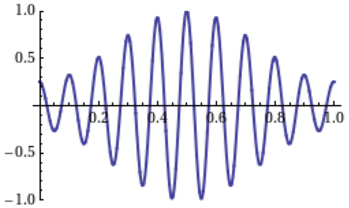

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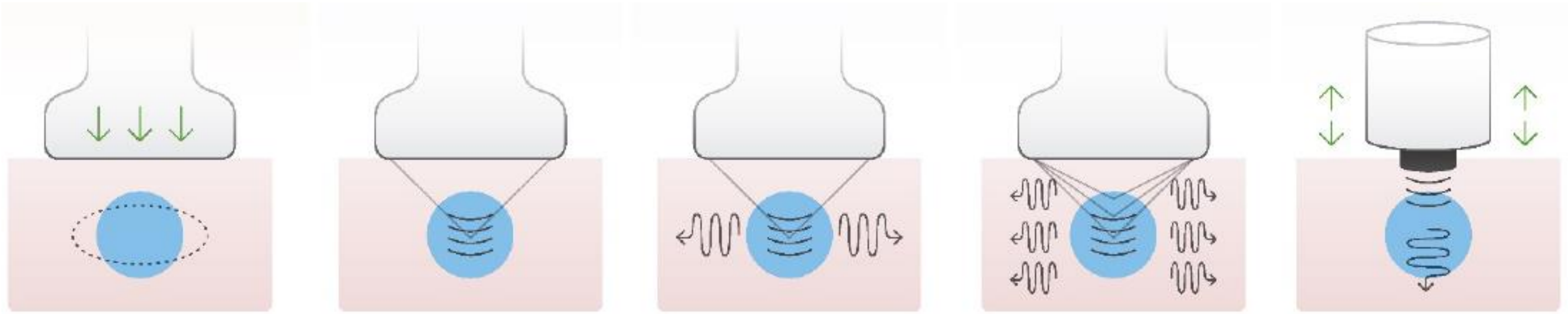
Ultrasound Elastography:

What are you measuring?

Kumar V Ramnarine



US elastography: what are you measuring?

Basic Physics
- Strain and Shear wave elastography
- Elastography definitions and parameters

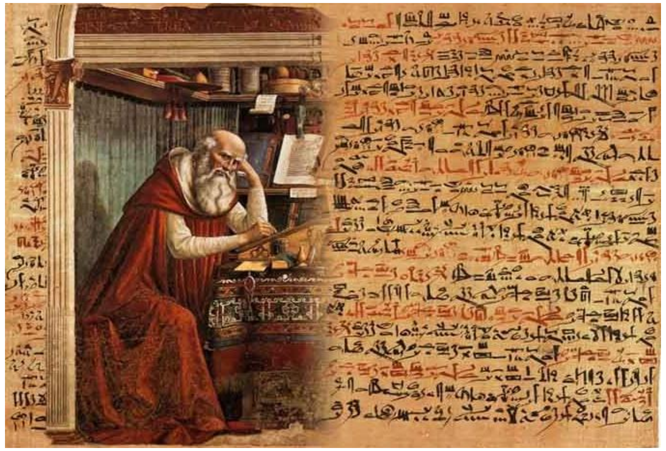
Clinical Applications
- Clinical applications- liver, breast……
- Vascular carotid research

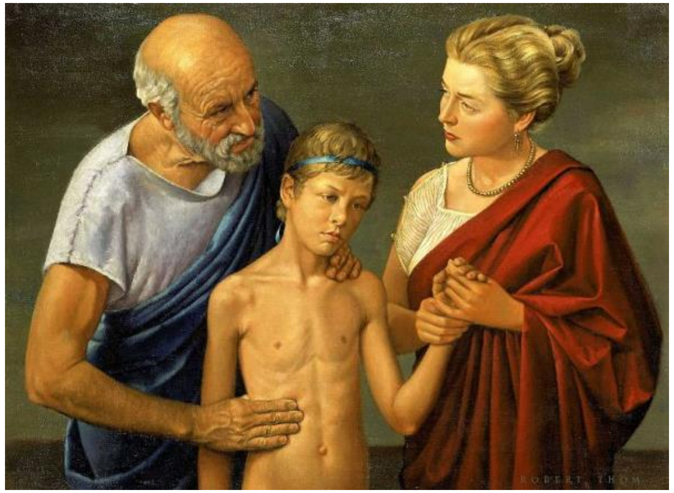
Test phantoms
- Performance assessment
- Routine USQA

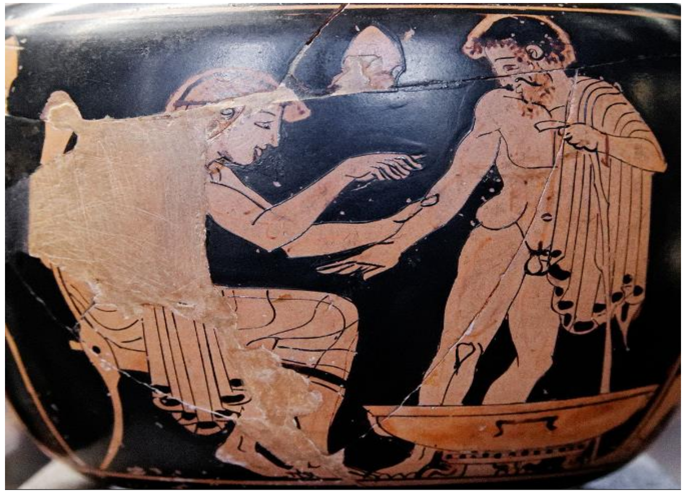
Reality of clinical estimates
- Assumptions and artifacts: viscoelasticity
- Clinical measurements: how to measure?

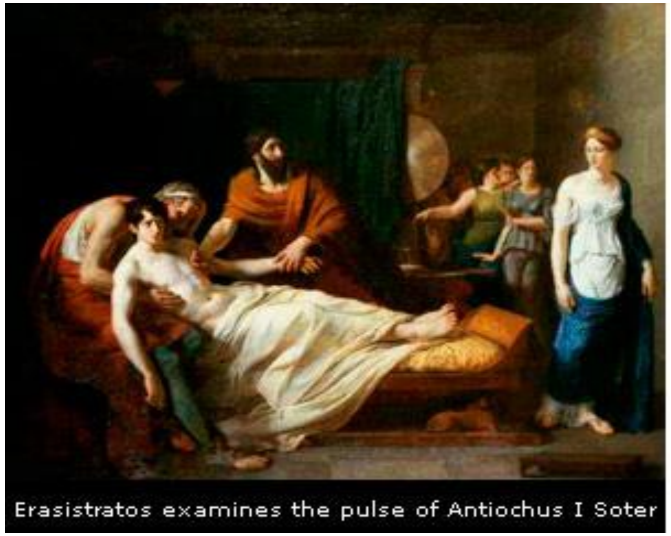
Palpation: used as a diagnostic tool since the earliest days of civilization

e.g. benign and cancerous masses harder than surrounding tissues









Elastography Techniques

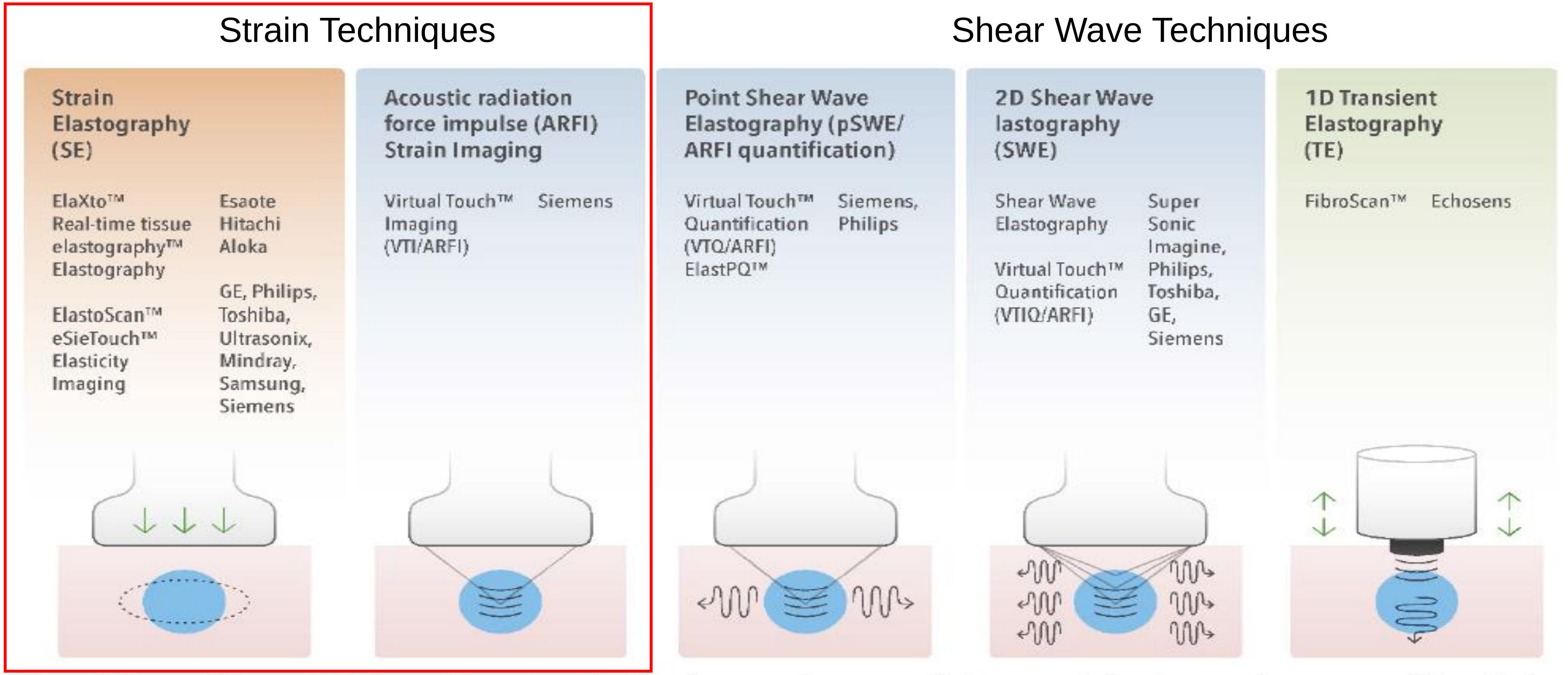
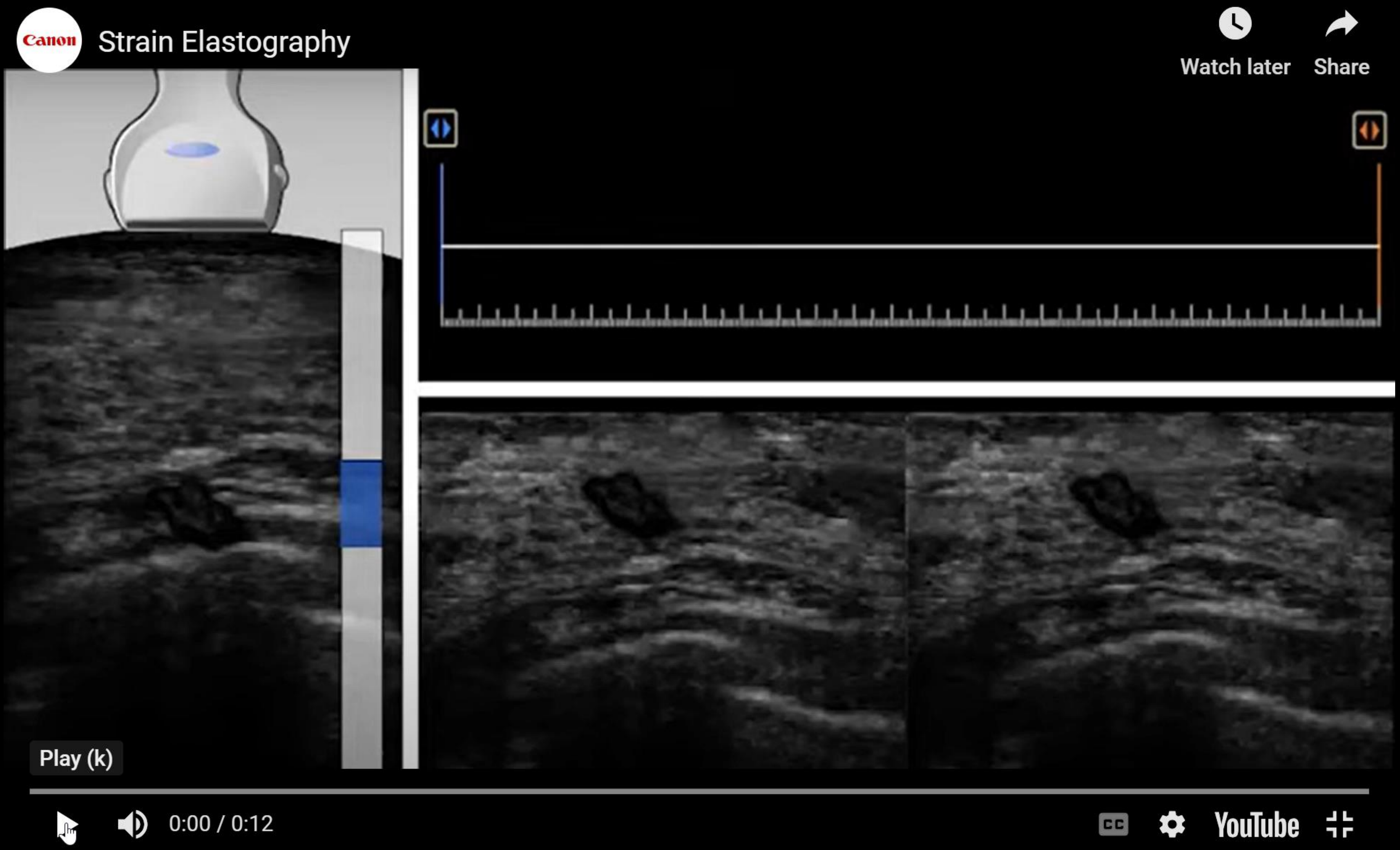
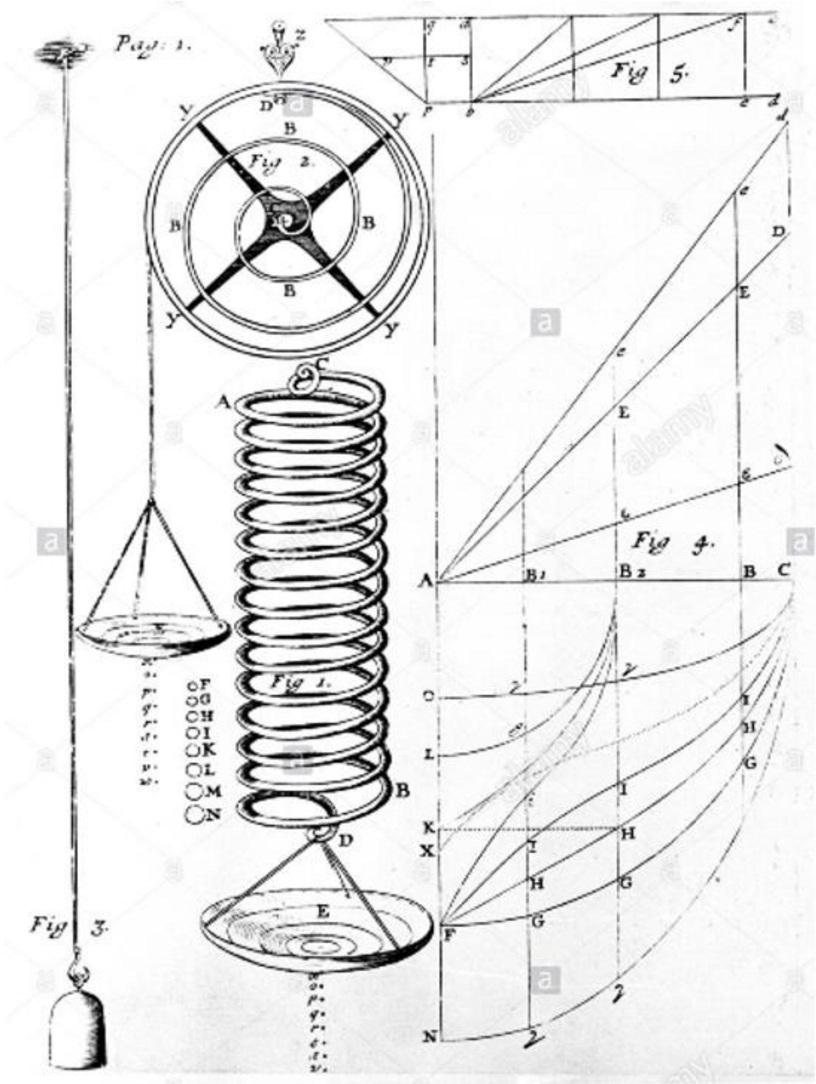


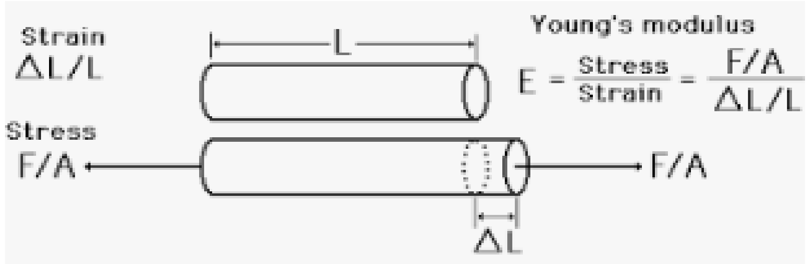
Figure 3. Ultrasound Elastography Techniques. Currently available USE techniques can be categorized by the measured physical quantity: 1) strain imaging (left), and 2) shear wave imaging (right). Excitations methods include quasi-static mechanically-induced displacement via active external compression or passively-induced physiologic motion (orange), dynamic mechanically-induced compression via a "thumping" transducer at the tissue surface to produce shear waves (green), and dynamic ultrasound-induced tissue displacement and shear waves by acoustic radiation force impulse excitation (blue).

Sigrist et al. Ultrasound Elastography: Review of Techniques and Clinical Applications. Theranostics. 7;7(5):1303-1329, 2017


Canon
Strain Elastography
Watch later
Share
Play (k)
0:00 / 0:12
YouTube

Basic Physics: Hooke's Law





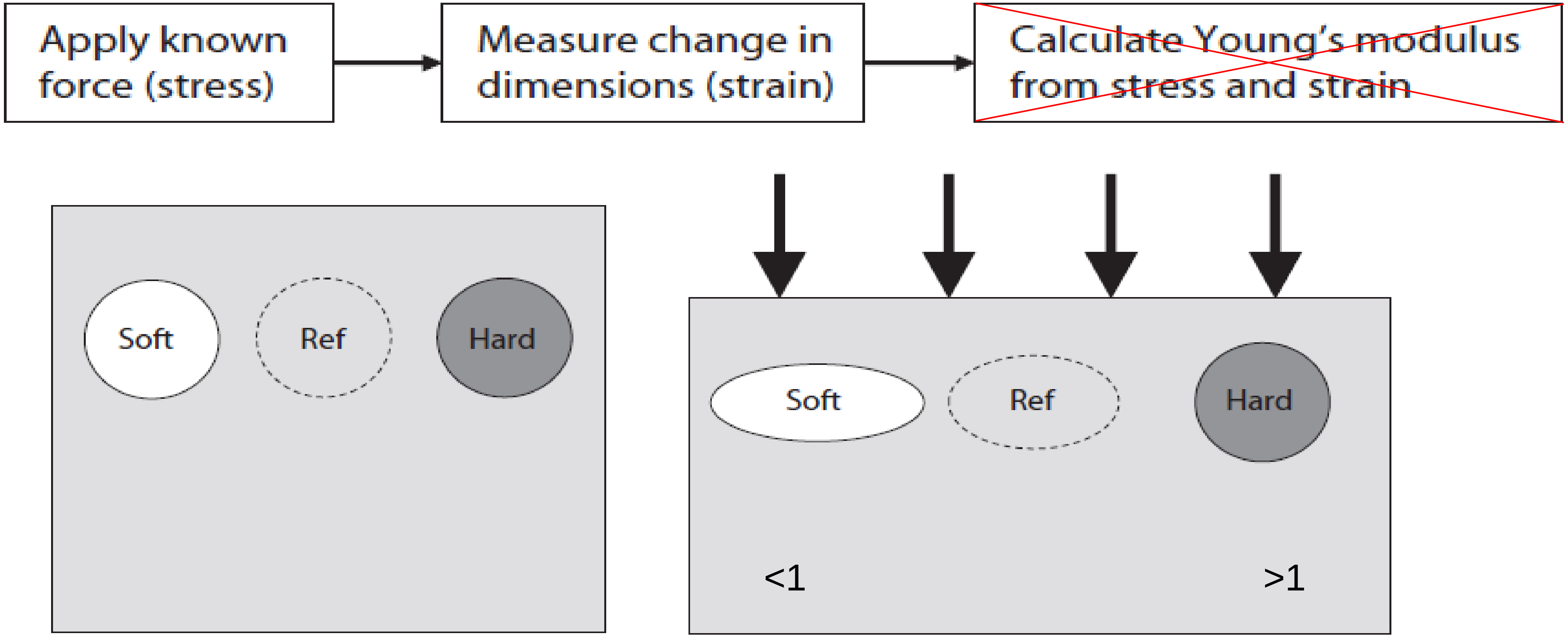
$$\text{Stress} = \text{Force/Area}$$

$$\text{Strain} = \frac{\text{Length (after)} - \text{Length (before)}}{\text{Length (before)}}$$

$$E = \text{Stress/Strain}$$

Young's modulus, *E*

Strain elastography: what are you measuring?



$$\text{Strain-ratio} = \frac{\text{Strain (reference region)}}{\text{Strain (lesion)}}$$

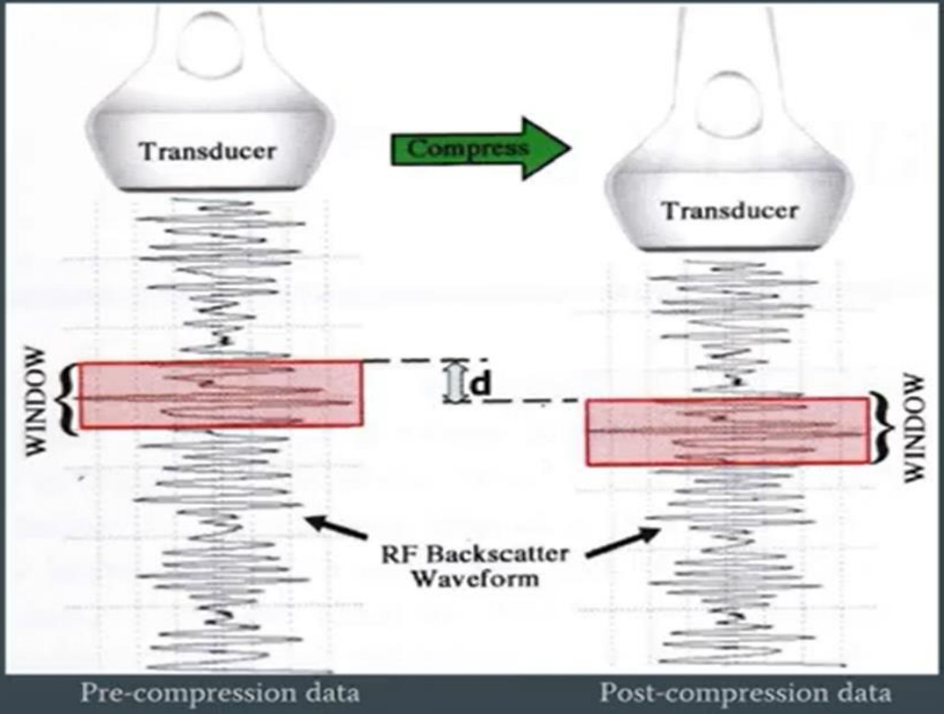
Strain ratio sometimes used clinically as an index of stiffness

Diagnostic Ultrasound – Hoskins, Martin, Thrush

Estimation of the strain: how are they measuring?

