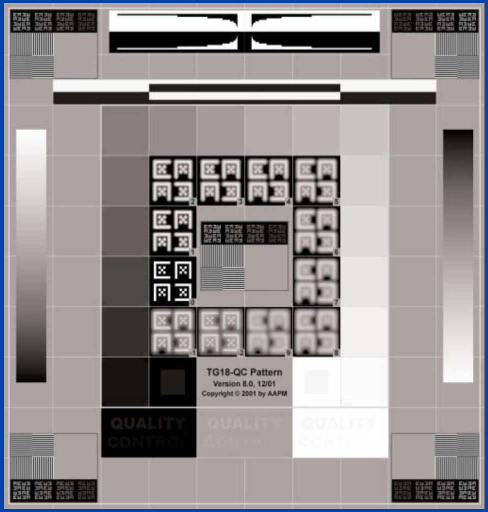
Current Image Quality Metrics

Doppler Ultrasound

- Doppler signal sensitivity
- Doppler angle accuracy
- Color display and gray-scale image congruency
- Flow read-out accuracy



Scanner and PACS Displays



Common approaches are mainly visual & qualitative

1. System performance

- Introduction
- Ultrasound phantoms
- Ultrasound image quality metrics

2. System implementation

- Efficacy and sensitivity of current ultrasound QA/QC
  Reports in literature draw mixed conclusions

3. Testing paradigm

- Survey of voluntary ultrasound accreditation programs
  AIUM, ACR
- Survey of available standards for diagnostic ultrasound

Role of physics in future ultrasound practices
Performance testing

- Image quality metrics and assessment methodology
  - Further development of quantitative software analysis tools and test protocols is needed
    - *Traditional performance metrics*
    - *New performance metrics (elastography, QUS)*
    - Validation of methods
      - Signal accuracy/sensitivity and precision
      - Automated or semi-automated tools → repeatability
    - Real-time workflow
    - Wide availability

Phantom vendors

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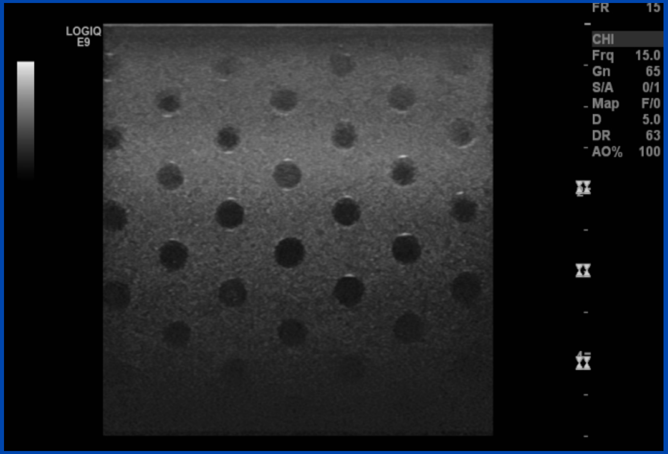
Role of physics in future ultrasound practices
Performance testing

- Image quality metrics and assessment methodology
  - Task-specific performance measures based on detection or characterization of phantom targets
    → *more integrated and clinically-relevant quality measures*
    - Contrast-detail analysis
    - Target signal-to-noise ratio
    - Resolution integral



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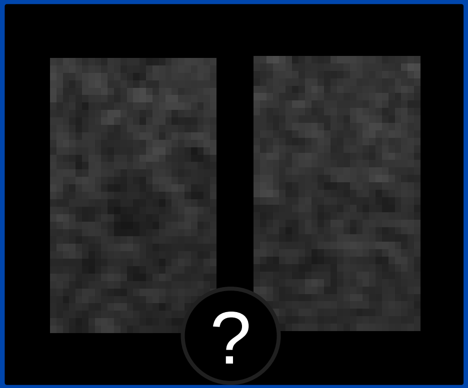
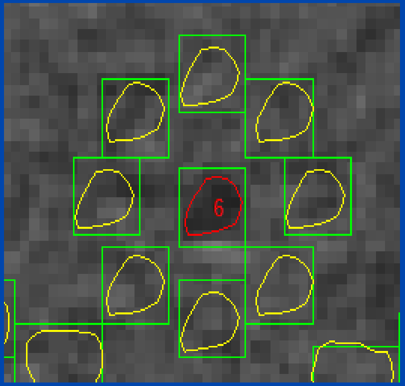
Role of physics in future ultrasound practices
Performance testing

