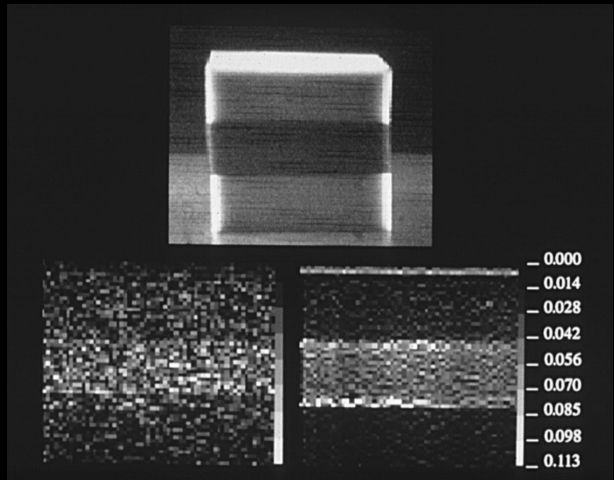
2012 :15th SESSION of ESMP

Lecture presented in Archamps (Salève Building) by :

Jean-Martial MARI (INSERM Lyon)

Elastography

Tissue Elasticity Imaging



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Elasticity Imaging

- Stiffness related to Pathological State
- Palpation
  - Useful, but subjective & low depth
- Ultrasound
  - Real-time, high resolution, inexpensive

Elasticity Imaging

- Stiffness
  - Linear isotropic elastic solid: 2 constants !
    - Young's modulus (*E*)
    - Poisson's ratio (ν)
  - General case more complicated
    - Anisotropy: Fibre orientation
      - Up to 36 coefficients
    - Non-linearity: Strain-dependent E(ε)
    - Viscosity: Frequency-dependent E(*f*)
    - Porosity: Liquid-filled matrix

Elasticity Imaging

- Direct stiffness measurement
  – No modality available
- Indirect stiffness measurement
  – Apply a controlled load
    - Static stress, shear wave, …
  – Measure the tissue response
    - Static strain, wave speed & amplitude, …
  – Infer the elastic properties (optional ?)

Elasticity Imaging

- Short review of ultrasonic techniques
  - Sono-Elasticity Lerner 1990
  - Elastography Ophir 1991
  - Vibro-acoustography Fatemi 1998
  - Transient Elastography Sandrin 1999
  - Acoustic Radiation Force Imaging (ARFI) Nightingale 2001

Ultrasonic Elastography

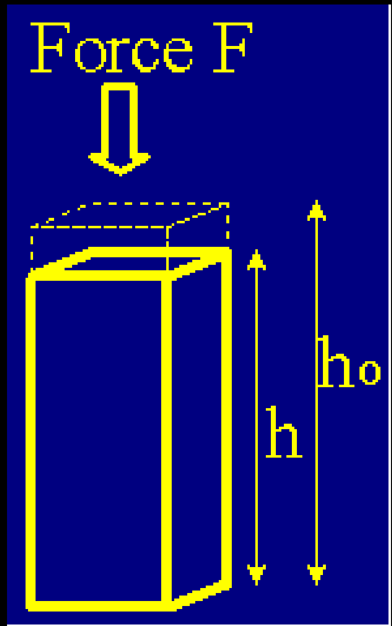
(Strain Imaging)

Ultrasonic Elastography
Ophir et al. 1991

- Definition: A Strain Imaging technique
- Strain is the relative deformation of an object undergoing compression (or expansion)

  ε = Change in Length / Original Length

  $\varepsilon = (h-h_o)/h_o$



Ultrasonic Elastography

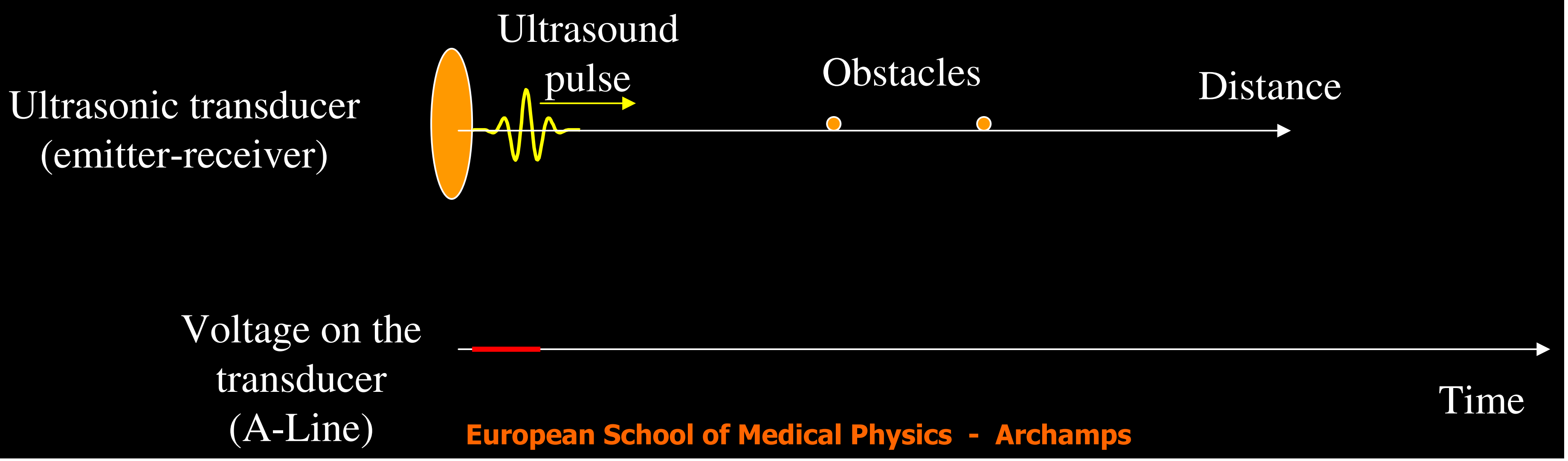
- Strain is related to tissue stiffness
  - Assuming a linear isotropic elastic medium :

$$\varepsilon = \sigma / E$$

    - ε = Strain (dimensionless)
    - σ = Stress (Pascal) = Force / Area
    - E = Young's Modulus (Pascal)
- Stiff Tissues (Large E) $\Leftrightarrow$ Low Strains
- Soft Tissues (Small E) $\Leftrightarrow$ High Strains