Quasi-static (strain) Elastography

- Reference data must be acquired prior to compression



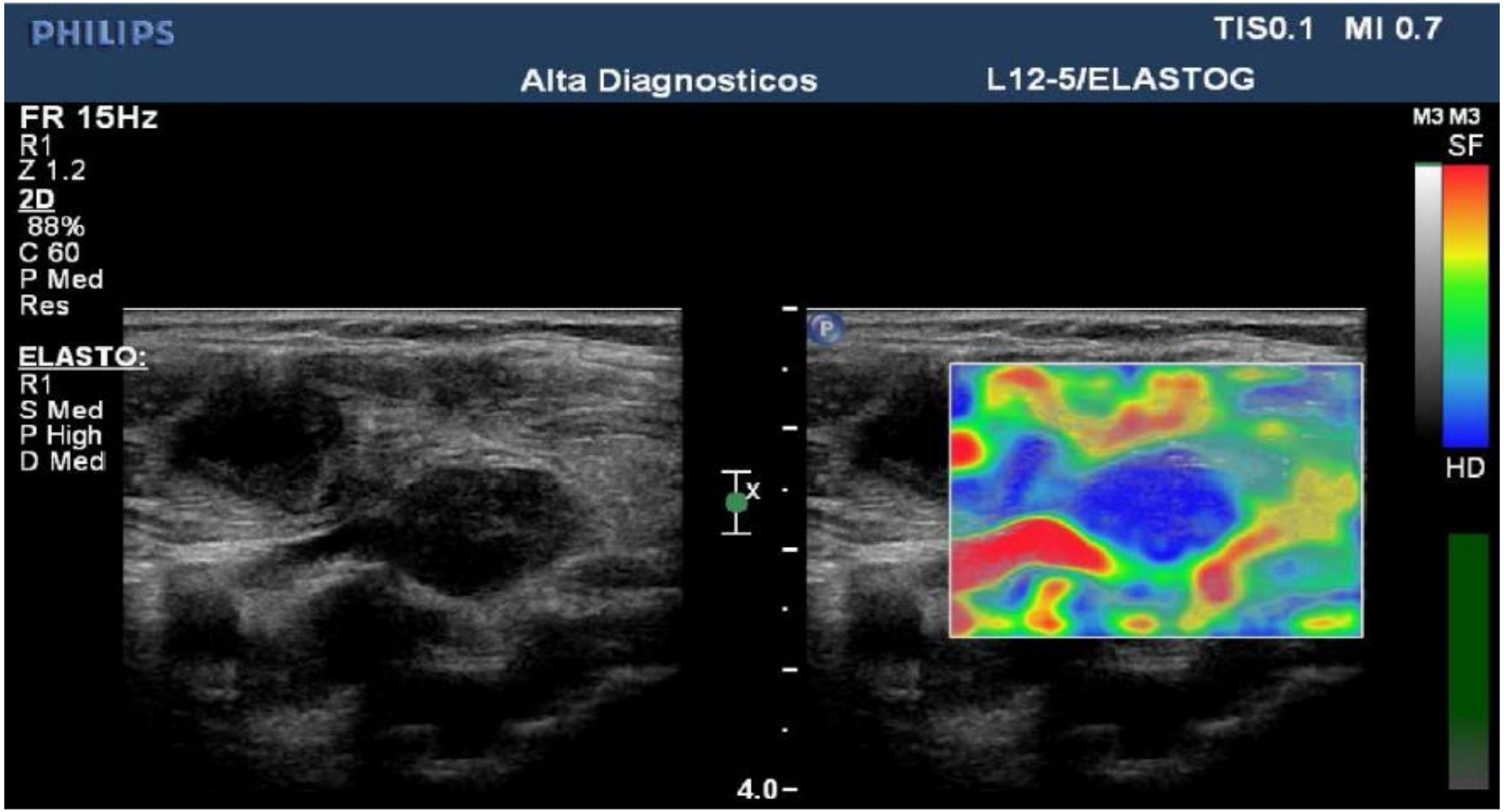
- Cross-correlation
  Matches pre and post compression data

  The difference in distance between the matched data is the displacement (Represented as d in the image)

- Elastic (softer) tissue
  Will have a larger displacement
- Inelastic (stiff) tissue
  Will have a smaller displacement

https://www.youtube.com/watch?v=lq9cCsOLBv4

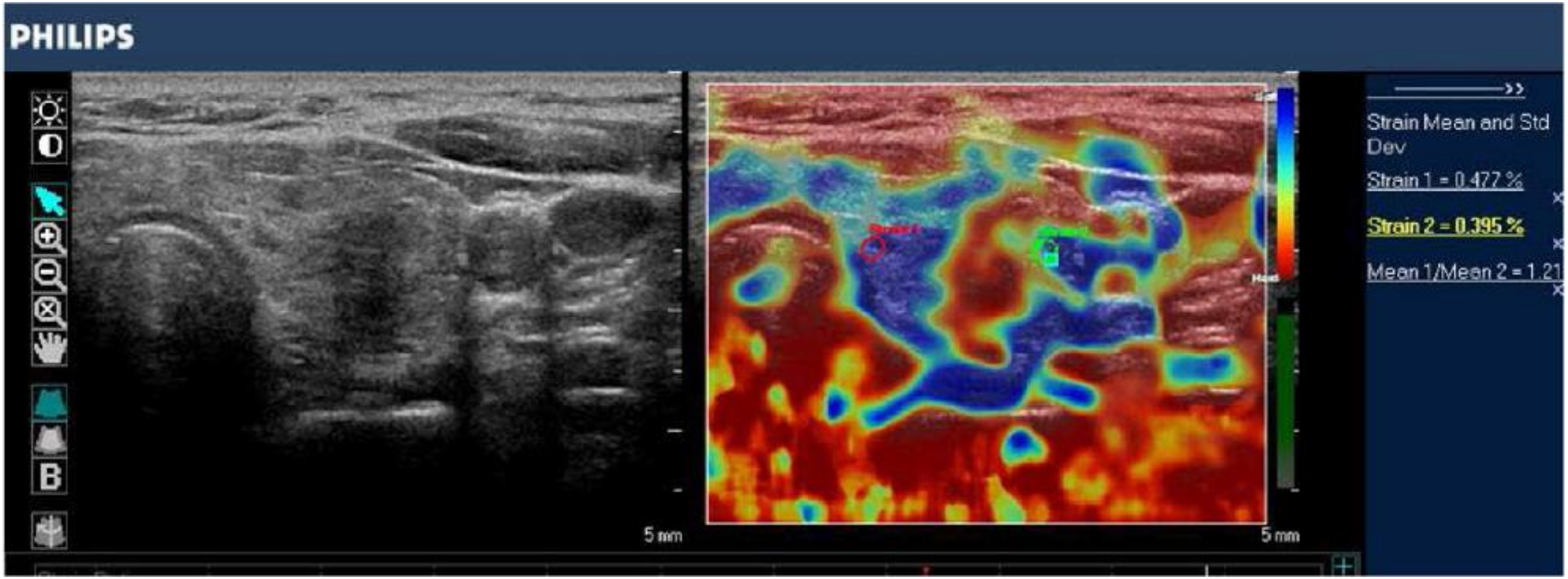
Strain imaging in the cervical lymph node



B-mode image (left) of a cervical lymph node shows a hypoechoic rounded lymph node. Elastogram (right) demonstrated that the lymph node is stiffer compared to surrounding tissue (homogeneous blue color elasticity signal on SE imaging with a Philips iU22 system), suggesting an abnormal lymph node that warrants biopsy. Subsequent biopsy resulted in the diagnosis of tuberculous lymphadenitis.

Sigrist et al. *Theranostics* 2017, Vol. 7, Issue 5

Strain elastography imaging in the thyroid



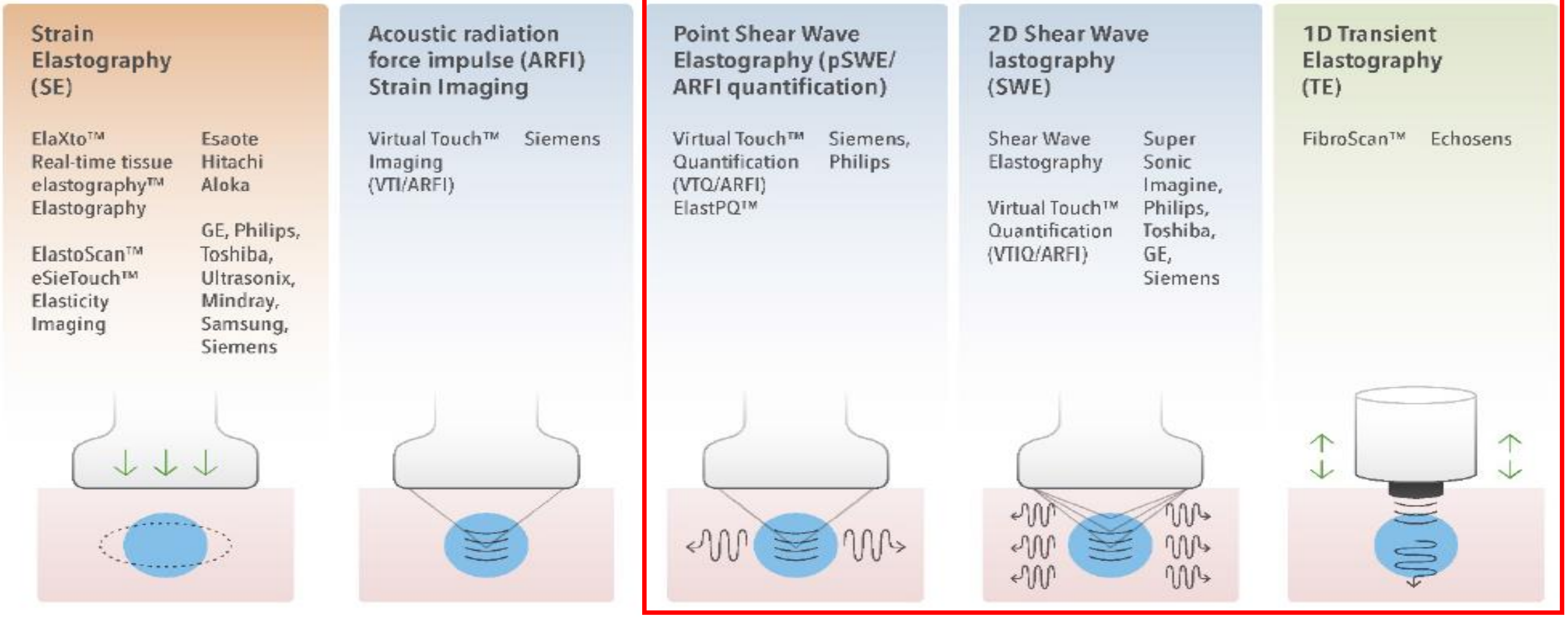
B-mode image (left) and color-coded elastogram (right) of a thyroid nodule in the left thyroid gland, imaged with SE on a Philips iU22 system. The nodule appears hypoechoic with ill-defined borders on anatomical B-mode image. The elastogram shows normal thyroid tissue encoded with blue color (soft tissue) and the nodule with red color (stiff tissue), suggesting a malignant nodule. This was confirmed by histology which showed papillary thyroid carcinoma.

Sigrist et al. *Theranostics* 2017, Vol. 7, Issue 5

Elastography Techniques

Strain Techniques

Shear Wave Techniques



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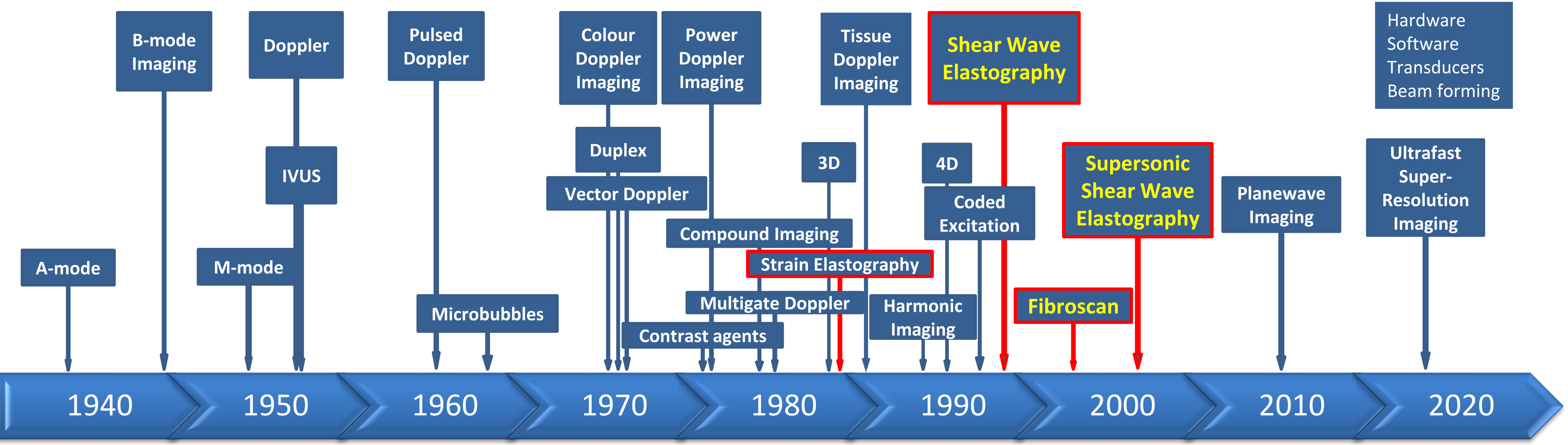
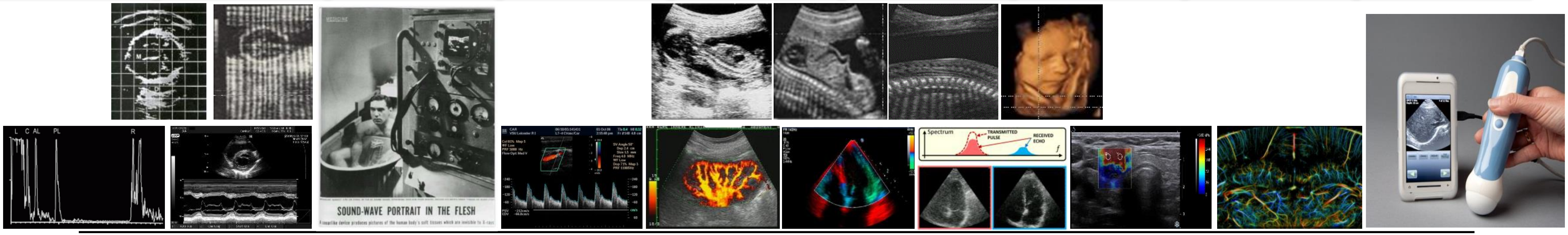
Sigrist et al. Ultrasound Elastography: Review of Techniques and Clinical Applications. Theranostics. 7;7(5):1303-1329, 2017

A Timeline of Diagnostic Ultrasound Innovations





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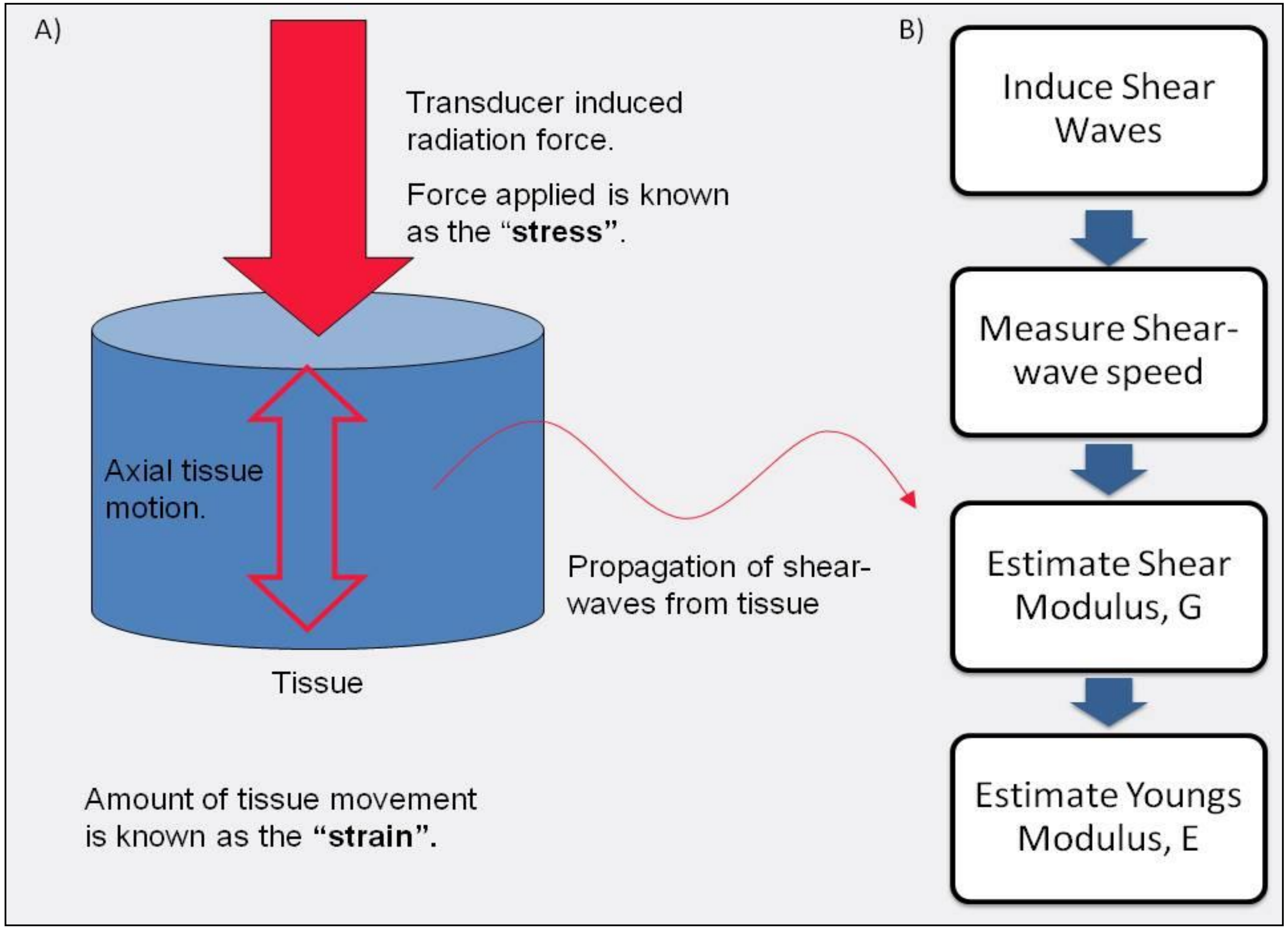
Shear Wave Elastography: Basic Principle



Nahas et al. From supersonic shear wave imaging to full-field optical coherence shear wave elastography. J Biomed Opt 2013.

$$c_s = \sqrt{\frac{G}{\rho}}$$

If tissue assumed to be incompressible (no change in density) and uniformly elastic the shear modulus *G* is related to Young's modulus *E* by the following equation:

$$E = 3G$$

Hence:

$$E = 3\rho c_s^2$$

Soft tissue properties

Density

Tissue	Density (kg m^{-3}) mean (range)
Fat	928 (917–939)
Muscle – skeletal	1041 (1036–1056)
Liver	1050 (1050–1070)
Kidney	1050
Pancreas	1040–1050
Spleen	1054
Prostate	1045
Thyroid	1050 (1036–1066)
Testes	1040
Ovary	1048
Tendon (ox)	1165
Average soft tissues,[a] mean (S.D.)	1047 (5)

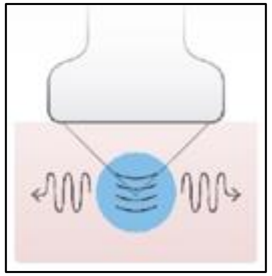
Young's modulus

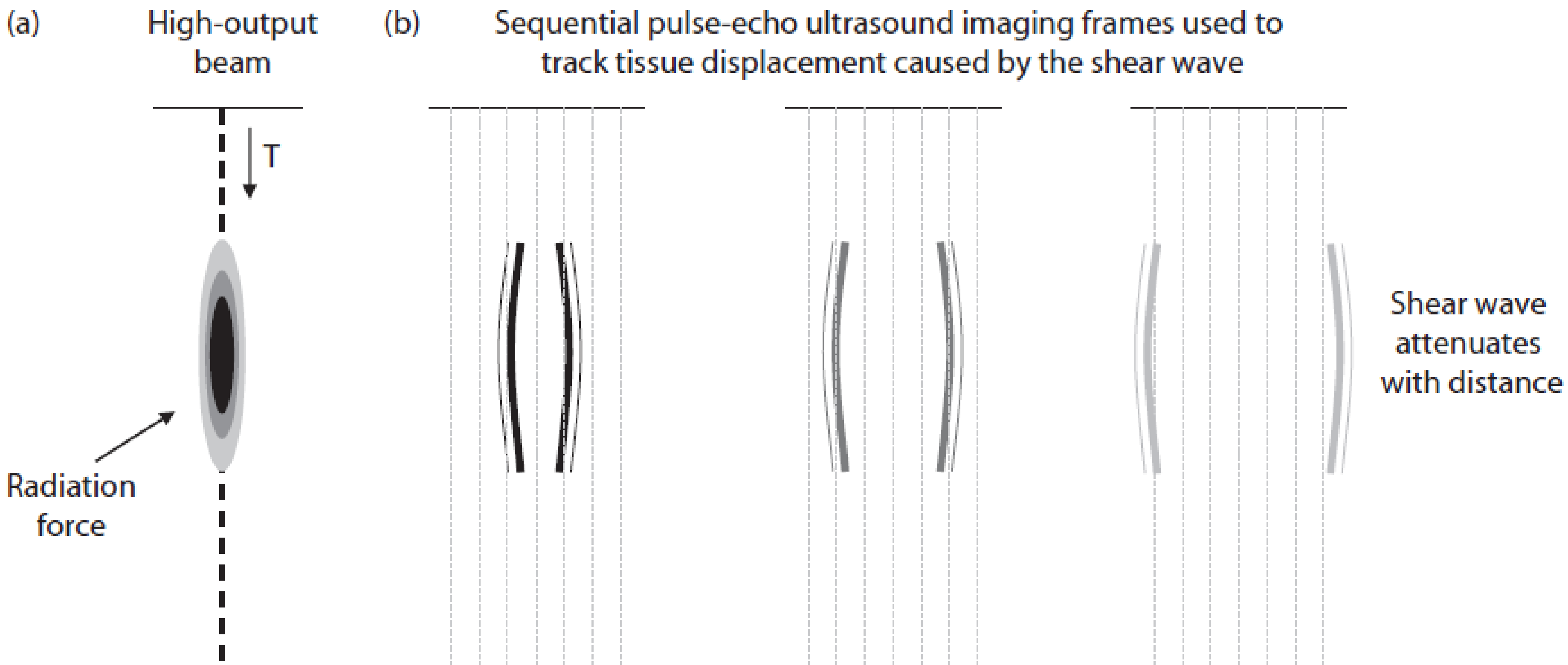
Material	E (kPa)
Non-human materials	
Silicone rubber	500–5000
PVA cryogel tissue mimic	35–500
Agar/gelatine tissue mimic	10–70
Human tissues	
Artery	700–3000
Cartilage	790
Tendon	800
Healthy soft tissues[a]	0.5–70
Cancer in soft tissues[a]	20–560

[a] Breast, kidney, liver, prostate.