- Image quality metrics and assessment methodology: *Task-specific measures*
  - Phantoms and targets
    - Anechoic and echogenic cylinders
    - Anechoic spheres
  - Observers
    - Human (ROC, 2AFC tasks)
    - Computer (matched filter, model observers, target segmentation)





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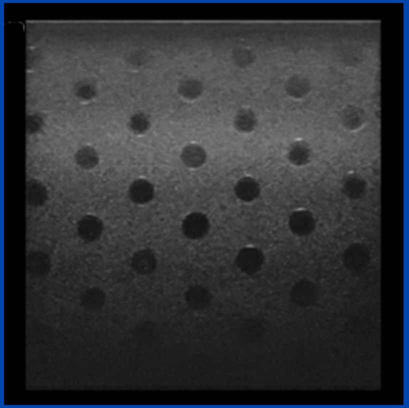
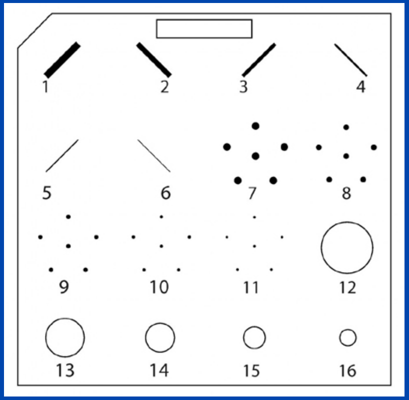
Role of physics in future ultrasound practices
Performance testing

- Image quality metrics and assessment methodology: *Task-specific measures*
  - Challenges include…
    - Statistical requirements
      - Many independent target images
      - Assumptions about the imaging system (Linear? Shift-invariant? Gaussian noise?)
    - Testing the system, *not* the operator
    - Phantoms that can accommodate all modern imaging equipment, and model a wide variety of clinical applications
    - *Testing paradigms reflecting wider variety of clinical tasks*





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Role of physics in future ultrasound practices
Performance testing

- Testing scenarios – *Why do we test?*

Purpose	Frequency	Methods	Personnel
Technology assessment / Pre-purchase testing	Ad hoc	***Most comprehensive, objective, quantititative, clinically-relevent, robust vs basic control settings + acceptance tests***	**Physicist** & physics assistant
Acceptance testing	At clinical implementation	***Objective,*** traditional performance measures (DOP, Uni, Geo, Spatial res, Contrast, Display, etc) + connectivity	Physics assistant & **physicist**
Re/application for practice accreditation	As specified by accrediting body	As specified by accrediting body (subset of acceptance tests)	Physics assistant with **physicist** support and oversight
Routine QC (Testing levels 1 & 2)	Daily	***On-board vendor diagnostics*** ***- Auto data logging, problem alert*** ***- Practice specification of alert levels***	***Service group to respond to alerts***
Comprehensive physics survey (Testing level 3)	Same as for accred., or *as appropriate for the specific US system*	Same as acceptance or accreditation testing	Physics assistant with **physicist** support and oversight

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Role of physics in future ultrasound practices
Performance testing

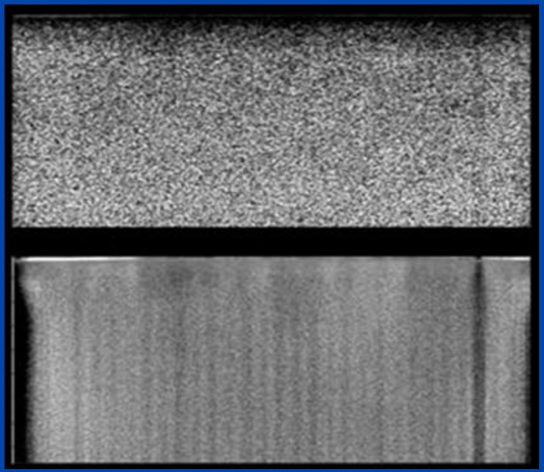
- Testing scenarios
  - ***Technology assessment*** */ pre-purchase testing*
    - ***Most comprehensive level of system evaluation***
      - Extensive physics/phantom testing, with quantitative methods, even at expense of efficiency
      - Volunteer imaging, categorical data
      - Patient imaging, categorical data
      - Connectivity and workflow
      - Usability, service-ability, etc




…

Role of physics in future ultrasound practices
Performance testing

- Testing scenarios
  - ***Accreditation and regulatory compliance***
    - Acceptance testing
    - Comprehensive physics survey
    - Routine quality control
    - *Challenge: clinically-relevant performance benchmarks*
      - What defines acceptable and unacceptable performance?
      - What quality and risk factors should be considered?