Diagnostic Ultrasound – Hoskins, Martin, Thrush

Point Shear Wave Elastography using ARFI





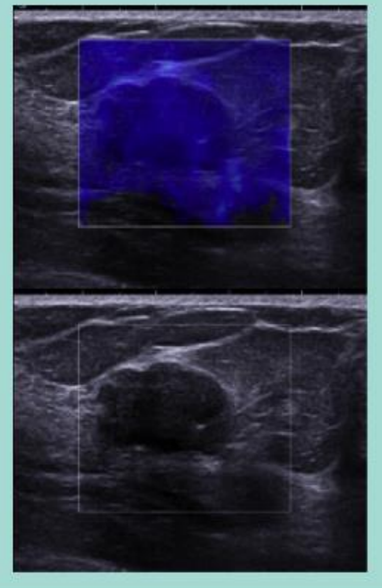
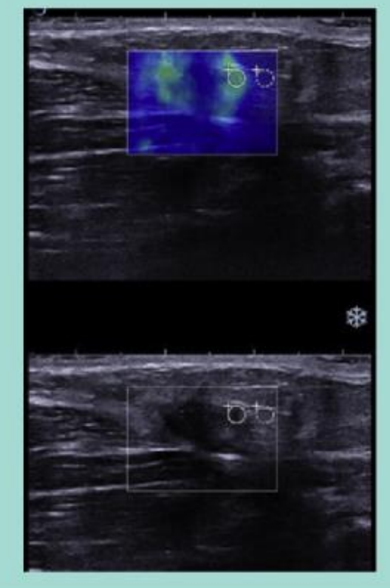
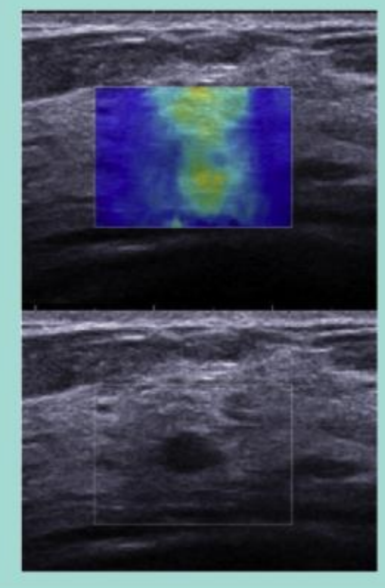
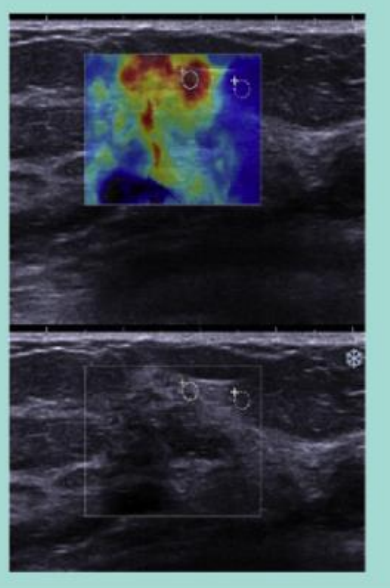
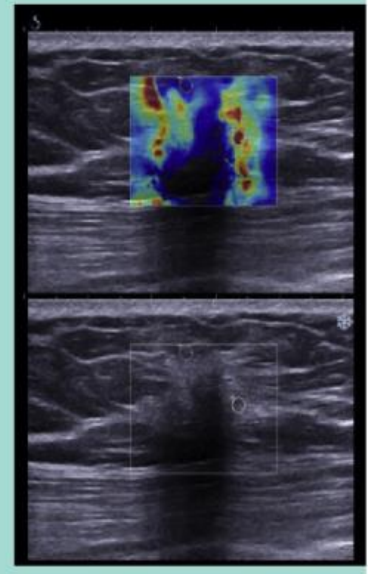
(a) A high-output ultrasound beam produces a radiation force which displaces tissue in the focal region producing shear waves which propagate in 3D.
(b) High frame-rate imaging techniques are used to track the tissue displacement caused by the shear wave.

Diagnostic Ultrasound – Hoskins, Martin, Thrush

PHILIPS
ELASTO
03121120150630
PHILIPS DEMO
30/06/2015
12:22:13
Live
Calc List
Protocol
Abdominal->Abdomen Stiffness
Application:
Abdominal
Abdomen General
Abdomen Arterial
Abdomen Renal
Abdomen Venous
Abdomen Stiffness
Measurements
Tissue Stiffness
Sample 1
2
3
4
5
6
7
8
9
10
11
12
Calculations
Stiffness Avg
Stiffness Std
Stiffness Med
Abd Gen
C5-1
31Hz
RS
2D
61%
Dyn R 55
P Low
HGen
TIS0.1 MI 1.3
M3
16cm
1
2
3
4
5
6
EPIQ 7G

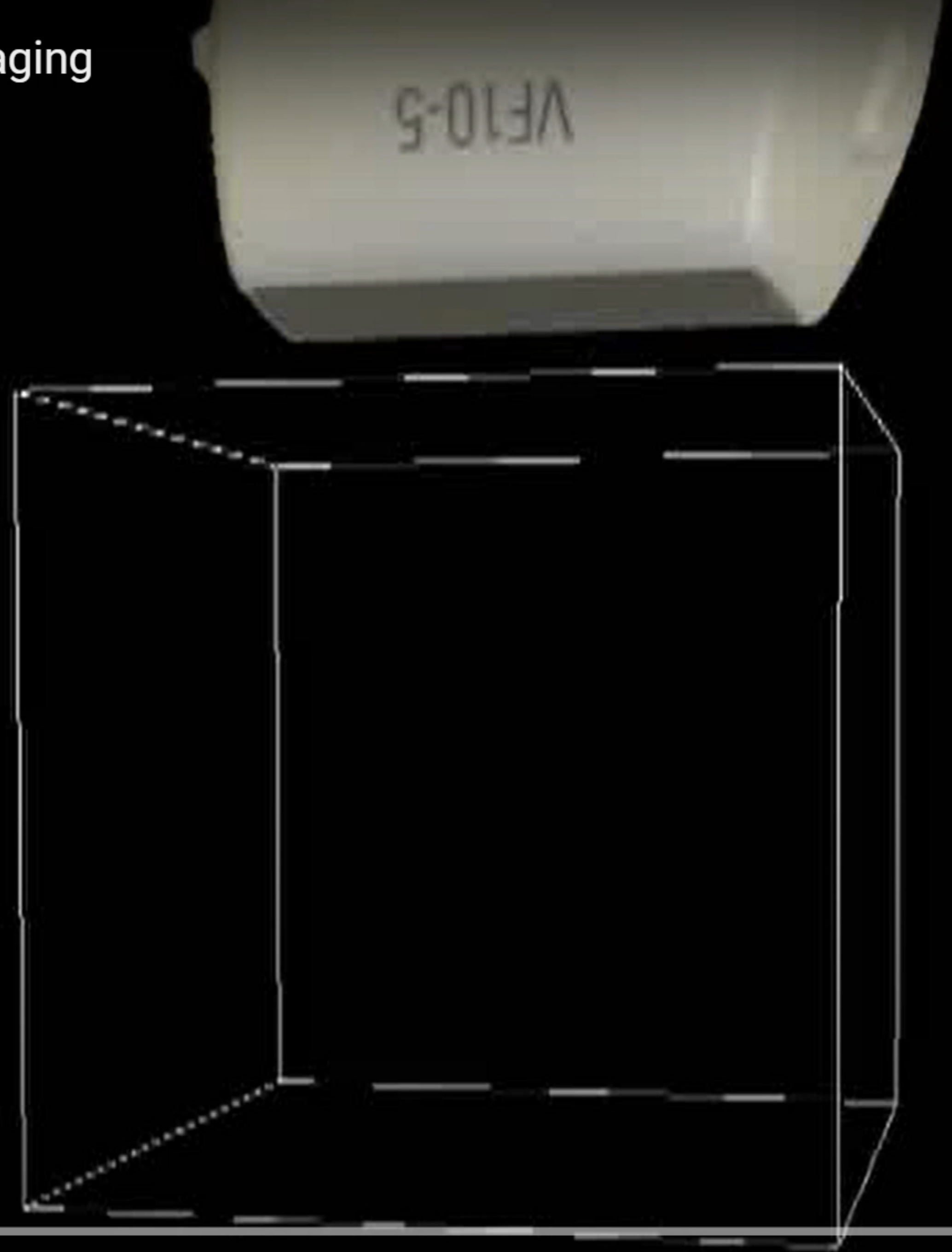
2D Shear wave elastography imaging: Breast lesions

Table 1 ShearWave™ Elastography: qualitative classification (Qual).

Types	1	2	3	4	5
Homogeneity	Homogeneous	Not very homogeneous	Heterogeneous	Heterogeneous	Heterogeneous
Maximum color	Blue	Green	Yellow	Red	Red
Hard area	0	0	Intra- or Perilesional	Intra- or Perilesional	Perilesional
Intralesional echo	Present	Present	Present	Present	Absent (no echo)
					

Klotz, Thomas et al. “Shear wave elastography contribution in ultrasound diagnosis management of breast lesions.” Diagnostic and interventional imaging 95 9 (2014): 813-24.

Ultrasonic Shear Wave Imaging



Play (k)

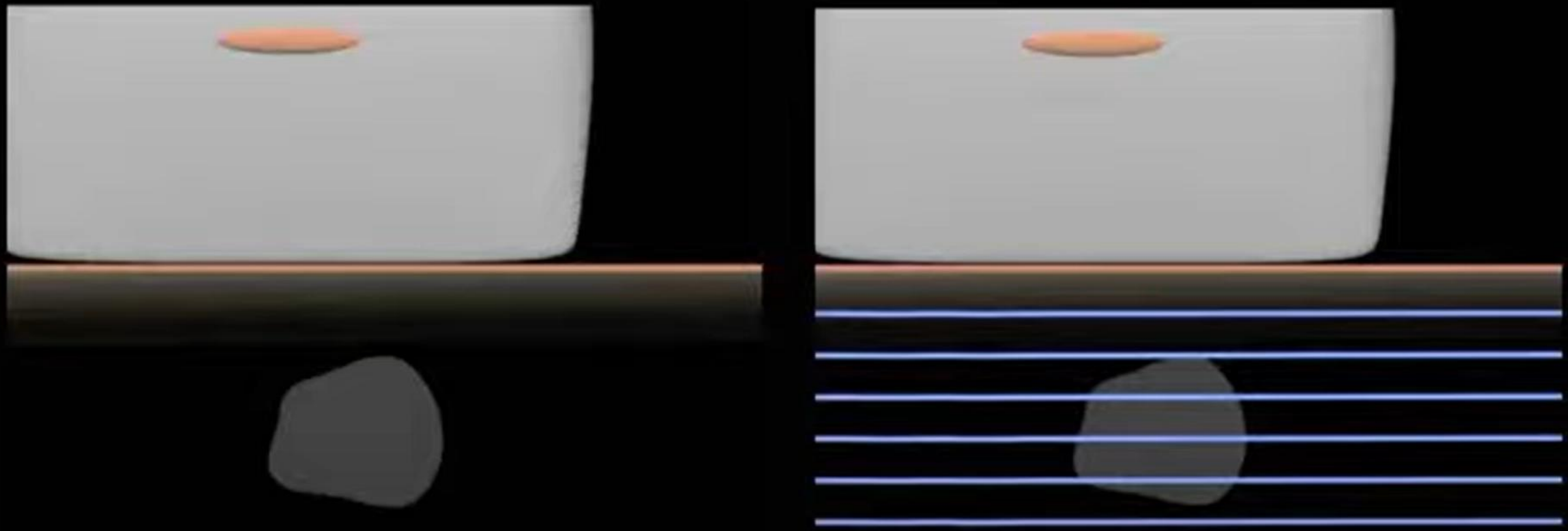
0:00 / 0:59

Scroll for details

https://www.youtube.com/watch?v=Q_5qcqDN1cU

Shear Wave Elastography - Ultrasound - Canon Medical

Watch later Share Info



Play (k)

0:00 / 0:11

YouTube

Propagation map: Soft Inclusion Phantom

Elasticity kPa Map

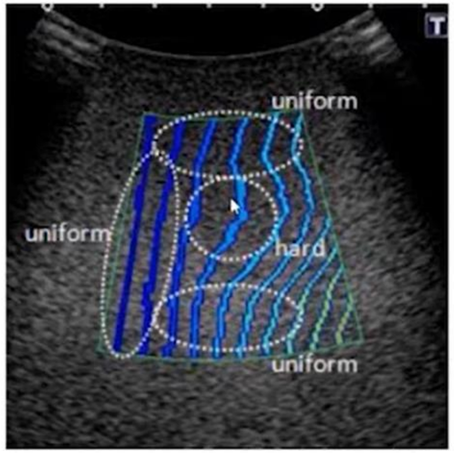
Propagation Map

Soft target → Slower Shear wave → Shorter distance between wavefronts

Acknowledgement G Guenette 2015

Propagation map: Hard Inclusion Phantom

Elasticity kPa Map



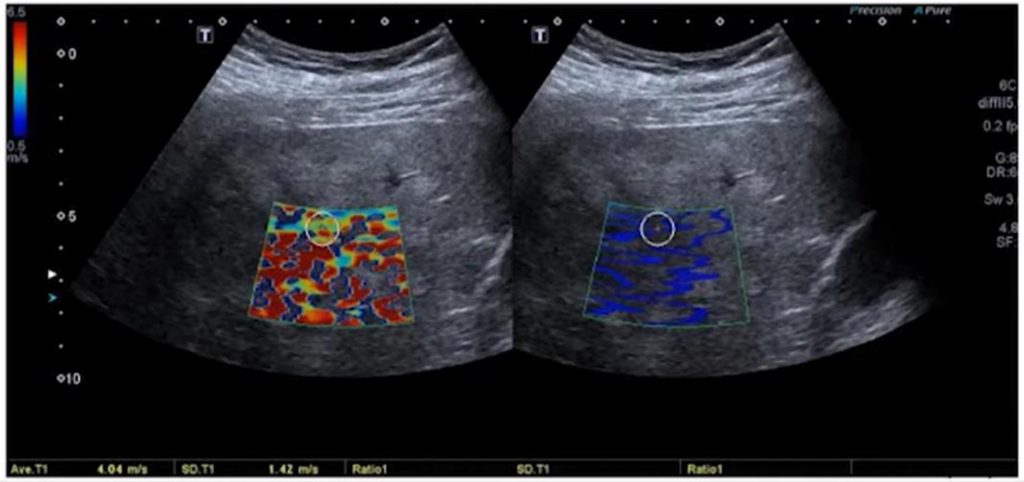
Propagation Map

Hard target → Faster Shear wave → Wider Distance between wavefronts

Acknowledgement G Guenette 2015

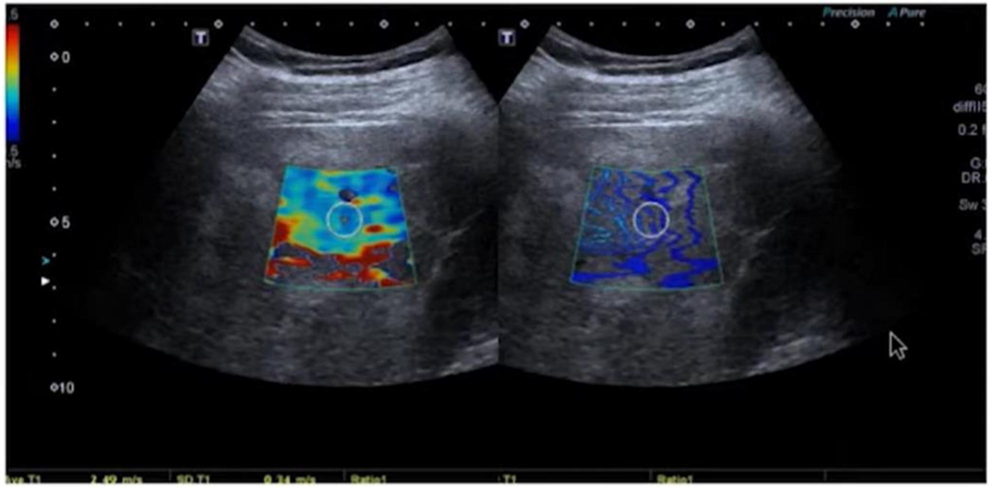
Examples: Too deep

Reposition box more superficial: Swiss Cheese: Some out of plane motion
The numbers tend to increase as you go deeper.



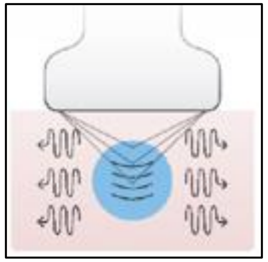
Examples: Same patient

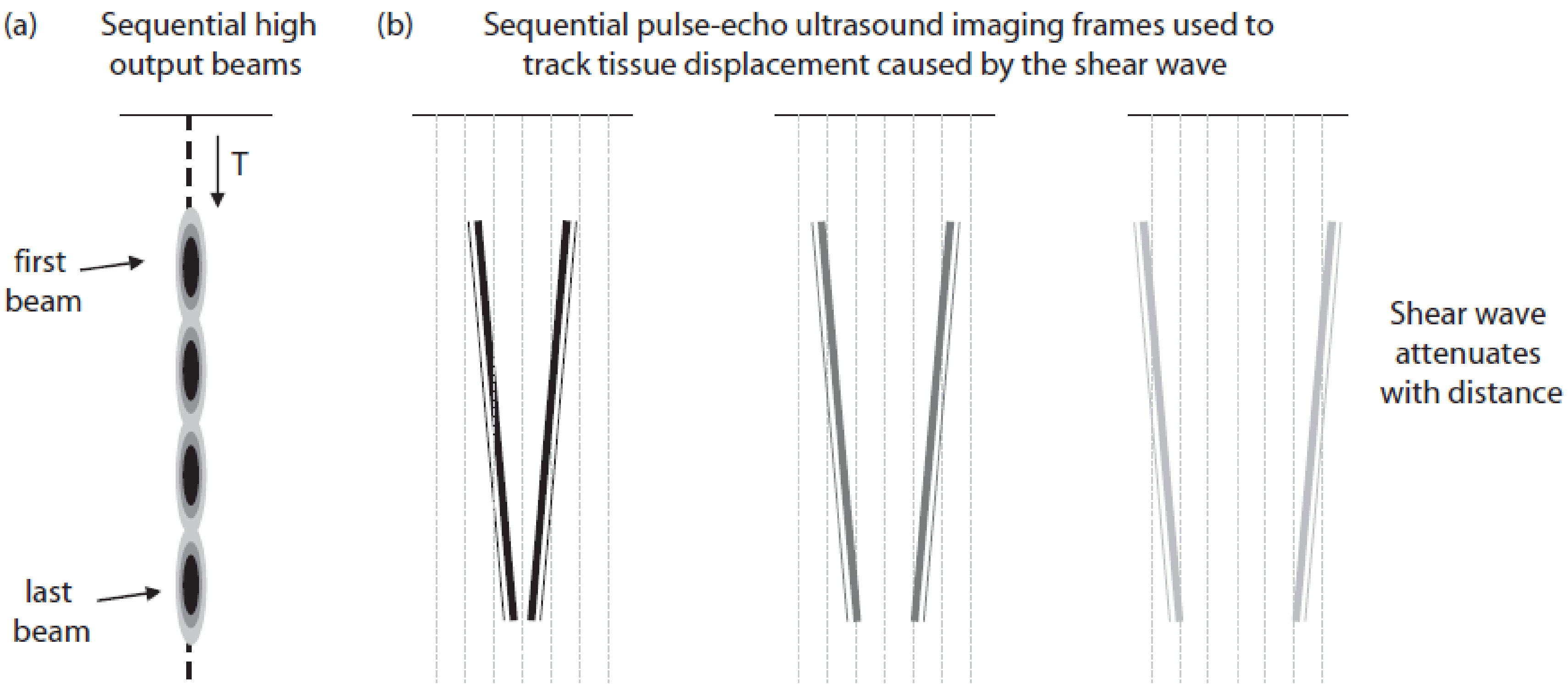
Much better with repositioned box

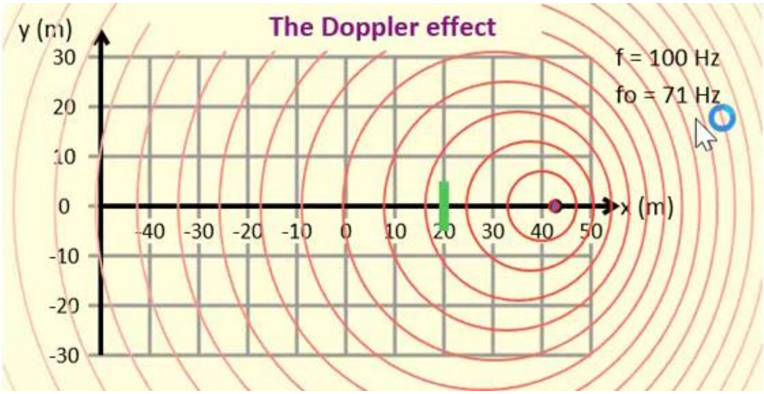


https://www.youtube.com/watch?v=5hTpuG5ezHI&t=2969s

Shear wave elastography imaging using supersonic ARFI



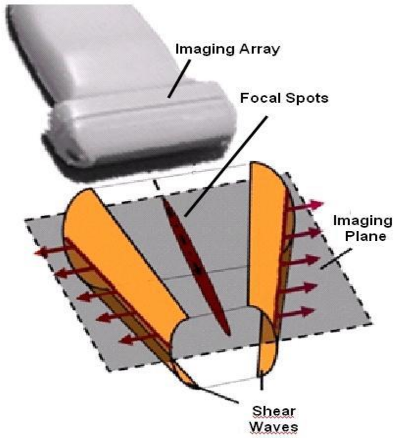


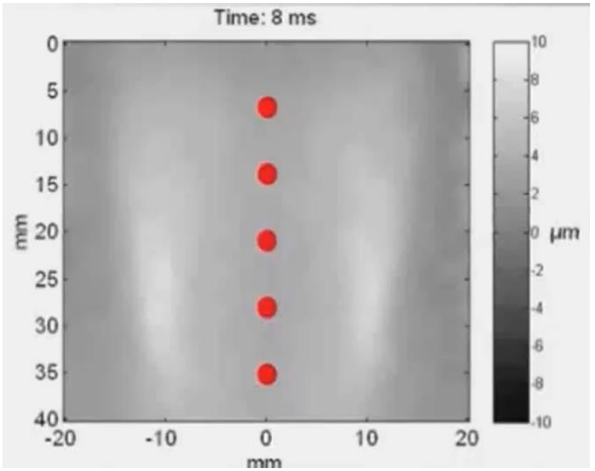


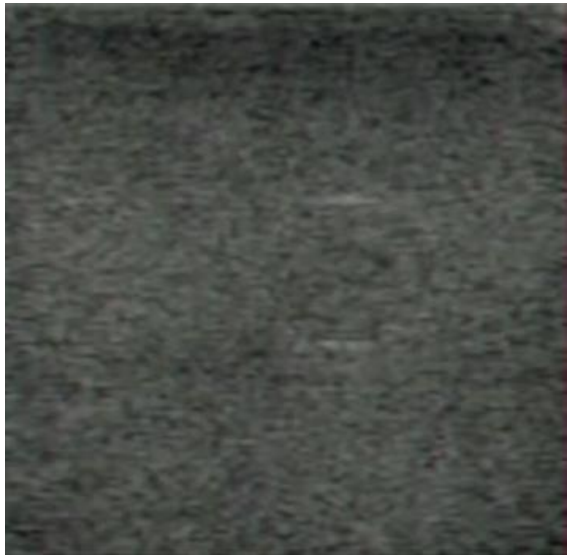
(a) Sequential high-output beams are generated with focal regions of increasing depth along the same line.
(b) A shear wave cone is formed, and high-frame-rate imaging techniques are used to track the tissue displacement caused by the shear wave.

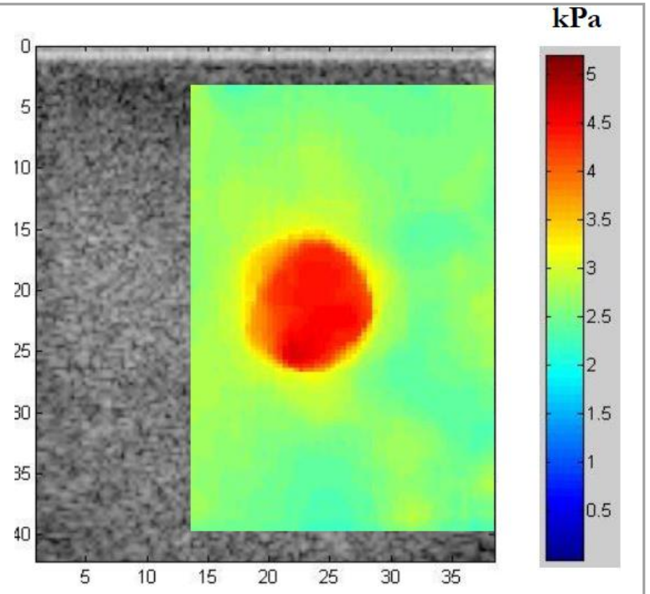
Diagnostic Ultrasound – Hoskins, Martin, Thrush

Supersonic shear wave propagation

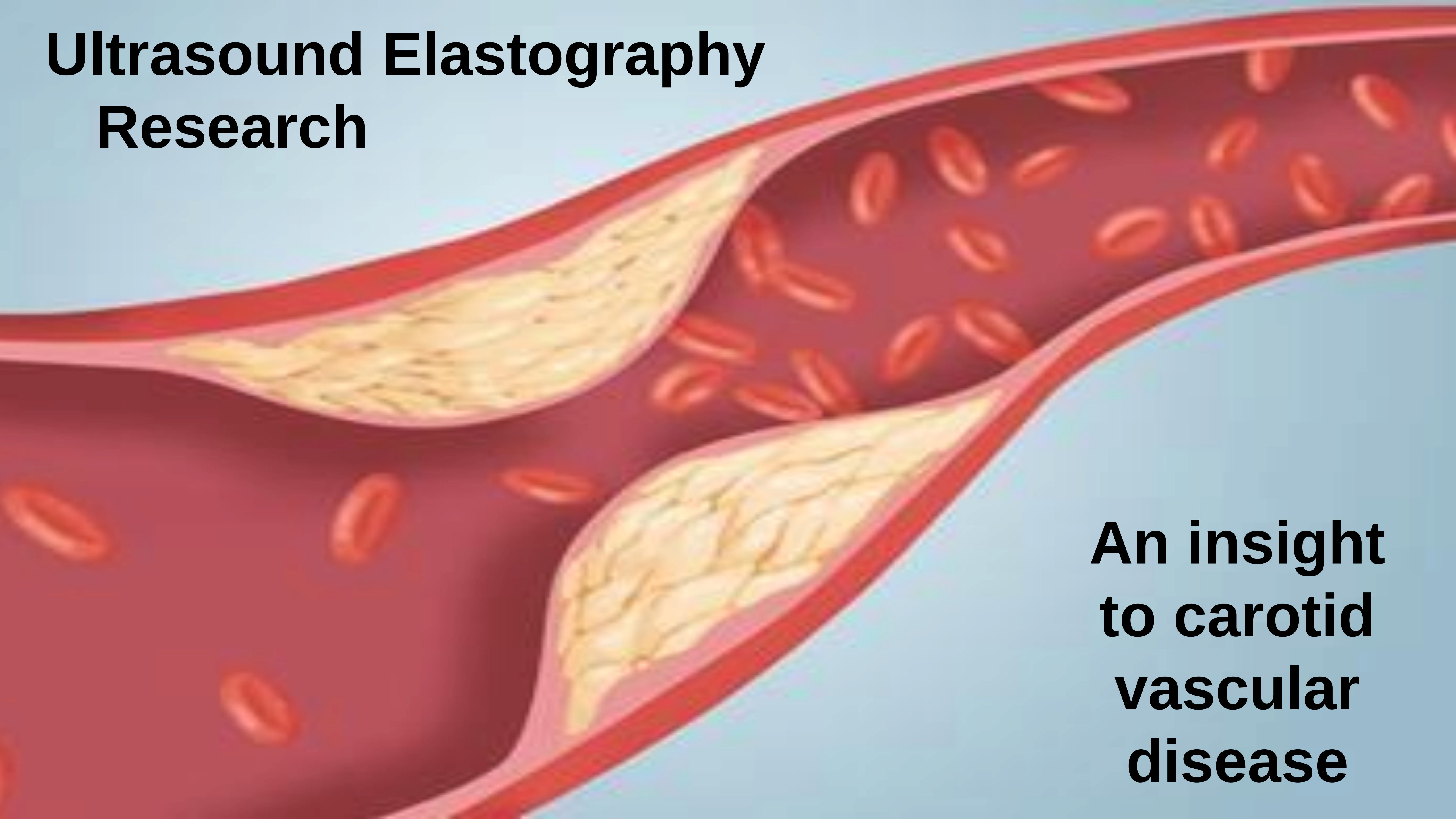






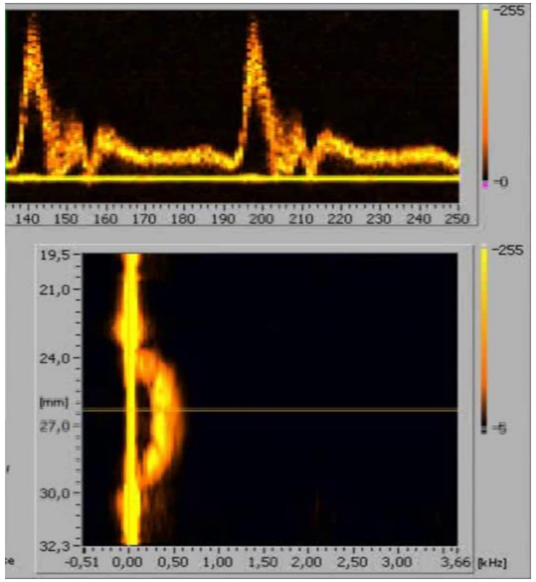


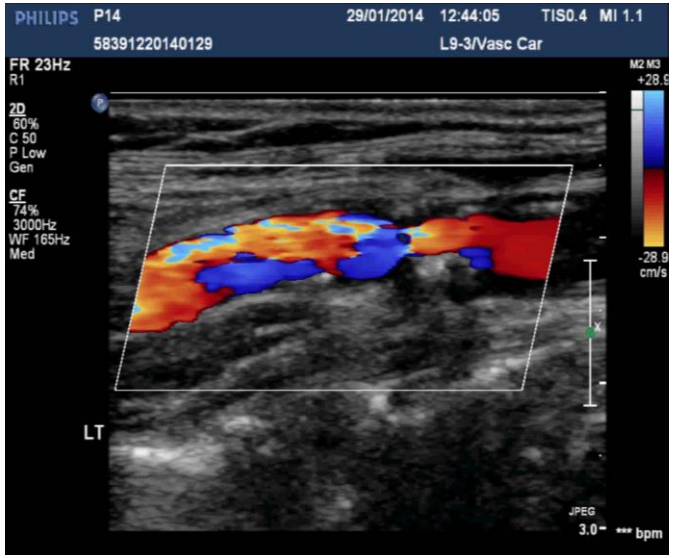
Ultrasound Elastography Research

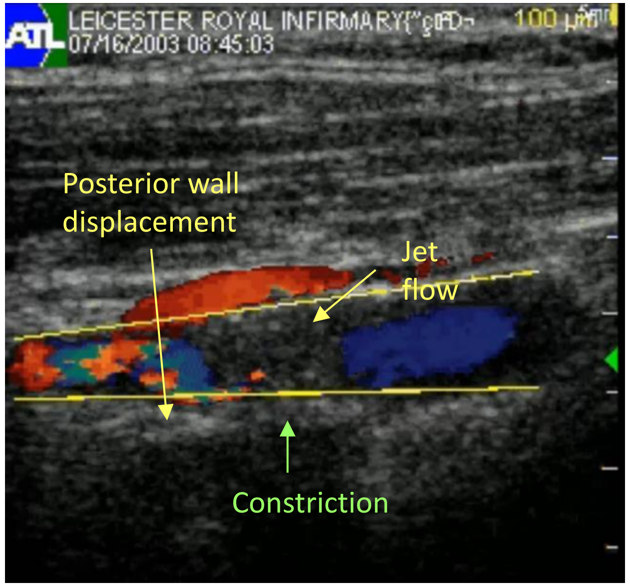


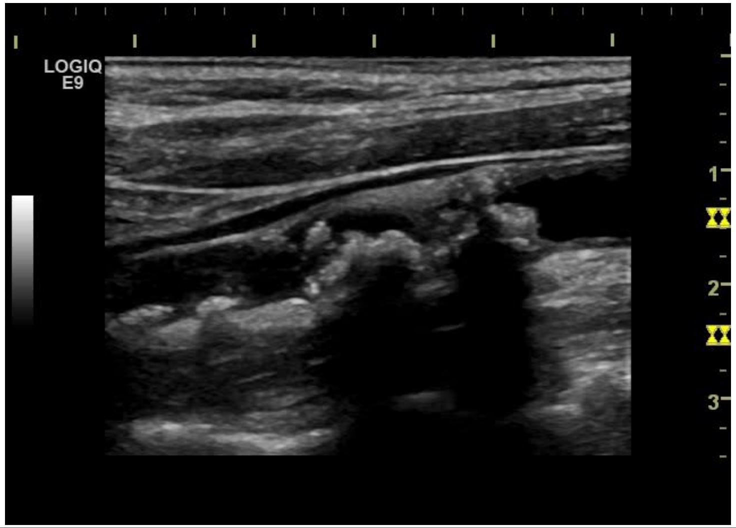
An insight to carotid vascular disease

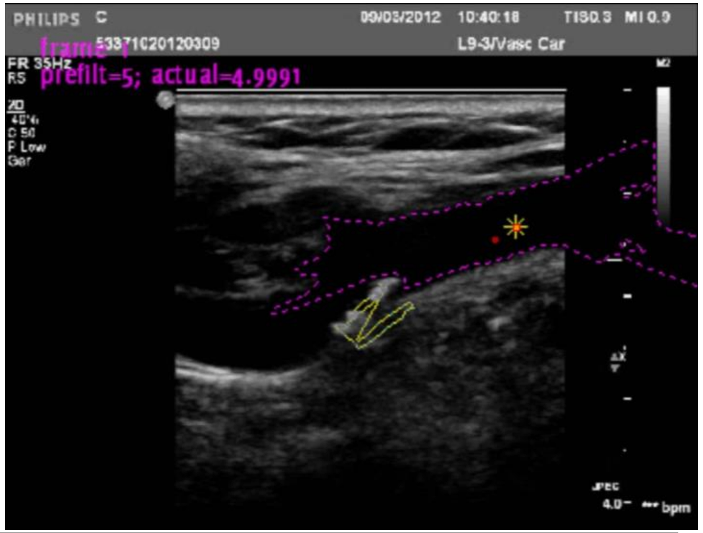
Carotid plaques- stable or unstable?









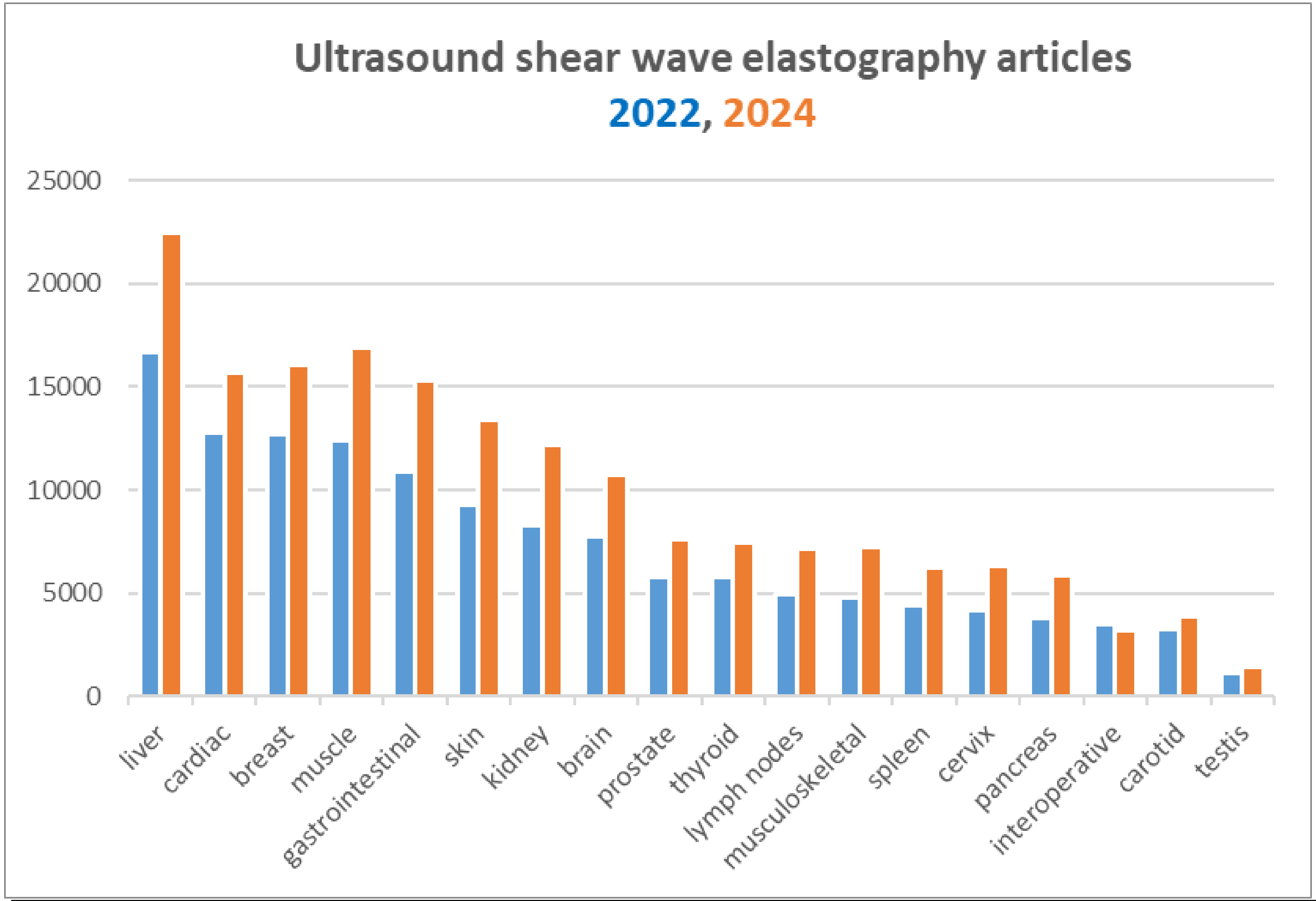


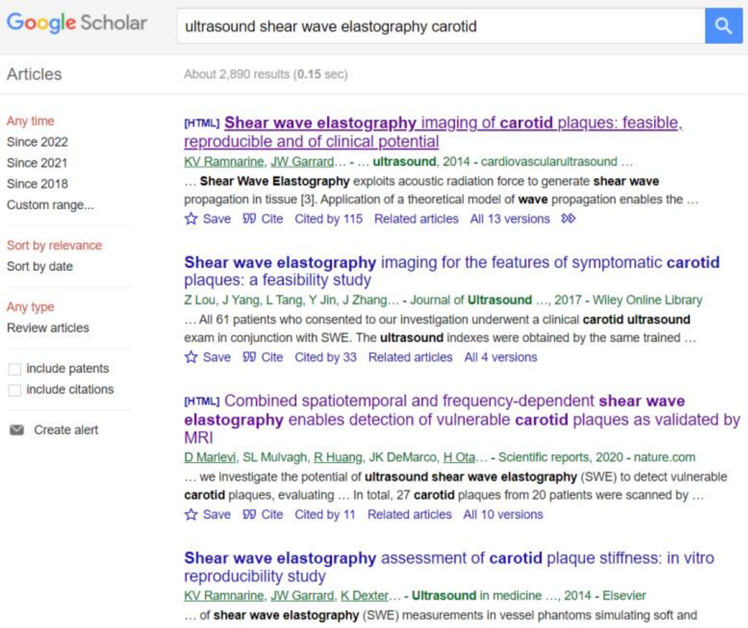
Shear wave elastography imaging of carotid plaque?

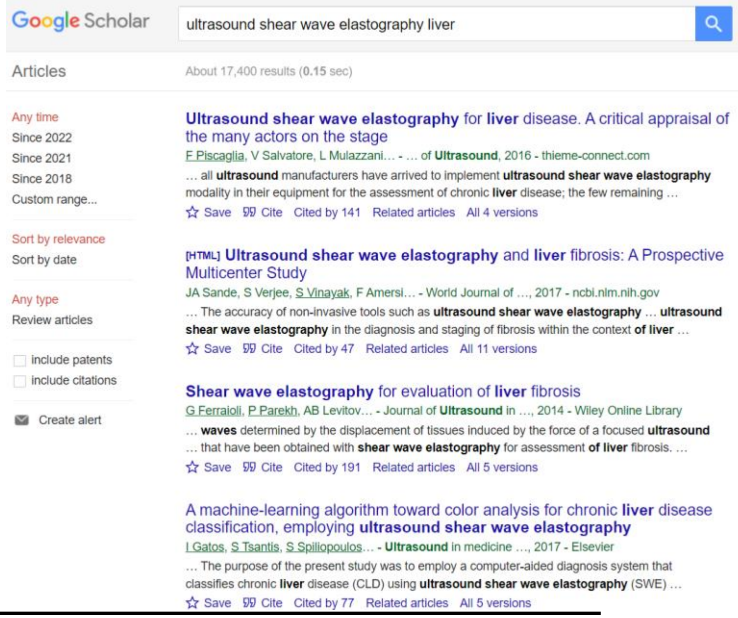
- **Challenging clinical application**
  - Small tissue size
  - Often heterogeneous
  - Dynamic environment due to pulsatile flow
  - Thin walls
  - Non-linear tissue elasticity
  - Shear wave propagation model assumptions not applicable
  - Young's modulus estimates?