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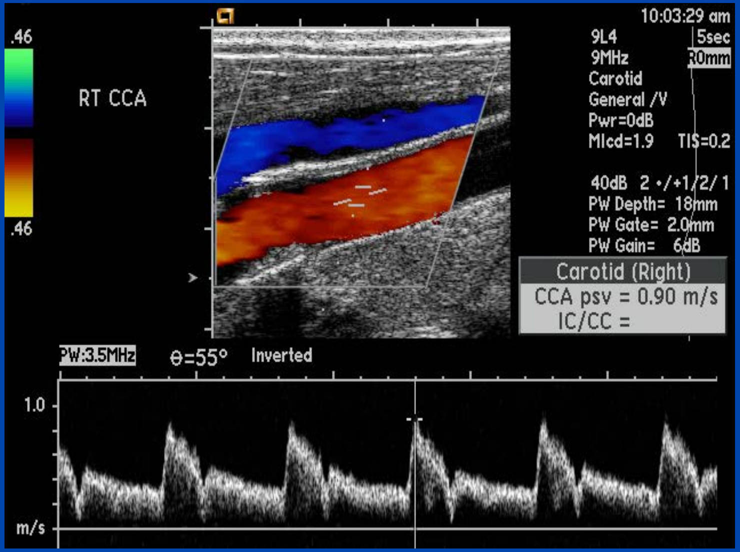
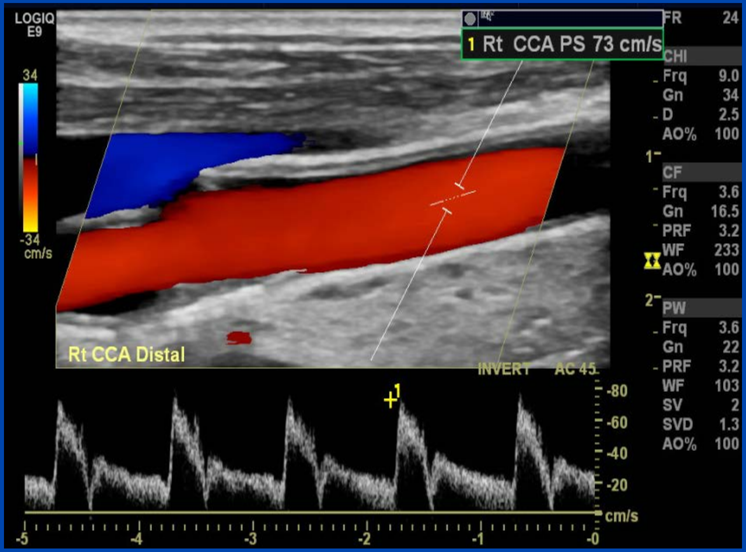
Role of physics in future ultrasound practices
Optimization of image quality & exam protocols

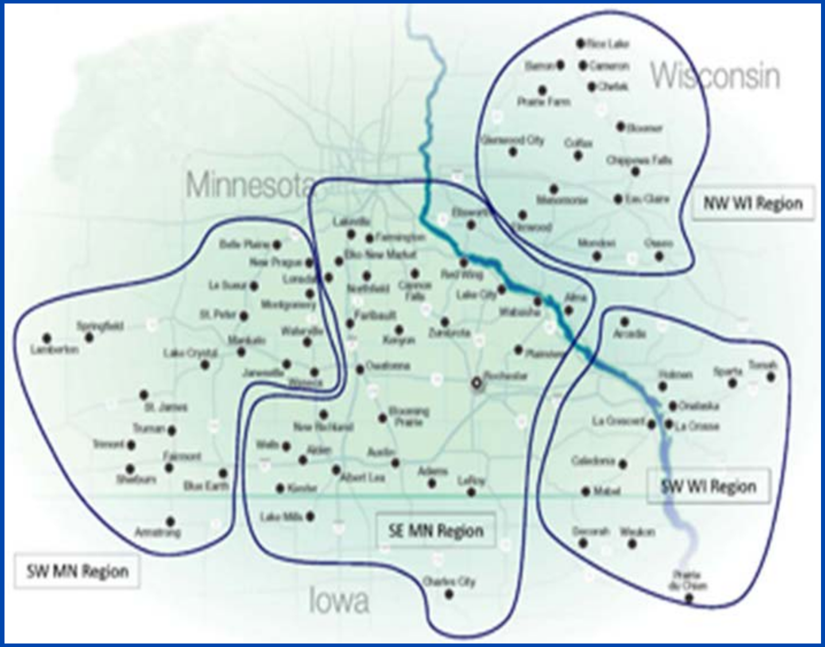
- Quantitative measurements
  - Limited vendor guidance re use of measurement tools
  - Normalize measurement calibration across ultrasound system models, probes, and vendors