- **Hypothesis**
  - SWE imaging of carotid plaque can help identify the unstable plaque

Shear wave elastography publications







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0301-5629/$ - see front matter
http://dx.doi.org/10.1016/j.ultrasmedbio.2013.09.014

Original Contribution

SHEAR WAVE ELASTOGRAPHY ASSESSMENT OF CAROTID PLAQUE STIFFNESS: *IN VITRO* REPRODUCIBILITY STUDY

KUMAR V. RAMNARINE,* JAMES W. GARRARD,† KATIE DEXTER,* SARAH NDUWAYO,†

Case Report

Shear-Wave Elastography in Carotid Plaques:
e Median and
n an Interesting Case

Shear Wave Elastography May Be Superior to Greyscale Median for the Identification of Carotid Plaque Vulnerability: A Comparison with Histology

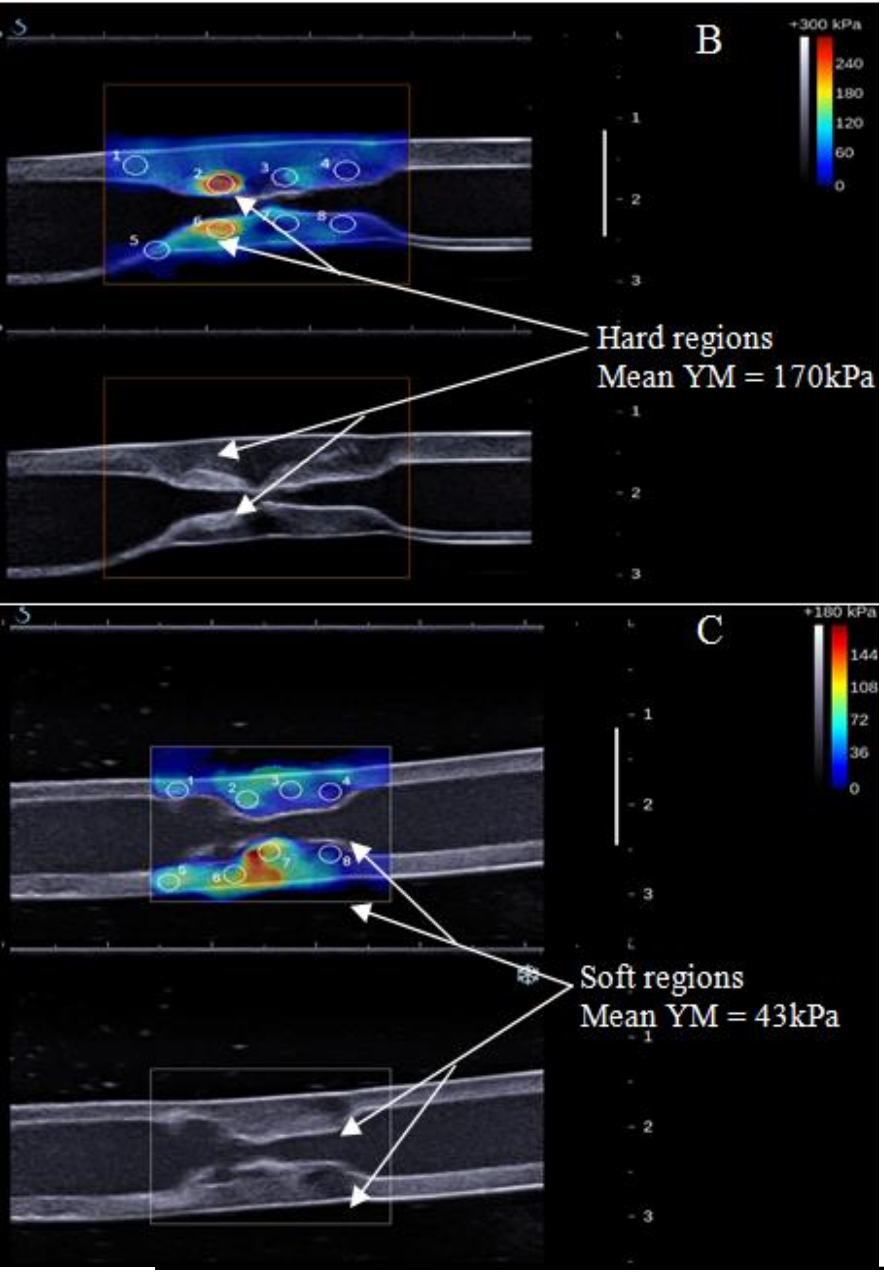
Mögliche Überlegenheit der Scherwellen-Elastografie gegenüber dem medianen Grauwert bei der Identifikation der Vulnerabilität von Karotisplaques: Vergleich mit der Histologie

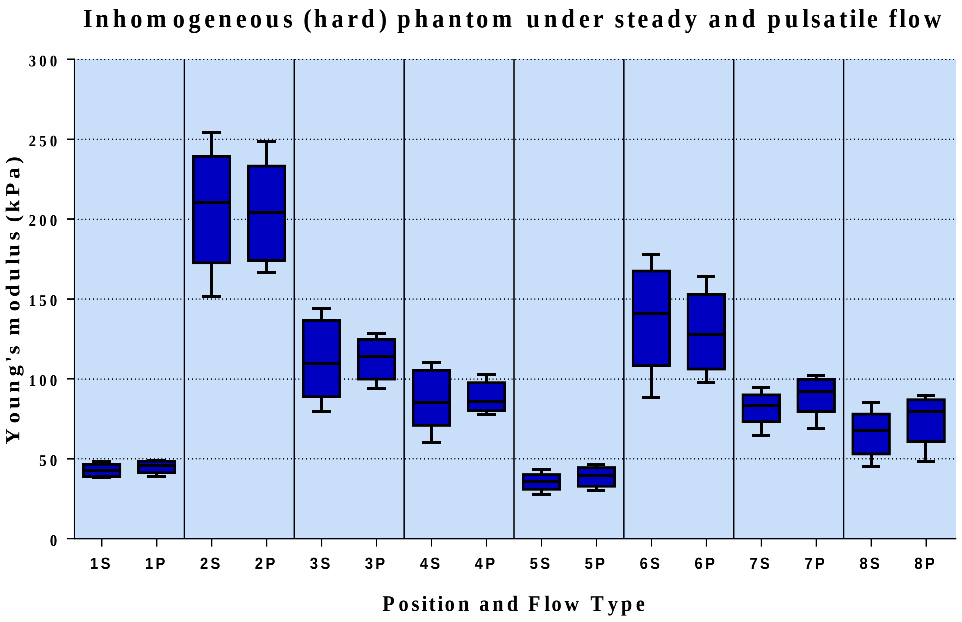
Research | Highly accessed | Open Access

Shear wave elastography imaging of carotid plaques: feasible, reproducible and of clinical potential

Kumar V Ramnarine[1]*, James W Garrard[2], Baris Kanber[2], Sarah Nduwayo[2], Timothy C Hartshorne[3] and Thompson G Robinson[2,4]

Experimental Flow Phantom Studies





Phantom	Flow	Mean % difference	Inter-observer ICC	Wall CV	Plaque CV	Inhomo-geneous region CV
Homogeneous	Steady	15.9%	0.71	0.12	0.11	-
	Pulsatile	15.4%	0.69	0.17	0.08	-
Inhomogeneous (hard)	Steady	18.4%	0.78	0.08	0.15	0.15
	Pulsatile	14.4%	0.79	0.12	0.09	0.10
Inhomogeneous (soft)	Steady	18.1%	0.82	0.15	0.11	0.15
	Pulsatile	22.7%	0.78	0.13	0.15	0.20

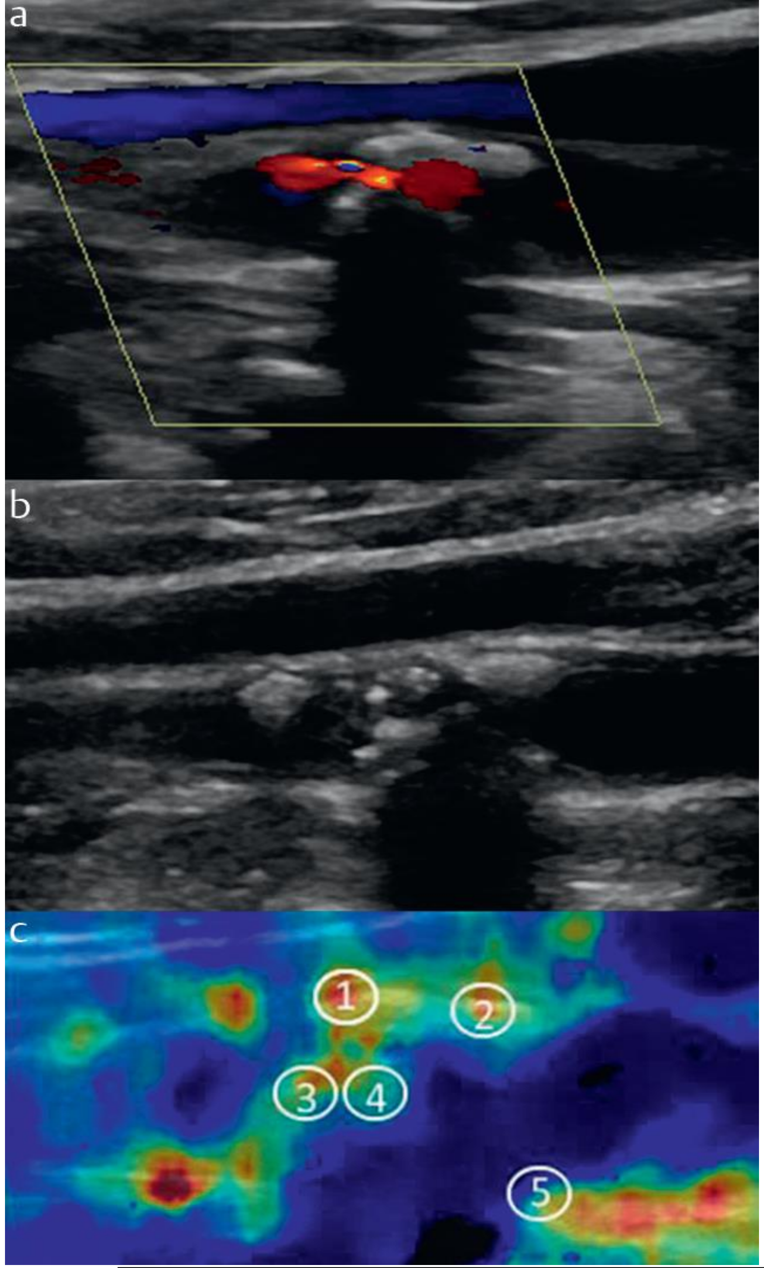
Key findings:

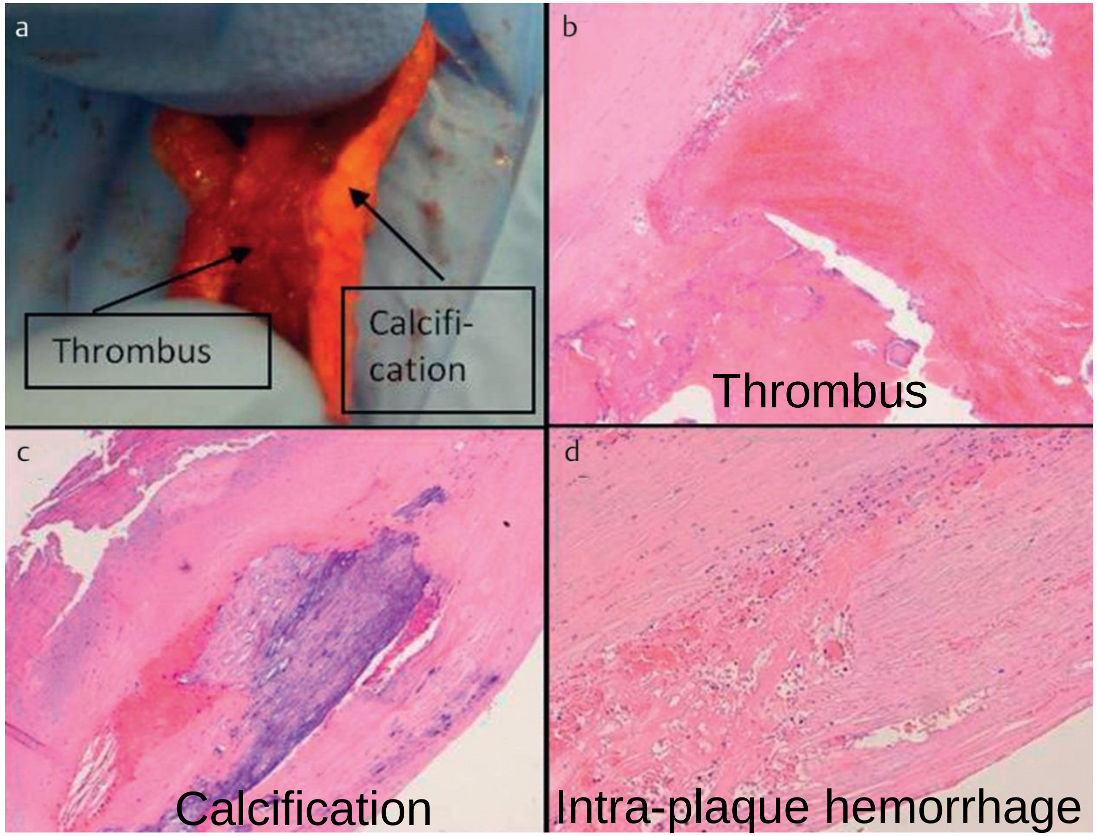
SWE able to distinguish hard and soft areas of plaque model even under pulsatile flow

Reproducible YM estimates

Ramnarine KV et al. Shear wave elastography assessment of carotid plaque stiffness: in vitro reproducibility study. Ultrasound in Medicine & Biology 2014; 40: 200–209.

Clinical case report



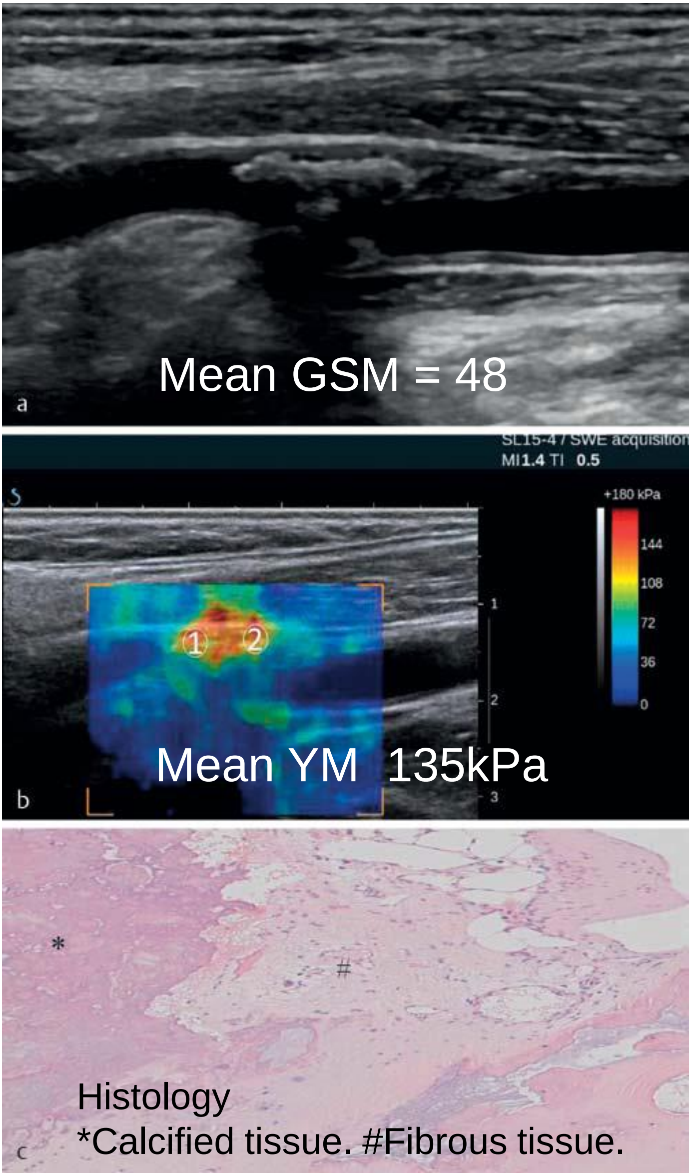


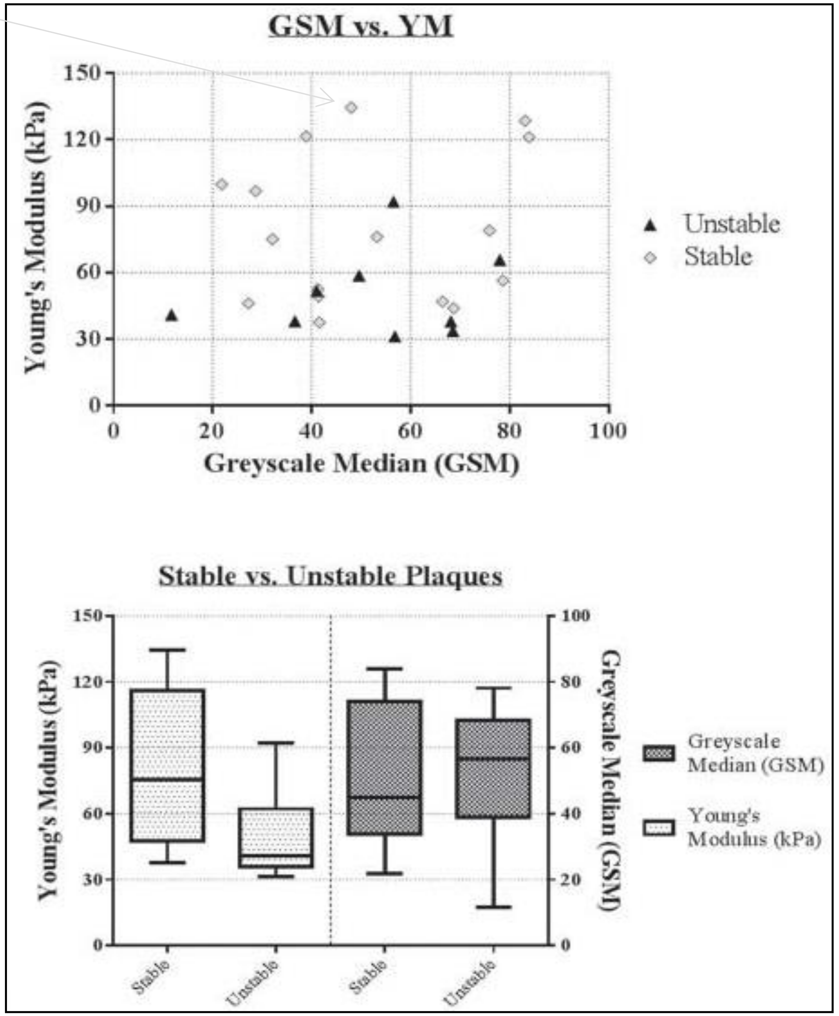
First case study to suggest SWE assessment of Young's Modulus of plaque may correlate with macroscopic and microscopic assessment as well as conventional greyscale imaging appearance.

Garrard J and Ramnarine KV. Shear-wave elastography in carotid plaques: comparison with Greyscale Median and histological assessment in an interesting case. Ultraschall in der Medizin. 2013; Oct 23.

Fibrous plaque stable on histology

ShearWave Elastography May Be Superior to Greyscale Median for the Identification of Carotid Plaque Vulnerability: A Comparison with Histology





Key Findings:

Histological study on 25 plaques

Mean YM of unstable plaques significantly lower than stable plaques:

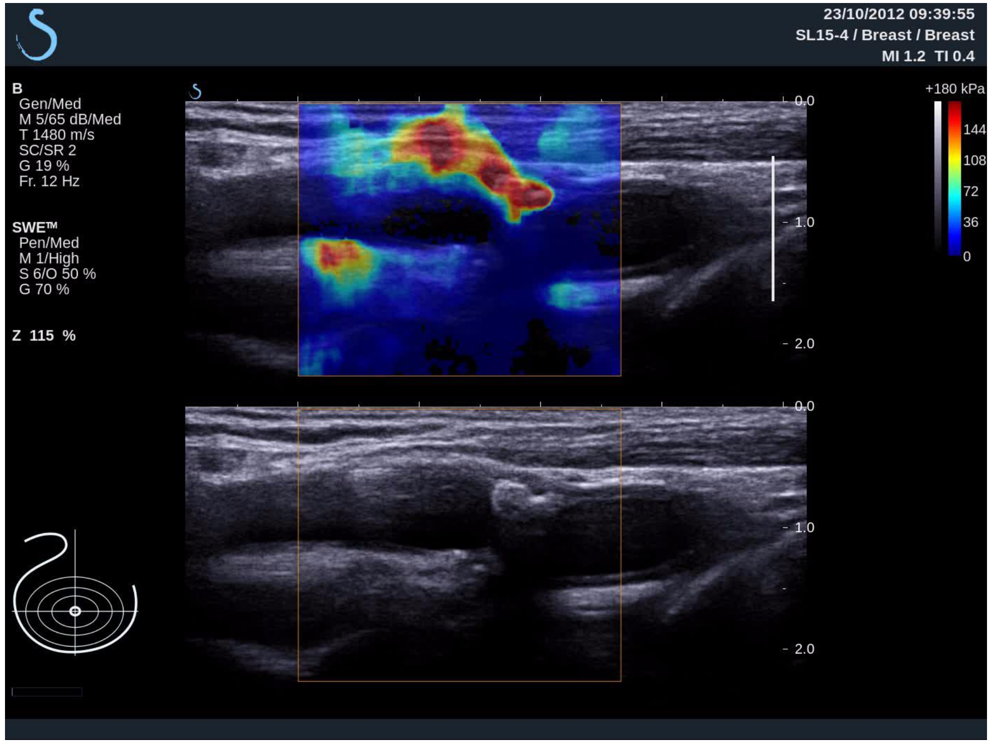
50kPa vs. 79kPa; p = 0.027

Mean GSM:
No significant difference.

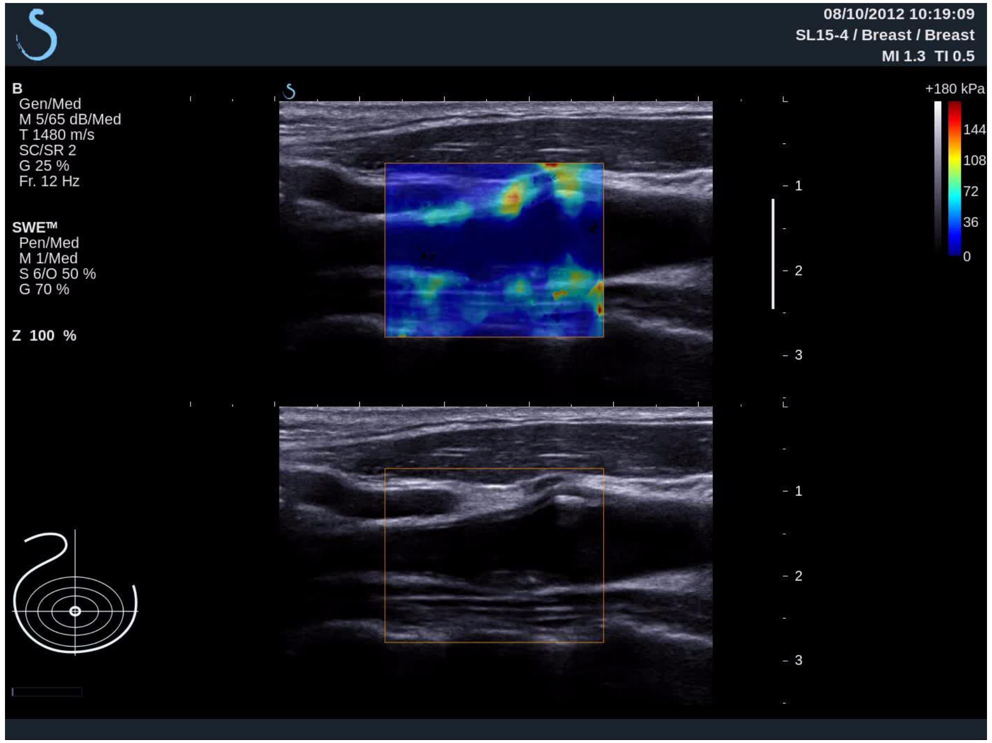
[1]Garrard JW et al. Shear Wave Elastography May Be Superior to Greyscale Median for the Identification of Carotid Plaque Vulnerability: A Comparison with Histology. Ultraschall in Med 2015; 36: 386–390

Clinical studies

Shear Wave Elastography imaging of carotid plaque



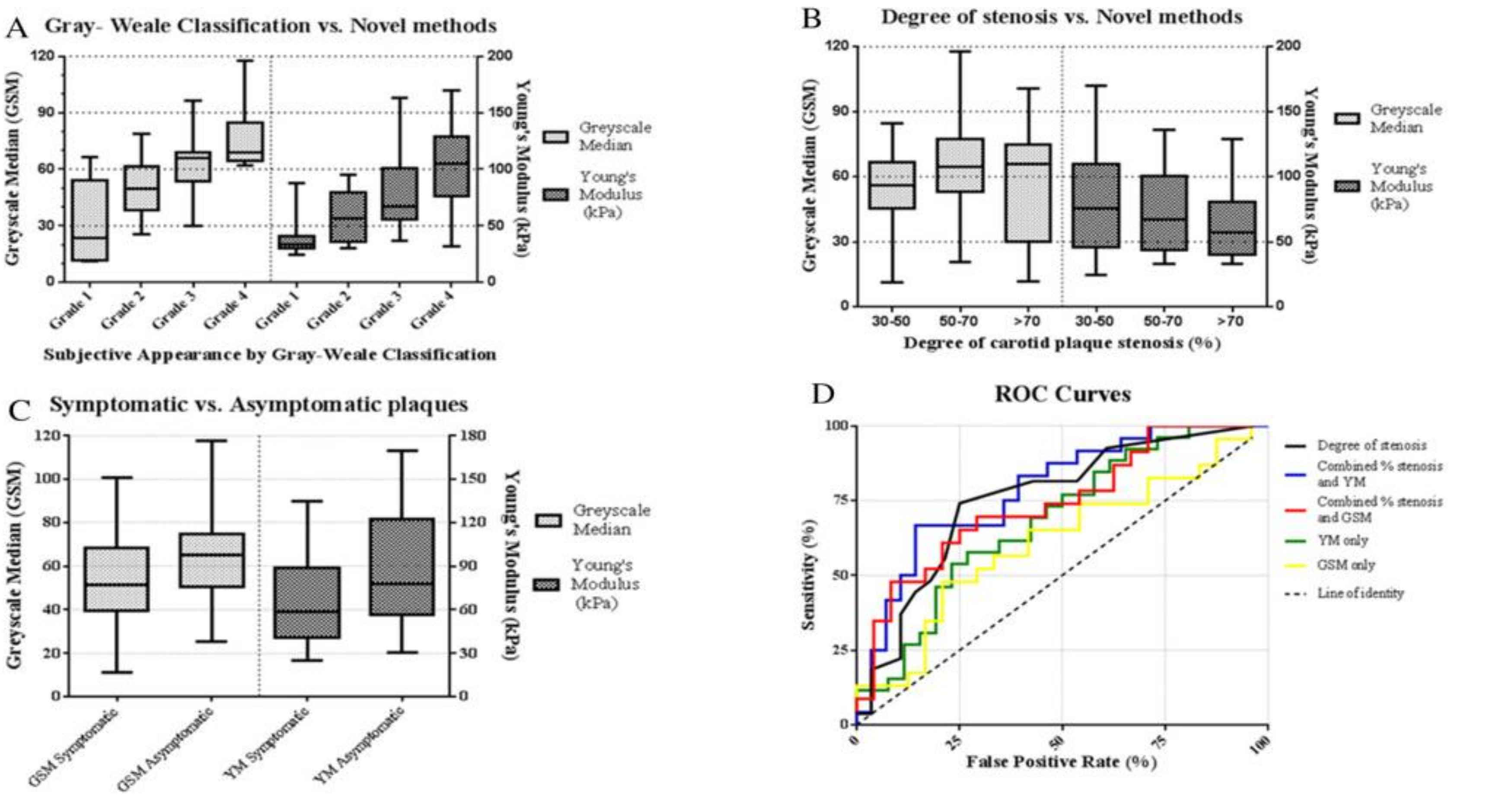
Ultrasound B-mode and SWE video clip of carotid plaque causing a ≥70% stenosis demonstrated at the origin to the ICA. Greyscale imaging demonstrates apparently large fibrous and calcified plaque corresponding to relatively high YM in the SWE image.



Ultrasound B-mode and SWE video clip of minor carotid plaque demonstrated at the carotid bifurcation. Greyscale imaging demonstrates a predominately anechoic type 1 plaque on the posterior wall corresponding to relatively low YM in the SWE image.

Ramnarine et al. Shear wave elastography imaging of carotid plaques: feasible, reproducible and of clinical potential. Cardiovascular Ultrasound 2014, 12:49

Clinical study in 81 patients: potential clinical value



Graphs illustrating key results.
A) Box and whisker plots showing the Greyscale median (GSM) and Young's Modulus (YM) of plaques against subjective Gray-Weale Classification. Both values increase with higher classification of plaque appearance.
B) Box and whisker plots illustrating plaque GSM and YM against the percentage stenosis, grouped into either mild (30-50%), moderate (50-70%) or severe (>70%).
C) Box and whisker plots illustrating the plaque GSM and YM of symptomatic and asymptomatic plaques.
D) ROC curves for the logistical regression of different ultrasound methods, and percentage stenosis as an individual method.

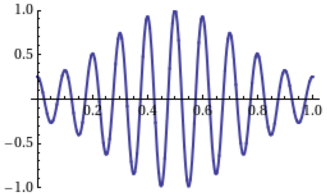
Table 4 Summary of YM and GSM values in vessel wall and plaque and inter-frame reproducibility of measurements[1]

All patients	Wall YM	Plaque YM	Plaque GSM
Mean	42 kPa (95% CI: 37-48 kPa)	75 kPa (95% CI: 64-85 kPa)	56 (95% CI: 52–65)
CV	22% (95% CI: 20-24%)	19% (95% CI: 17-21%)	7% (95% CI: 5-8%)

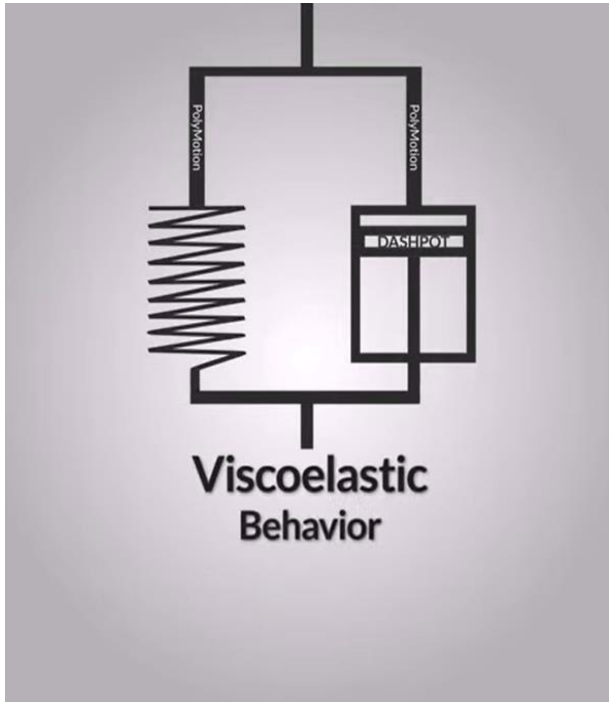
[1]The mean and 95% confidence intervals (CI) of results across all patients are shown in addition to the average inter-frame coefficient of variation (CV) of YM and GSM measurements.

Ramnarine et al. 2014. Shear wave elastography imaging of carotid plaques: feasible, reproducible and of clinical potential. Cardiovascular Ultrasound 2014, 12:49

The reality: what is being measured?



The reality: what is being measured?



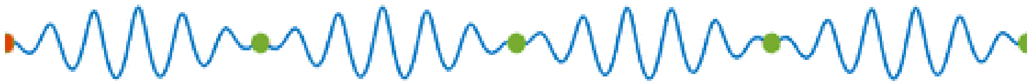
Assumes medium is:

Linearly elastic
Infinitely homogeneous
Isotropic
Continuous
Incompressible
Constant density
Non-dispersive

Reality:

Non-linear, time dependent
Tissue boundaries, structures…
Tissue anisotropy
Discontinuities, structures, fluid…
Compressible, viscoelastic
Variable density
Dispersive tissue

Challenges:
Need to consider viscoelasticity, poroelasticity, artifacts…
Propagation speed depends on methodology, frequency, bandwidth, position….



Group velocity vs Phase velocity

https://en.wikipedia.org/wiki/Group_velocity

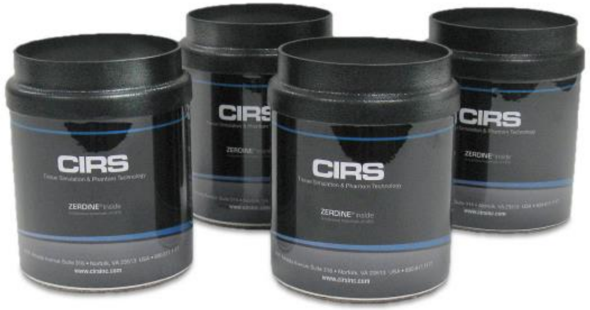
Elastography Phantoms and Test Objects

- **Well characterised phantoms and test objects:**
  - **For Experimental Studies**
    - Vascular flow phantom of carotid plaque
  - **For Routine USQA of elastography modalities**
  - **For Performance Assessment**
    - Leicester-St Thomas' Elastography Pipe phantom (L-STEP)
  - **For Teaching/Training**

Some commercial elastography phantoms

Shear Wave Liver Fibrosis Phantoms

Model 039



ZERDINE® Inside
A registered trademark of CIRS

MEASURE KNOWN TISSUE ELASTICITIES WITH SHEAR WAVE SYSTEMS

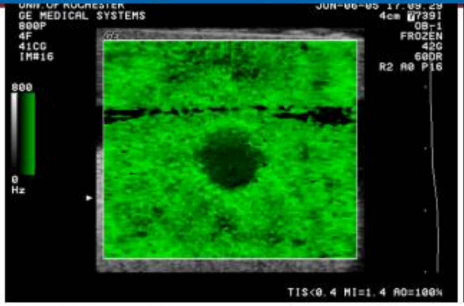
Elasticity QA Phantoms

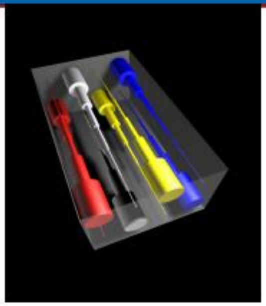
Model 049 & 049A

ZERDINE® Inside
A registered trademark of CIRS

DEVELOPED TO PROVIDE USERS WITH ACOUSTIC TARGETS OF DISCRETE KNOWN STIFFNESS

ELASTICITY QA PHANTOMS Model 049 & 049A



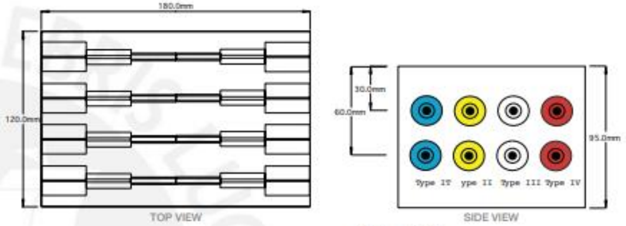


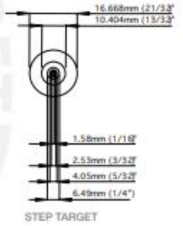
SPECIFICATIONS

DIMENSIONS: [1]	8.5" in x 6" in x 4" in (20cm x 15cm x 10cm)
PHANTOM WEIGHT:	Model 049 - 6 lb Model 049A - 7 lb
MATERIALS:	**Background** Material: Zerdine® Speed of Sound: 1540 m/s Attenuation: 0.5 dB/cm-MHz **Lesions** Material: Zerdine Attenuation: 0.5 dB/cm-MHz **Elasticity** [2,3] Background: 25 kPa Lesion Type I: 8 kPa Lesion Type II: 14 kPa Lesion Type III: 45 kPa Lesion Type IV: 80 kPa
SCANABLE SURFACE AREA	17 x 10 cm

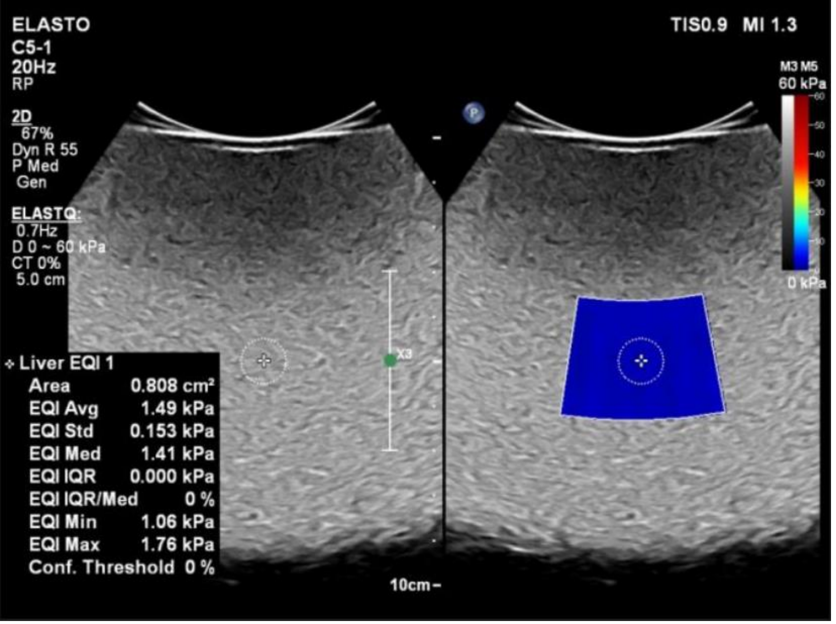
[1] Users of magnetic resonance elastography (MRE) systems may require custom housing to provide a larger opening for MRE drivers. Contact CIRS to customize the phantom for this application.

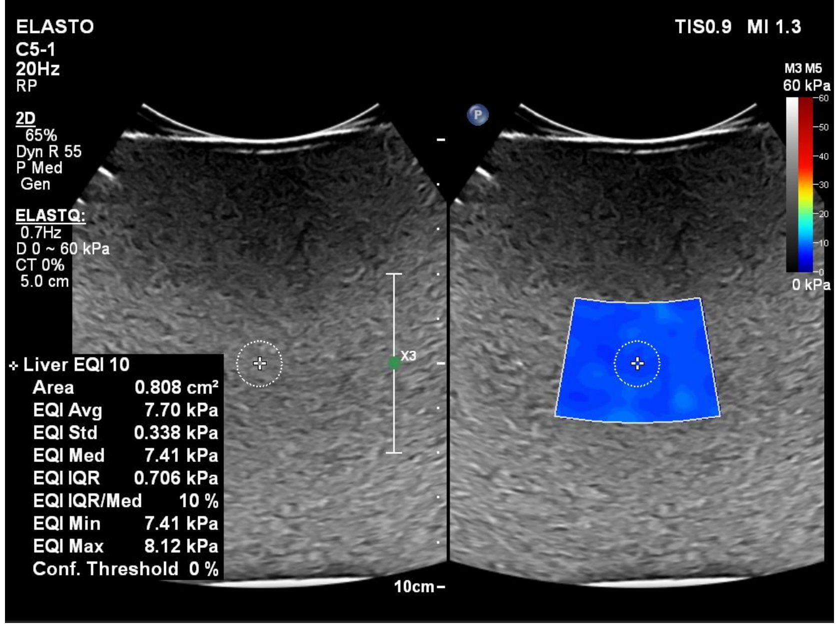
MODEL 049A ELASTICITY QA PHANTOM - STEPPED CYLINDER

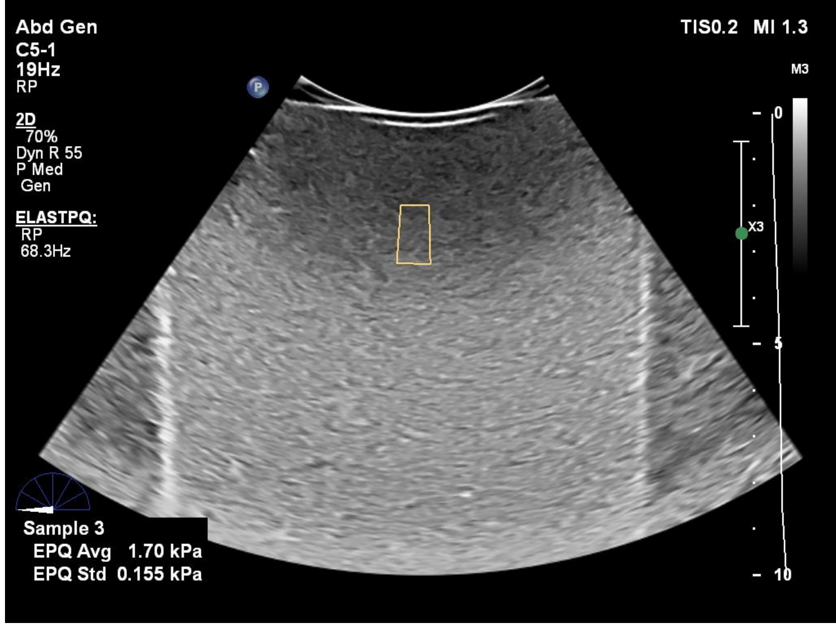


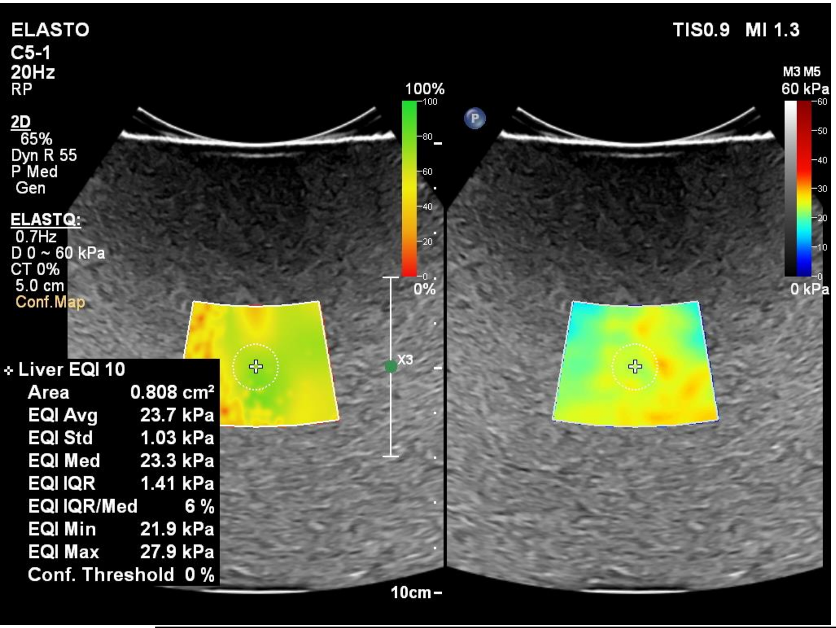


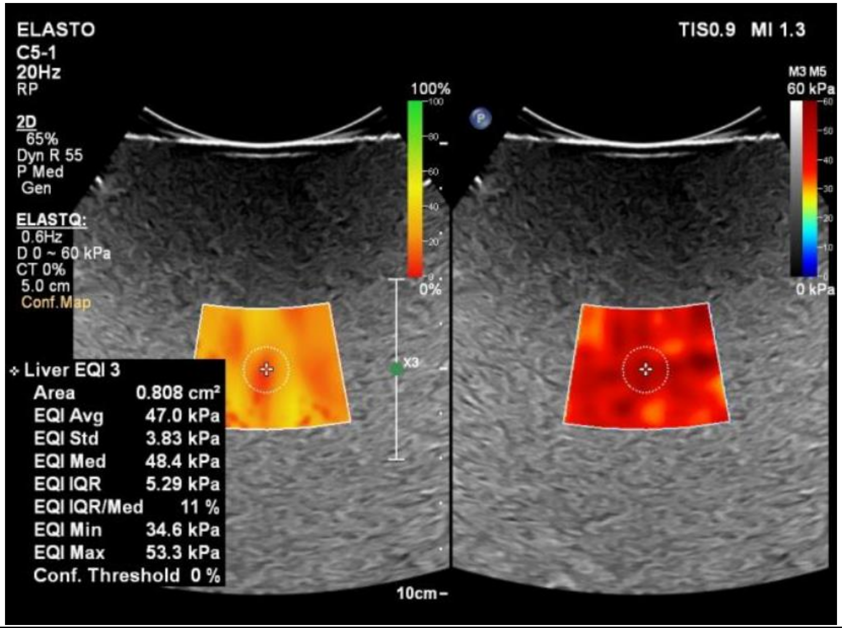
MODEL 049 ELASTICITY QA PHANTOM - SPHERICAL

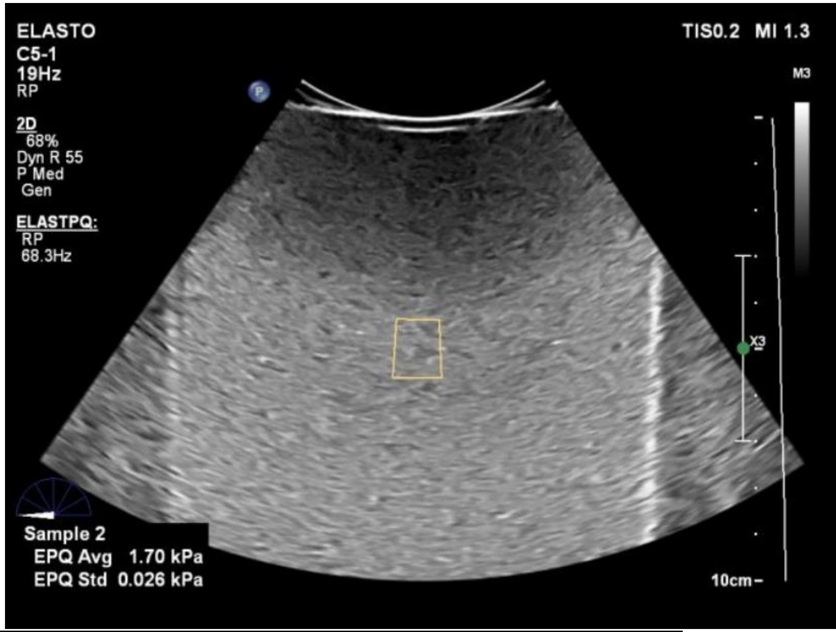

ELASTO
C5-1
20Hz
RP
TIS0.9 MI 1.3
2D
67%
Dyn R 55
P Med
Gen
ELASTQ:
0.7Hz
D 0 ~ 60 kPa
CT 0%
5.0 cm
M3 M5
60 kPa
0 kPa
Liver EQI 1
Area 0.808 cm²
EQI Avg 1.49 kPa
EQI Std 0.153 kPa
EQI Med 1.41 kPa
EQI IQR 0.000 kPa
EQI IQR/Med 0 %
EQI Min 1.06 kPa
EQI Max 1.76 kPa
Conf. Threshold 0 %
10cm


ELASTO
C5-1
20Hz
RP
TIS0.9 MI 1.3
2D
65%
Dyn R 55
P Med
Gen
ELASTQ:
0.7Hz
D 0 ~ 60 kPa
CT 0%
5.0 cm
M3 M5
60 kPa
0 kPa
Liver EQI 10
Area 0.808 cm²
EQI Avg 7.70 kPa
EQI Std 0.338 kPa
EQI Med 7.41 kPa
EQI IQR 0.706 kPa
EQI IQR/Med 10 %
EQI Min 7.41 kPa
EQI Max 8.12 kPa
Conf. Threshold 0 %
10cm


Abd Gen
C5-1
19Hz
RP
TIS0.2 MI 1.3
M3
2D
70%
Dyn R 55
P Med
Gen
ELASTPQ:
RP
68.3Hz
Sample 3
EPQ Avg 1.70 kPa
EPQ Std 0.155 kPa


ELASTO
C5-1
20Hz
RP
TIS0.9 MI 1.3
2D
65%
Dyn R 55
P Med
Gen
ELASTQ:
0.7Hz
D 0 ~ 60 kPa
CT 0%
5.0 cm
Conf.Map
100%
0%
M3 M5
60 kPa
0 kPa
Liver EQI 10
Area 0.808 cm²
EQI Avg 23.7 kPa
EQI Std 1.03 kPa
EQI Med 23.3 kPa
EQI IQR 1.41 kPa
EQI IQR/Med 6 %
EQI Min 21.9 kPa
EQI Max 27.9 kPa
Conf. Threshold 0 %
10cm