Role of physics in future ultrasound practices
Optimization of image quality & exam protocols

- Standardized dx exam protocols & imaging presets
  - Sharing clinical diagnostic work across geographically-distributed practices, and
  - A variety of US systems and vendors
  - *Vendors: remote system management tools?*



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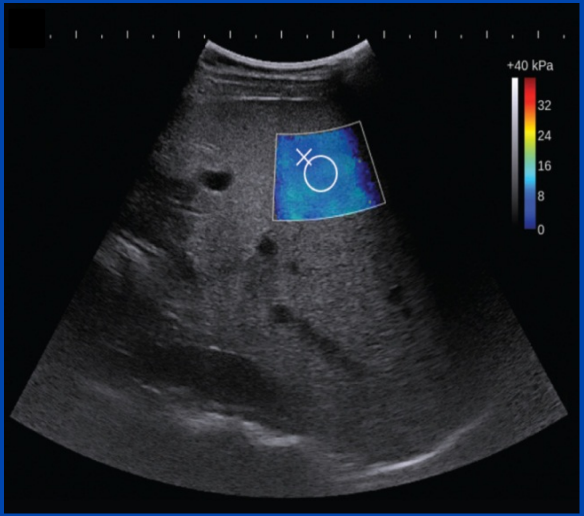
Role of physics in future ultrasound practices
Clinical innovation



- Assessment and implementation of new ultrasound technologies
  - Developing initial exam protocols, imaging presets, and measurement protocols, for new modes and features
- Greater use of image measurements & metadata
  - Practice resource utilization and management
  - Quality improvement of imaging presets
  - Enhanced exam interpretation modes and clinical result sets
  - Improved practice efficiency
- *General improvement of overall practice quality & safety, not just image quality*

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Role of physics in future ultrasound practices
Education

- Physicians, sonographers/technologists residents, medical students, patients
- Physics and technology of ultrasound imaging systems
  - Board certification
  - Sub/specialty certifications
  - Practical knowledge to improve the quality of exam interpretations

What knowledge is really needed by practitioners?

KHAN ACADEMY

RSNA Radiological Society of North America (RSNA)
and the
American Association of Physicists in Medicine (AAPM)

RSNA/AAPM Online Physics Modules

Ultrasound

1. Ultrasound - Concepts and Transducers
2. Basic Ultrasound Imaging and Display
3. Interaction of Ultrasound Tissue and Doppler
4. Image Quality - Artifacts - Doppler - Safety