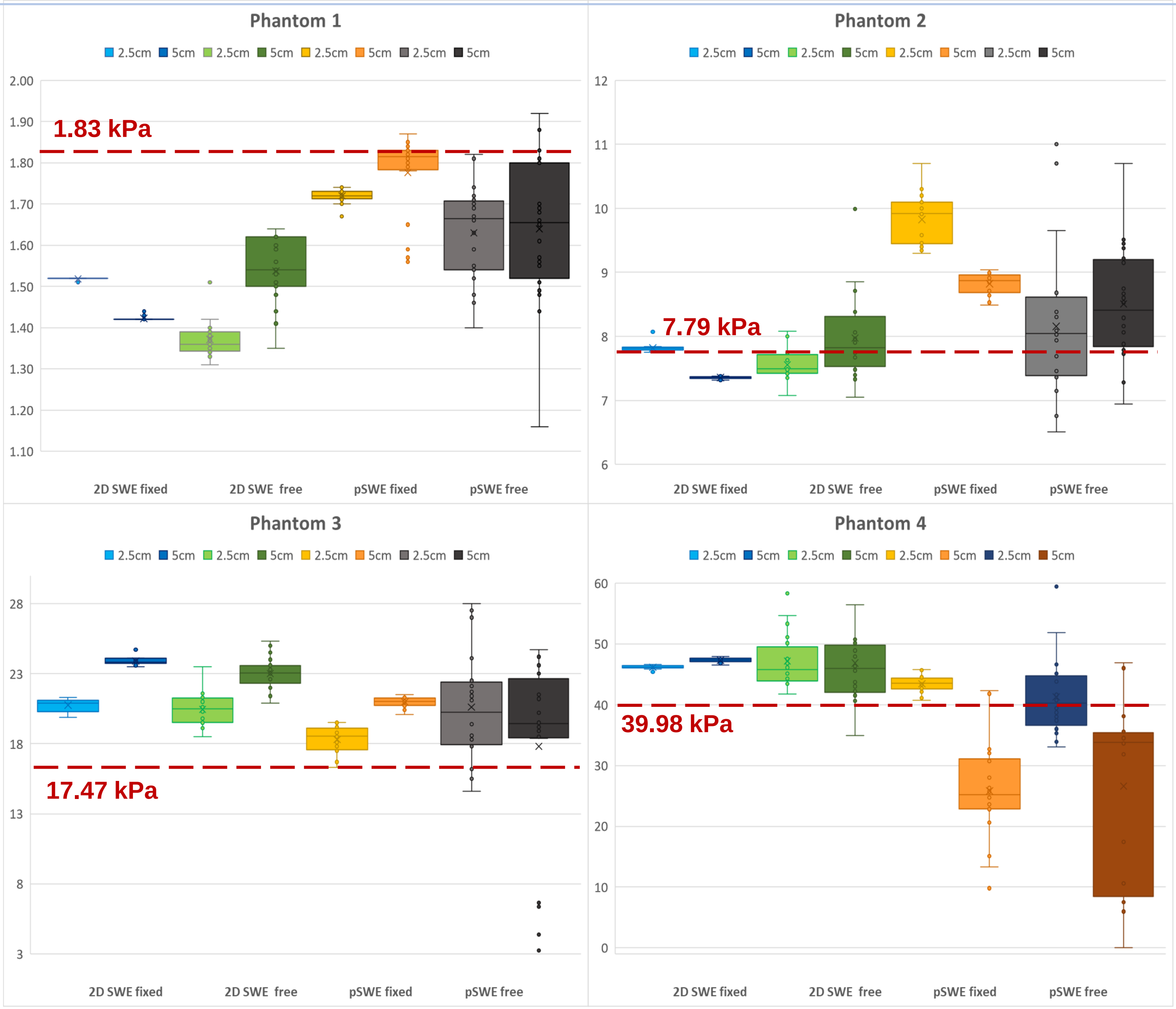

ELASTO
C5-1
20Hz
RP
TIS0.9 MI 1.3
2D
65%
Dyn R 55
P Med
Gen
ELASTQ:
0.6Hz
D 0 ~ 60 kPa
CT 0%
5.0 cm
Conf.Map
100%
0%
M3 M5
60 kPa
0 kPa
Liver EQI 3
Area 0.808 cm²
EQI Avg 47.0 kPa
EQI Std 3.83 kPa
EQI Med 48.4 kPa
EQI IQR 5.29 kPa
EQI IQR/Med 11 %
EQI Min 34.6 kPa
EQI Max 53.3 kPa
Conf. Threshold 0 %
10cm


ELASTO
C5-1
19Hz
RP
TIS0.2 MI 1.3
M3
2D
68%
Dyn R 55
P Med
Gen
ELASTPQ:
RP
68.3Hz
Sample 2
EPQ Avg 1.70 kPa
EPQ Std 0.026 kPa
10cm

2D-SWE better than pSWE in a phantom study?

Methods

- 4 CIRS 039 uniform phantoms (1.83–40 kPa)
- Philips Epiq Elite with C5-1 probe
- 2D-SWE and pSWE
- Two depths (2.5 and 5cm)
- Fixed clamp and free-hand random
- 20 measurements per configuration



Key results

- pSWE greater coefficient of variation (0–55%) compared to 2D-SWE (0–15%)
- Comparable accuracy (13.4% vs 15.7%).
- IQR/MED higher for pSWE (0–75%) than for 2D-SWE (0–15%)
- Fixed SWE had lowest CV (typically <5%)

Analysis courtesy of Ioana Pinzaru: GSTT/NPL collaboration

● *Original Contribution*

A NOVEL ELASTOGRAPHY PHANTOM PROTOTYPE FOR ASSESSMENT OF ULTRASOUND ELASTOGRAPHY IMAGING PERFORMANCE

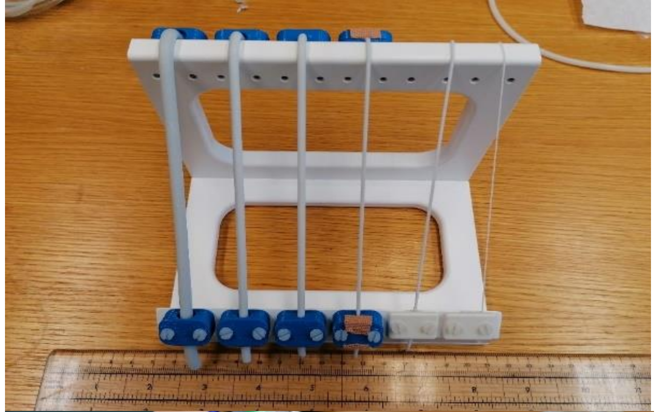
Fahad F. Al-Mutairi,[*,†] Emma ML. Chung,[†,‡,§] Carmel M. Moran,[¶] and Kumar V. Ramnarine[†,‖]

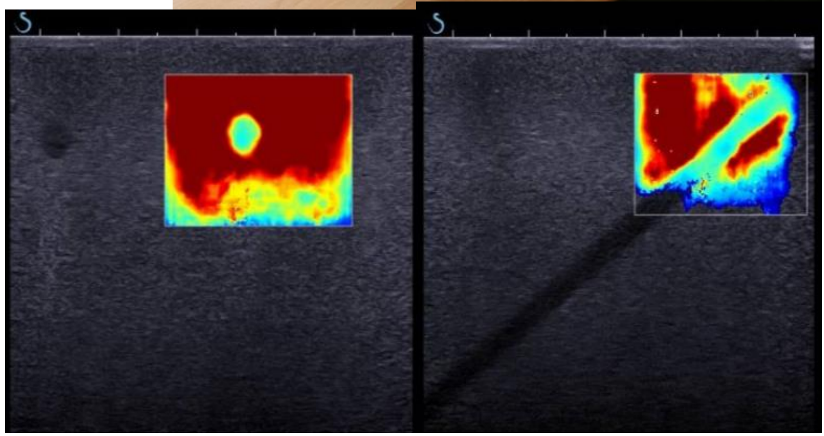
[*] Department of Diagnostic Radiology, Faculty of Applied Medical Sciences, King Abdulaziz University (KAU), Jeddah, Saudi Arabia; [†] Department of Cardiovascular Sciences, University of Leicester, Leicester, United Kingdom; [‡] National Institute for Health Research (NIHR) Leicester Biomedical Research Centre, Glenfield Hospital, Leicester, United Kingdom; [§] Department of Medical Physics, University Hospitals of Leicester NHS Trust, Leicester, United Kingdom; [¶] Centre for Cardiovascular Science, University of Edinburgh, Edinburgh, United Kingdom; and [‖] Medical Physics Department, Guy's and St Thomas' NHS Foundation Trust, London, United Kingdom

(*Received* 17 *March* 2021; *revised* 8 *May* 2021; *in final from* 17 *May* 2021)

Abstract—The aims of this study were firstly to manufacture and evaluate a novel elastography test phantom and secondly to assess the performance of an elastography system using this phantom. A novel Leicester–St. Thomas' Elastography Pipe (L-STEP) test phantom consisting of five soft polyvinyl acrylic–cryogel pipes of varying diameters (2–12 mm), embedded at 45° within an agar-based tissue-mimicking material was developed. A shear-wave elastography (SWE) scanner was used by two blinded operators to image and assess longitudinal sections of the pipes. Young's modulus estimates were dependent on the diameter of pipes and at superficial depths were greater than deeper depths (mean 98 kPa vs. 59 kPa) and had lower coefficients of variation (mean 21% vs. 53%). The penetration depth (maximum depth at which a SWE signal was obtained) increased with increasing pipe diameter. Penetration depth measurements had excellent inter- and intra-operator reproducibility (intra-class correlation coefficients >0.8) and coefficient of variation range of 2%–12%. A new metric, called the summative performance index, was defined as the sum of the ratios of the penetration depth/pipe diameter. The L-STEP phantom is suitable for assessing key aspects of elastography imaging performance: resolution, accuracy, reproducibility, depth dependence, sensitivity and our novel summative performance index. (E-mail: kumar.ramnarine@gstt.nhs.uk)

Key Words: **Ultrasound, Young's modulus, Elastography, Shear wave elastography, Phantom, Test object, Quality assurance.**

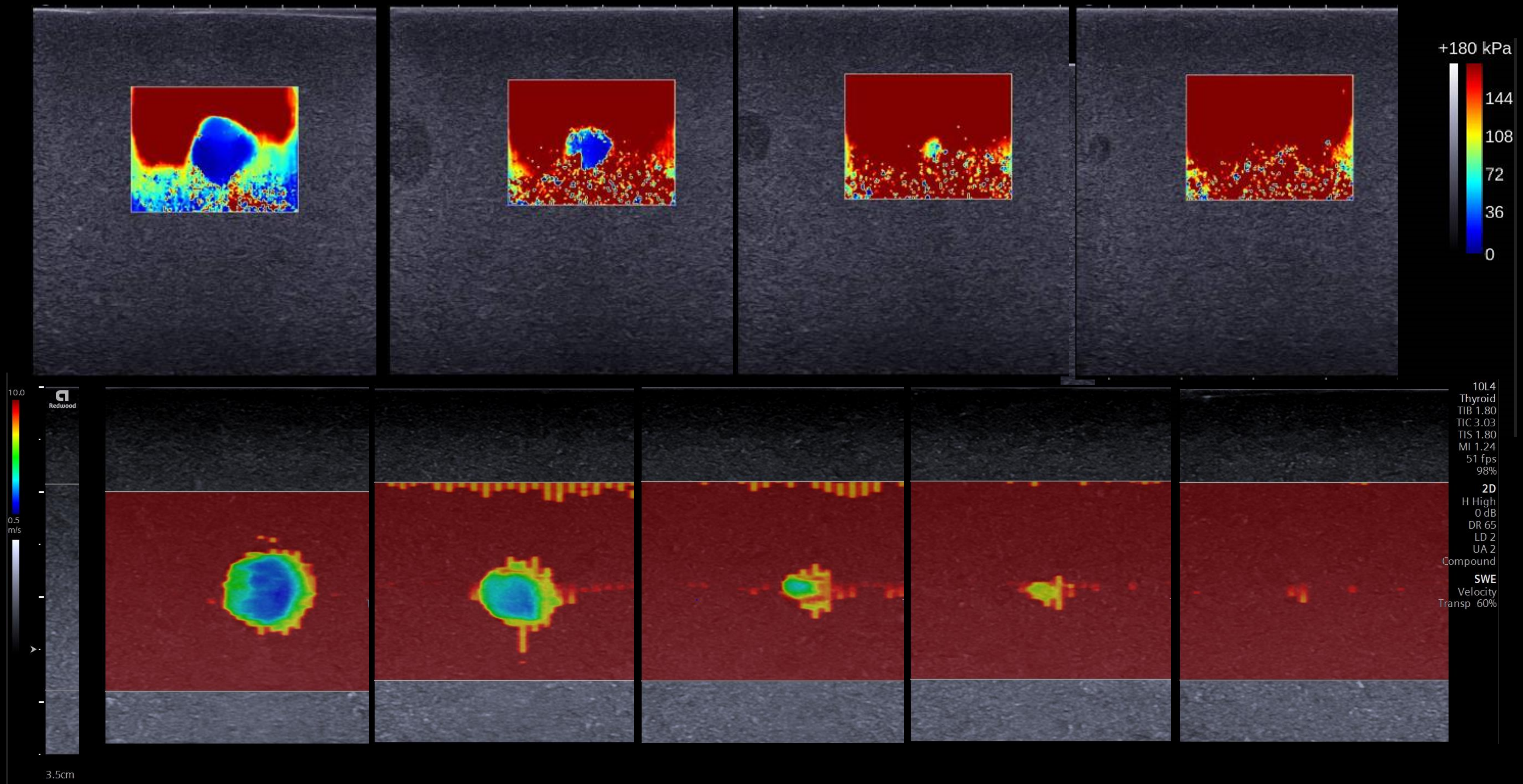




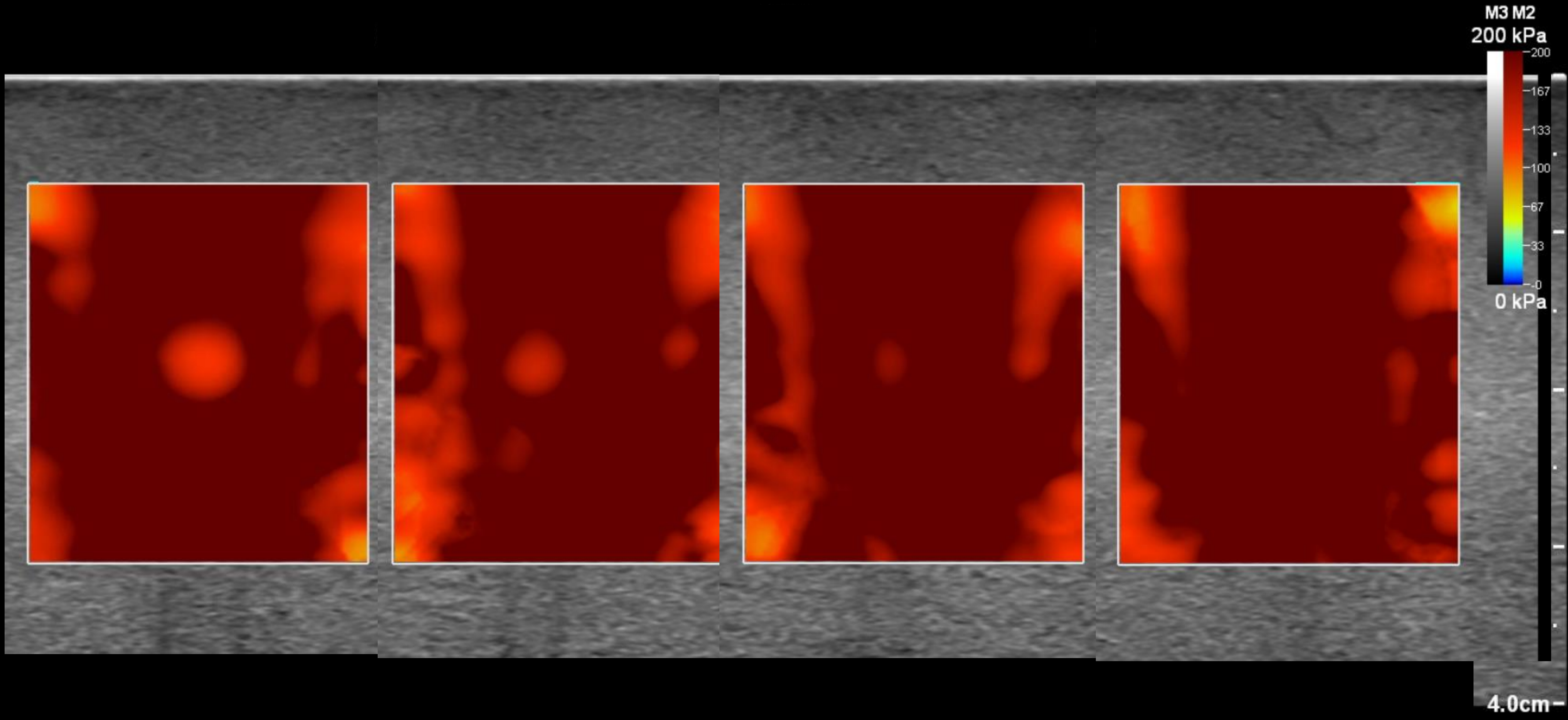
showing we care

Guy's and St Thomas' NHS Foundation Trust

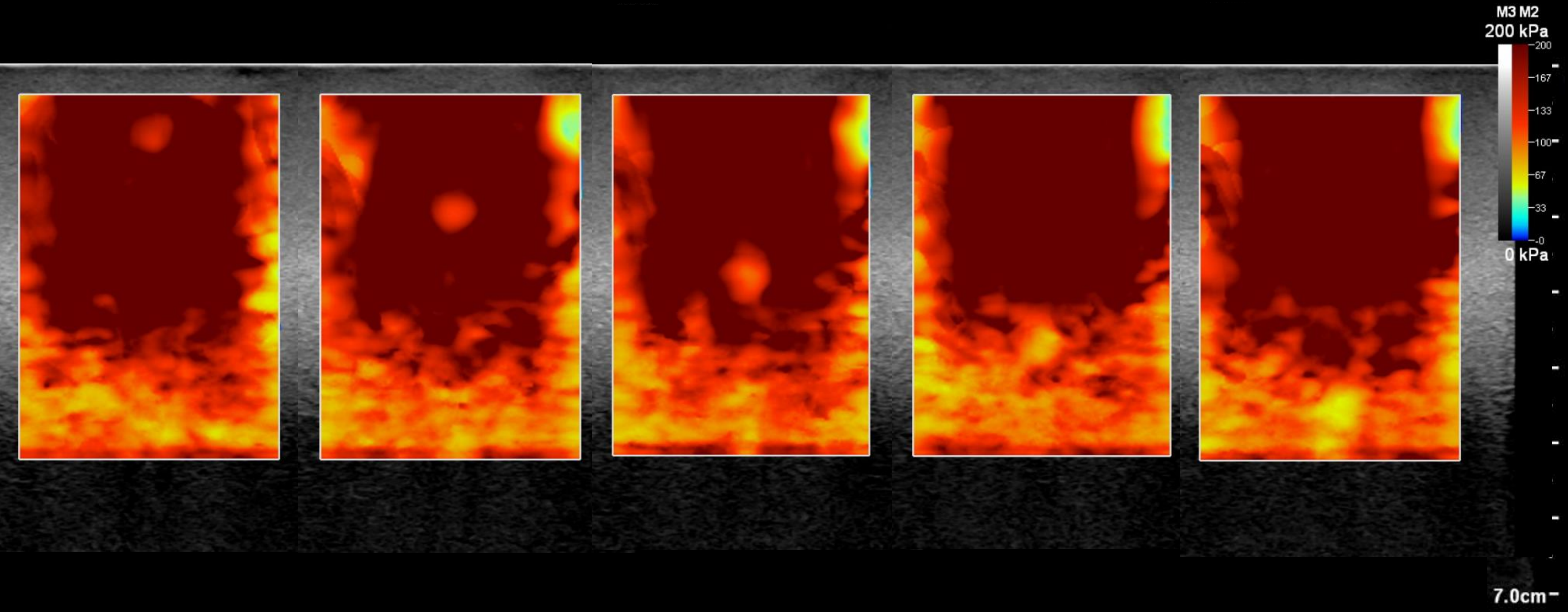
L-STEP: Assessment of spatial resolution performance

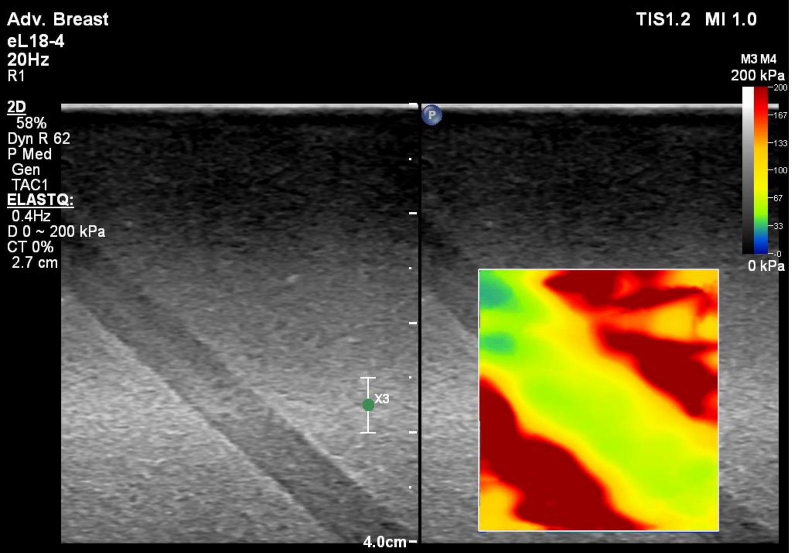


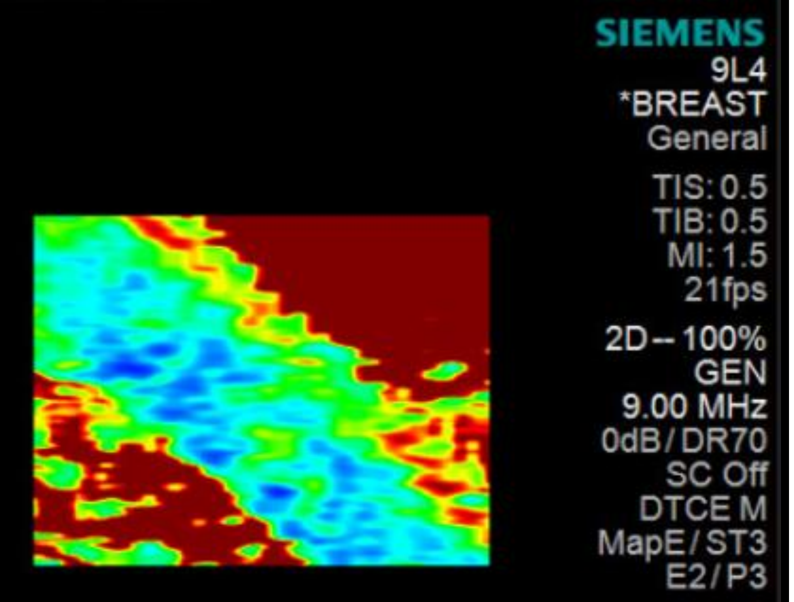
L-STEP: Assessment of spatial resolution performance



L-STEP: Assessment of sensitivity (penetration depth) and depth dependence







Shear wave elastography imaging performance of a range of scanners: A comparative study using the Leicester- St Thomas' Elastography Pipe Phantom.

Barton E[1], Amata P[2], Verdon I[1], Laureano B[1], Ambrogio S[1], Chung EML[3], Moran CM[4], C Bunton[1], Fedele F[1], Ramnarine KV[1]

NHS Guy's and St Thomas' NHS Foundation Trust

Introduction

Although clinical applications of elastography imaging techniques are expanding rapidly, the performance assessment and routine quality assurance of elastography scanners is limited. The aim of this study was firstly to develop custom image processing software to enable the quantification of all colour elastography map pixel values and second to assess and compare the elastography imaging performance of different ultrasound scanners.