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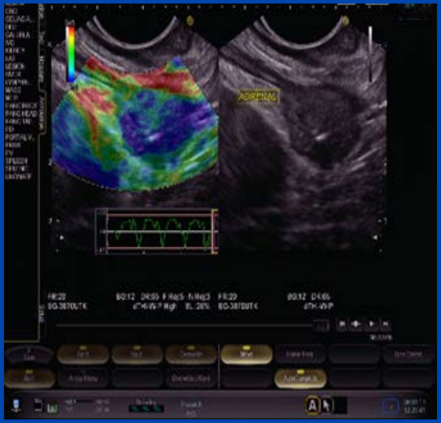
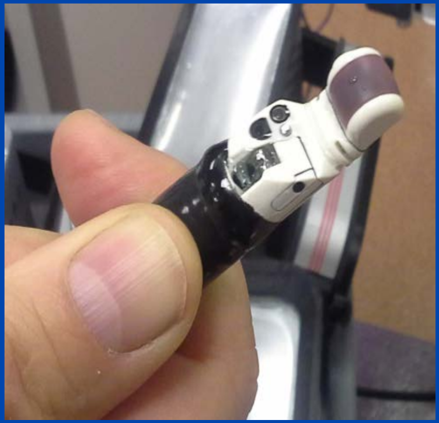
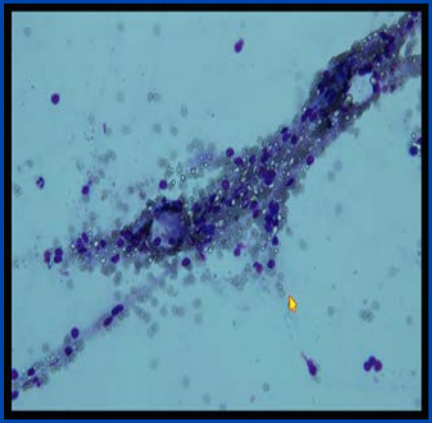
Clinical implementation
Partner with the clinical practice

- *The problem*:
  An enormous amount of clinical equipment, wide range of technology sophistication, implemented across multiple departments with different practice workflows, inconsistent training and education, *increasing financial pressures*, and limited technical support historically



Clinical implementation
Build and lead a technical support team

- *The team:*
  - Physician practice leader
  - Practice manager
  - Sonographer/tech manager, lead, educator
  - Service engineer
  - Physics assistant
  - Physicist
  - Vendor product team
    (key partners, not leaders)

- *Performance testing*
- *Optimization of image quality and exam protocols*
- *Clinical innovation in all aspects of practice*
- *Education*

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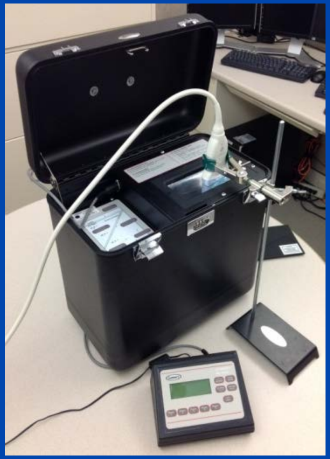
Clinical implementation
Continuous quality improvement

- Evidence-based performance testing program, that emphasizes actual value (risk/cost)
  - Expand the technology assessment protocol to address new functionality
    - Assess utility for annual performance surveys and routine QC on a small scale
    - Optimize routine QC methods
  - Optimize the routine testing program in response to technology level, clinical application, prior data, & technology advancement
    - What tests, methods, personnel, and frequency optimize actual value for the clinical practice?



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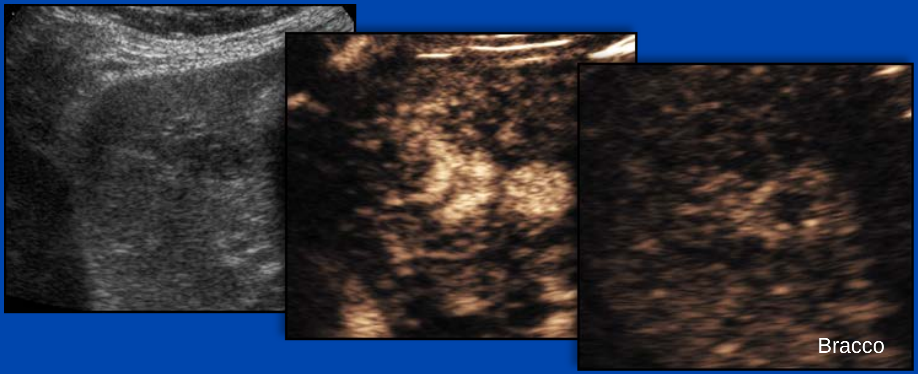
Conclusion

- Ultrasound use is expected to grow rapidly
- Ultrasound imaging systems are undergoing rapid development and innovation
  - New sources of image contrast
  - Improved quantitation
  - Improved metadata and practice analytics



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Conclusion

- Medical physicists working in partnership with clinical practices will be critical to optimizing practice quality, safety & value
  - Performance testing
  - Optimization of image quality and exam protocols
  - Clinical innovation *in all aspects of practice*
  - Education
- **Demonstrating the value of physics services will become increasingly important**