Image Acquisition

Images were taken on each scanner according to a standard acquisition protocol. Shear Wave Elastography (SWE) images were acquired using optimised settings on 7 probes from 5 manufactures.

Machine	Probe	Settings
Philips Epiq Elite	eL18-4	adv. Breast
Siemens Sequoia	15L5	Breast
Siemens Sequoia	10L4	Breast
Siemens S2000	9L4	Breast Gen
Toshiba a550	LS MB	Breast
GE E10	ML6 -15	Breast Res
Supersonic Imagine Aixplorer	S15-4	Breast Pen


Internal cryogel pipes.
Pipe Diameters: 1, 2.4, 3.2. 4. 6.4, 8 mm


Completed phantom with pipes covered by agar based tissue mimicking material

We used the Leicester- St Thomas' Elastography Pipe (L-STEP) phantom [1] to acquire longitudinal and transverse images of 6 soft cryogel pipes with diameters ranging 8-1 mm which were embedded at 45° within a stiff agar tissue mimic. Custom MATLAB software was developed to quantify the RGB pixel values and extract the Young's Modulus (YM) data. Our custom software was validated by subjective comparison with the displayed colour map and by quantitative comparison of region of interest (ROI) values obtained using the scanner measurement tools. Line profiles were taken along longitudinal sections of the cryogel pipes and at a tangent to them.

Image Analysis

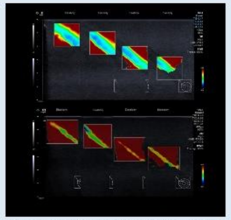
Extract colourbar information → Select profile/ Area of interest → Assign [RGB] pixels their YM value → Assess YM measurements

The Elastography colourbar is converted to RGB triplets which are then compared to the stiffness values displayed on the 2D SWE image. These images can then be sampled using standard image analysis techniques.

Parallel to Pipe

The ROIs were set to approximately 2cm²in size. 5 images were then acquired at **1cm** intervals until the SWE image fades into the background.
Line Profiles were taken along the centre of the pipe. The profiles were 3 pixels thick and averaged along their width.

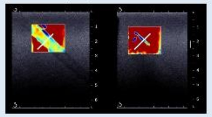
For almost all probes used in this study, the profiles taken along the smaller sized pipe give a higher Young's Modulus value than the larger Pipe
The only cases where this trend is not clear is the GE and the supersonic imagine.


An example collection of profiles across two different sized pipes.

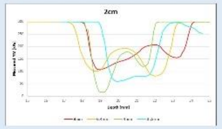
Across the Pipe

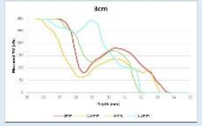
Profiles taken at 45 degrees across the pipe were taken at a depth of approximately 2cm and 3cm on the Supersonic Imagine Aixplorer.

Example of profiles



These profiles have shown a variance into how soon 2D-SWE can register a change of stiffness and the gradient of which this is displayed. Further work would be to use these profiles to investigate the spatial resolution of 2D-SWE. Previous articles, notably in breast imaging, show estimates of spatial resolution of about 1.5 mm [2]. The registration of the images is also an important factor, and the variance in the gradient of the profiles indicates investigating the Modular Transfer Function of 2D SWE would be beneficial.

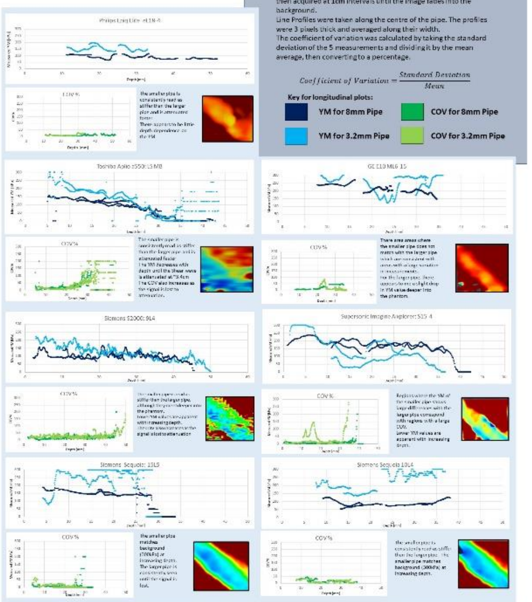




The ROIs were set to approximately 2cm² in size. 5 images were then acquired at **1cm** intervals until the image fades into the background.
Line Profiles were taken along the centre of the pipe. The profiles were 3 pixels thick and averaged along their width.
The coefficient of variation was calculated by taking the standard deviation of the 5 measurements and dividing it by the mean average, then converting to a percentage.

$$Coefficient\ of\ Variation = \frac{Standard\ Deviation}{Mean}$$

Key for longitudinal plots:
YM for 8mm Pipe — **COV for 8mm Pipe**
YM for 3.2mm Pipe — **COV for 3.2mm Pipe**



Comments:
Our image processing software enables analysis of elastography images and is more versatile than options currently available on scanners. The L-STEP phantom was able to quantify a number of image performance parameters and helped to assess and to compare the performance of different scanners.

References:
[1] Al- Mutairi et al. A Novel Elastography Phantom Prototype for Assessment of Ultrasound Elastography Imaging Performance. Ultrasound Med Biol. 2021 Sep;47(9):2749-2758
[3] Ferraioli, G. *et al.* (2022) 'How to perform shear wave elastography. part I', *Medical Ultrasonography*, 24(1), p. 95. doi:10.11152/mu-3217.

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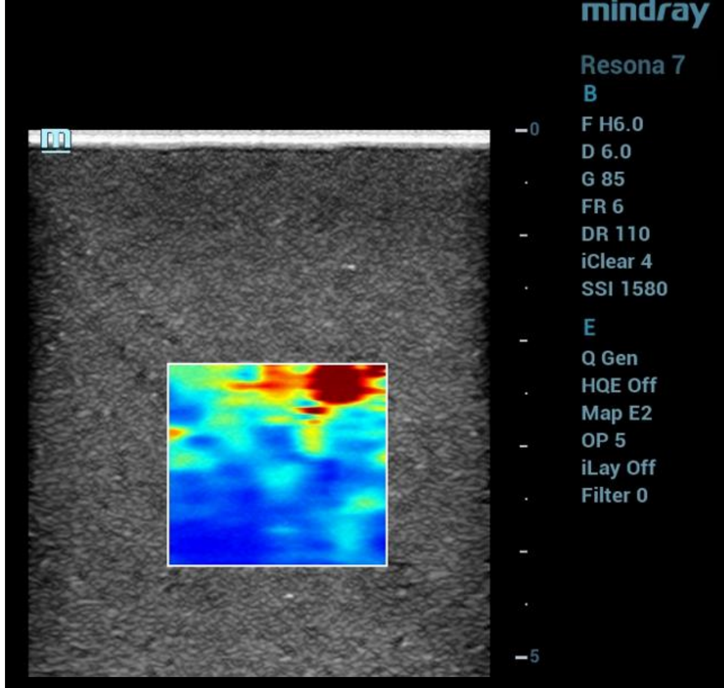
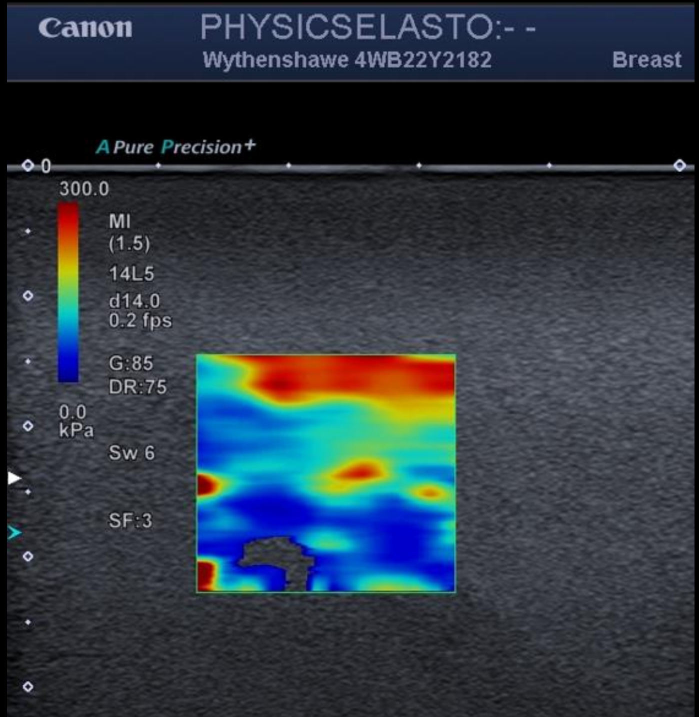
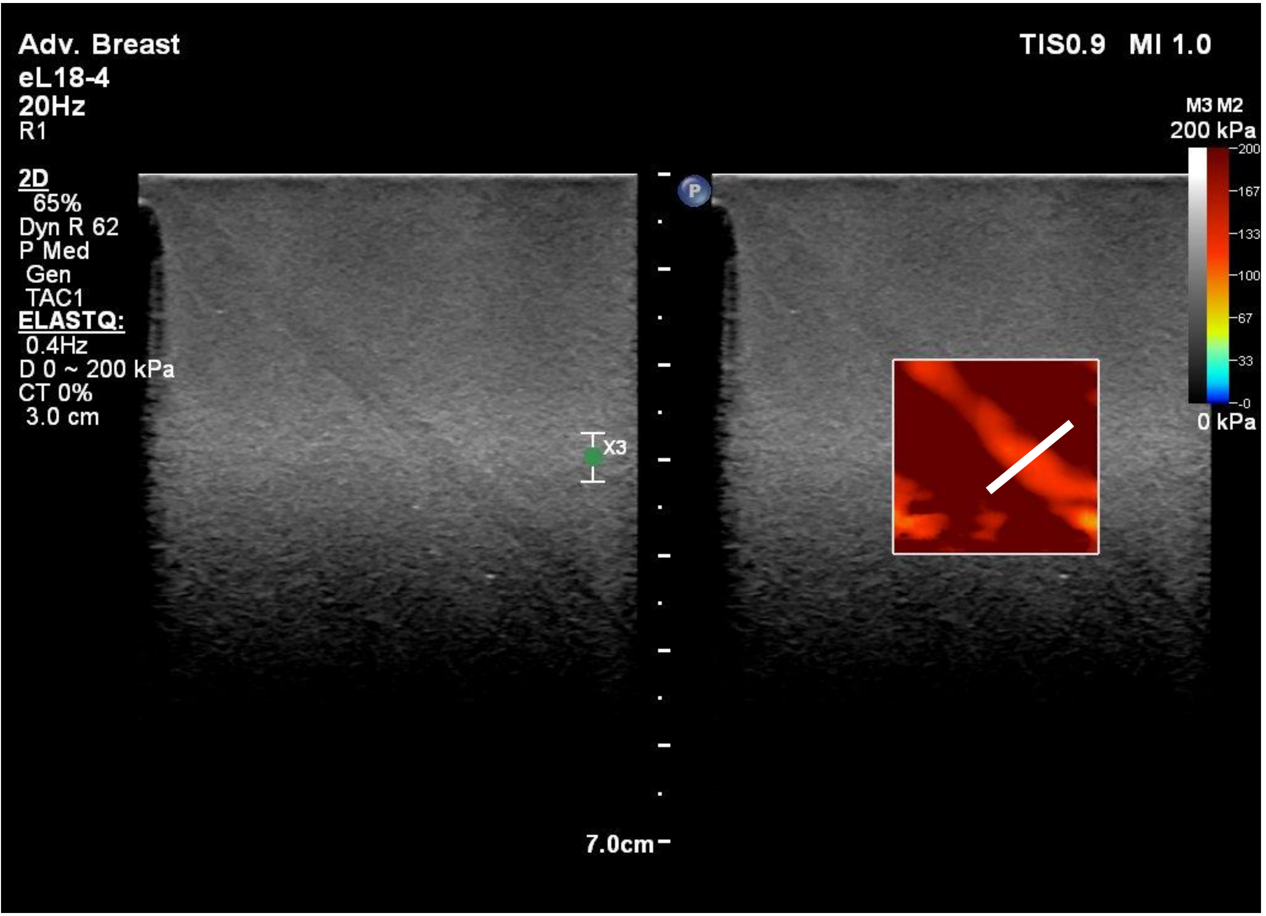
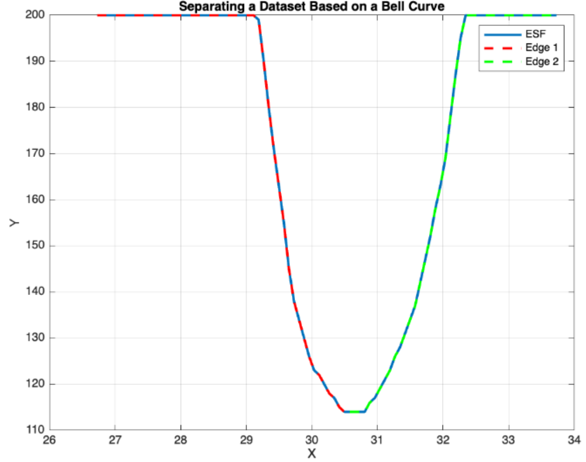
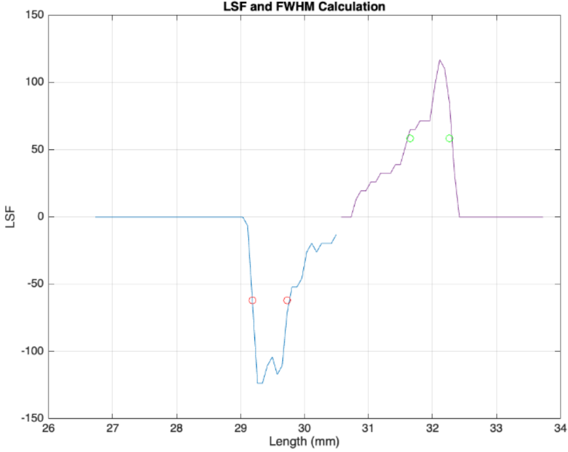


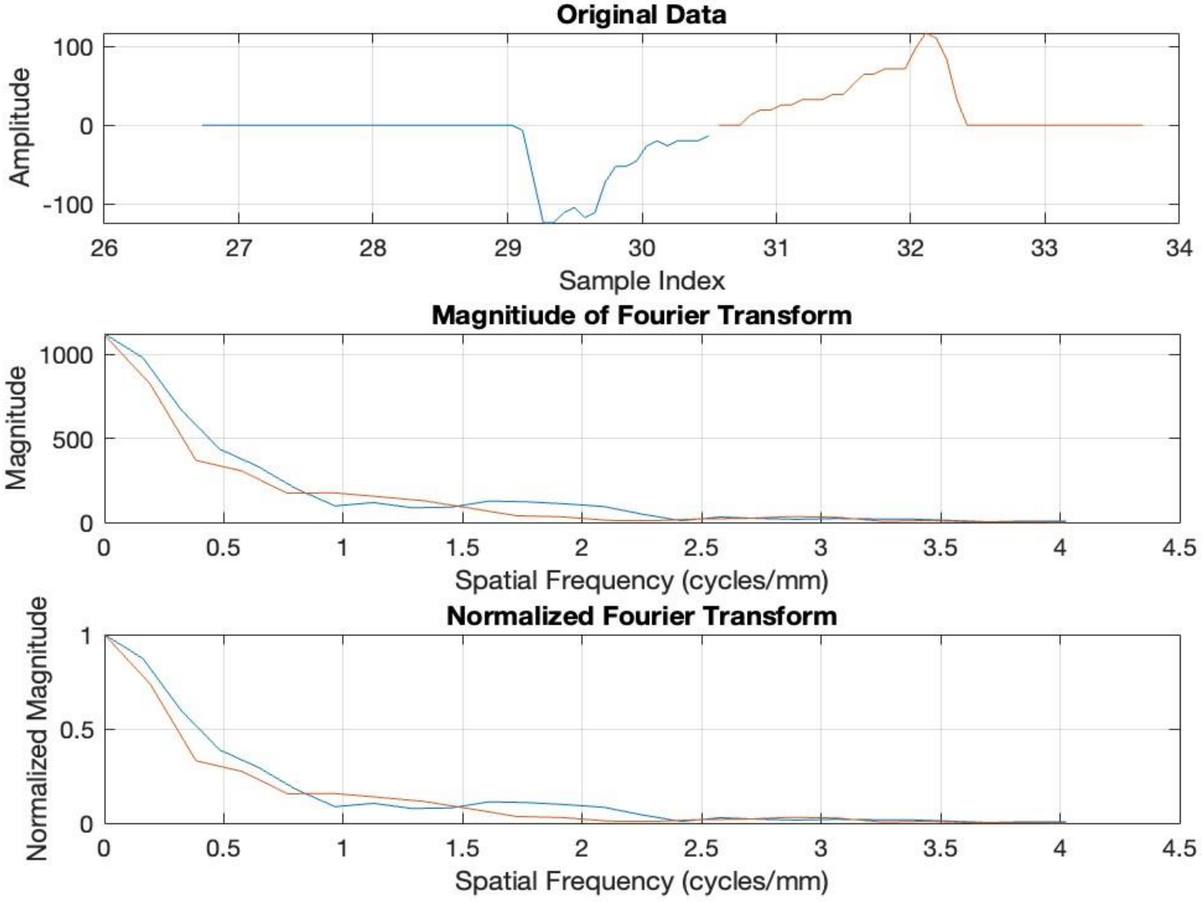


Quantifying Spatial Resolution using MTF









Edge Spread Function
Line Spread Function
Optical Transfer Function
Modulation Transfer Function

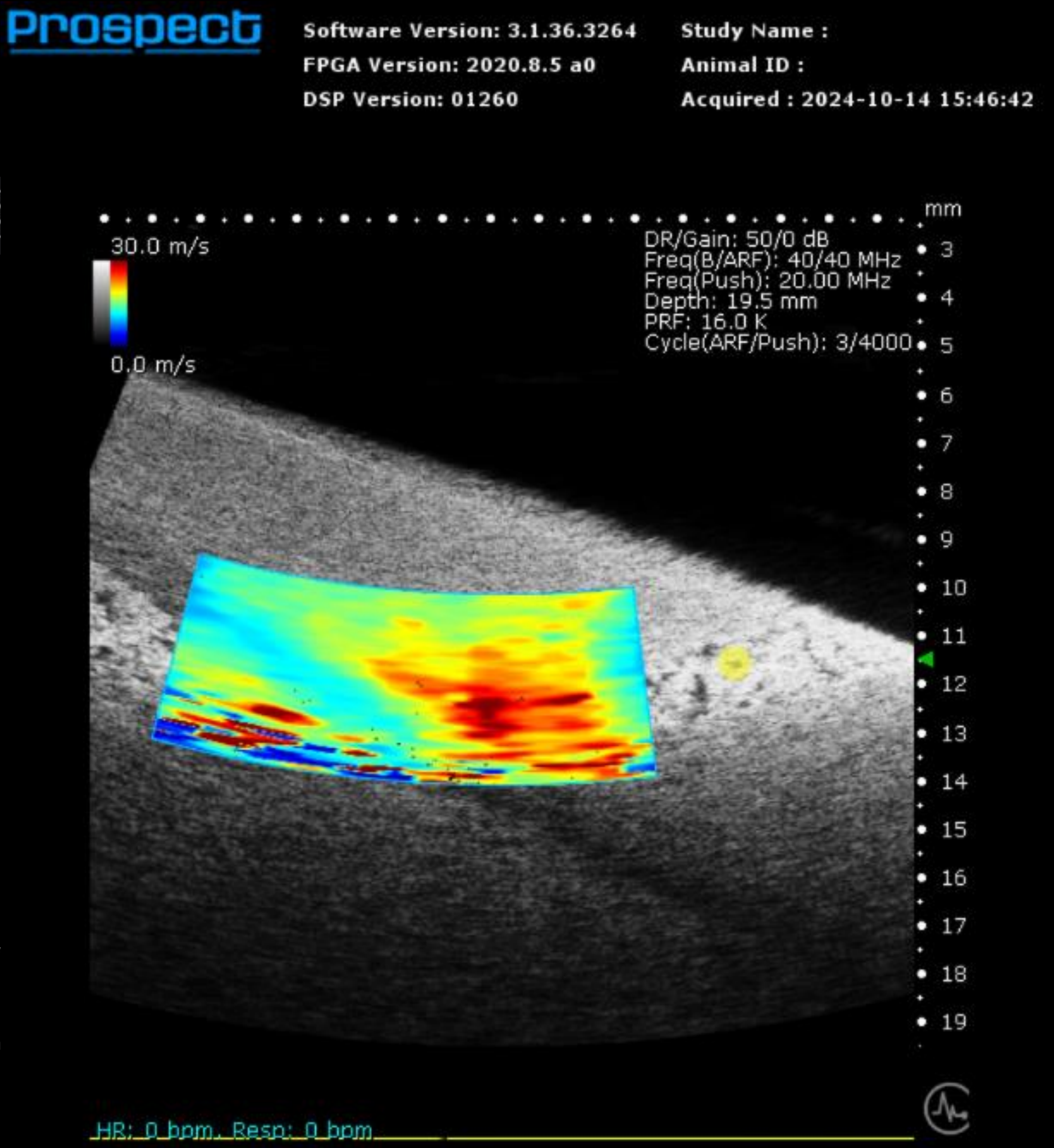
$$LSF = \frac{d(ESF)}{dx}$$

$$OTF = F(LSF)$$

$$MTF = \frac{|OTF(k)|}{|OTF(0)|}$$

Analysis courtesy of Isabella Verdon/Emma Barton

S-Sharp pre-clinical SWE scanner



Collaboration S-Sharp/GSTT/UoE Carmel Moran


SIEMENS
Healthineers
Room Air
Extract
ON
Sensitive care. Sensible choice.
Patient View
RESP

Conclusions

Ultrasound elastography:

- ✓ **Exciting development in diagnostic ultrasound**
  - ✓ Provides new information on tissue stiffness
  - ✓ Considerable clinical interest and potential
  - ✓ Many clinical applications
  - ✓ Easy to implement new ultrasound techniques into the routine clinic
- ✓ **Elastography phantoms and test objects needed**
  - ✓ For R&D
  - ✓ For performance testing
  - ✓ For USQA
  - ✓ For teaching and training

What are you measuring?.........How?

EFSUMB Guidelines and Recommendations on the Clinical Use of Ultrasound Elastography. Part 1: Basic Principles and Technology

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EFSUMB Guidelines and Recommendations on the Clinical Use of Liver Ultrasound Elastography, Update 2017 (Long Version)

EFSUMB-Leitlinien und Empfehlungen zur klinischen Anwendung der Leberelastographie, Update 2017 (Langversion)

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The EFSUMB Guidelines and Recommendations for the Clinical Practice of Elastography in Non-Hepatic Applications: Update 2018

Die EFSUMB-Leitlinien und Empfehlungen für die klinische Praxis der Elastografie bei nichthepatischen Anwendungen: Update 2018

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The NHS Constitution:

“The NHS belongs to all of us. It is there to improve our health and well-being, supporting us to keep mentally and physically well, to get better when we are ill and, when we can’t fully recover, to stay as well as we can to the end of our lives. ***It works at the limits of science, bringing the highest levels of human knowledge and skill to save lives and improve health”***