Ultrasonic Elastography

- Principle
  - Based on A-mode pulse-echo



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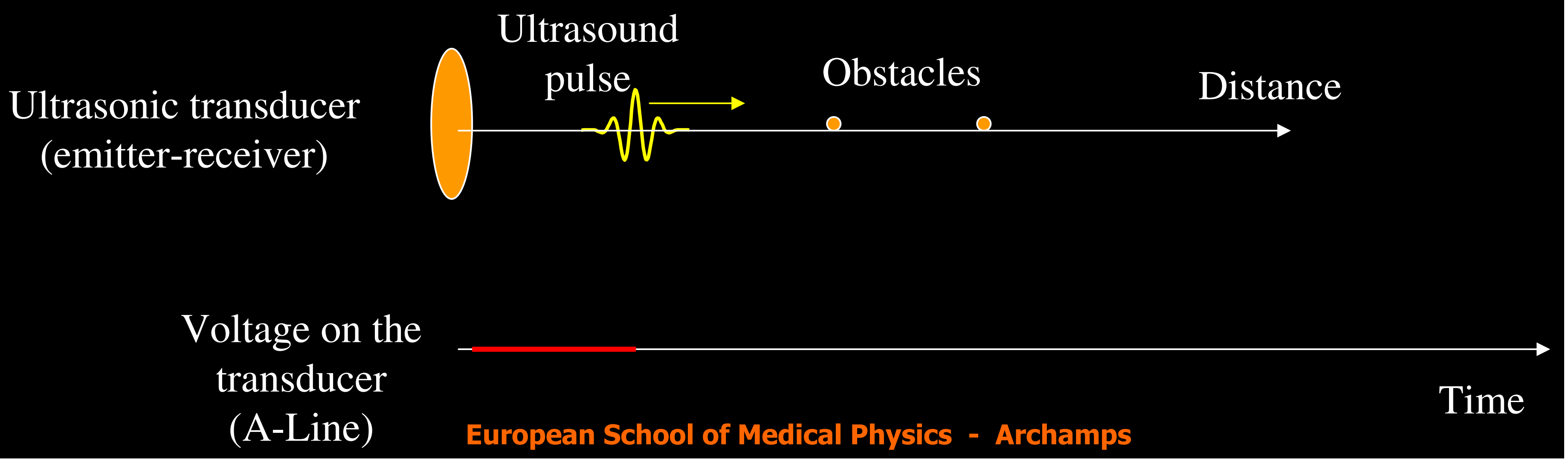

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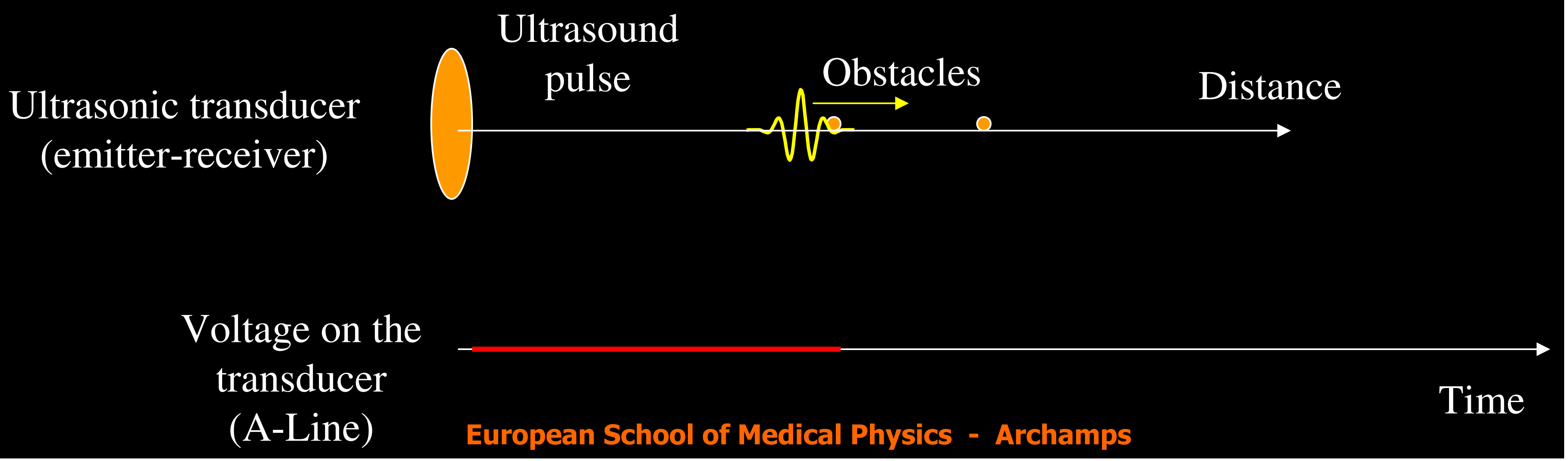

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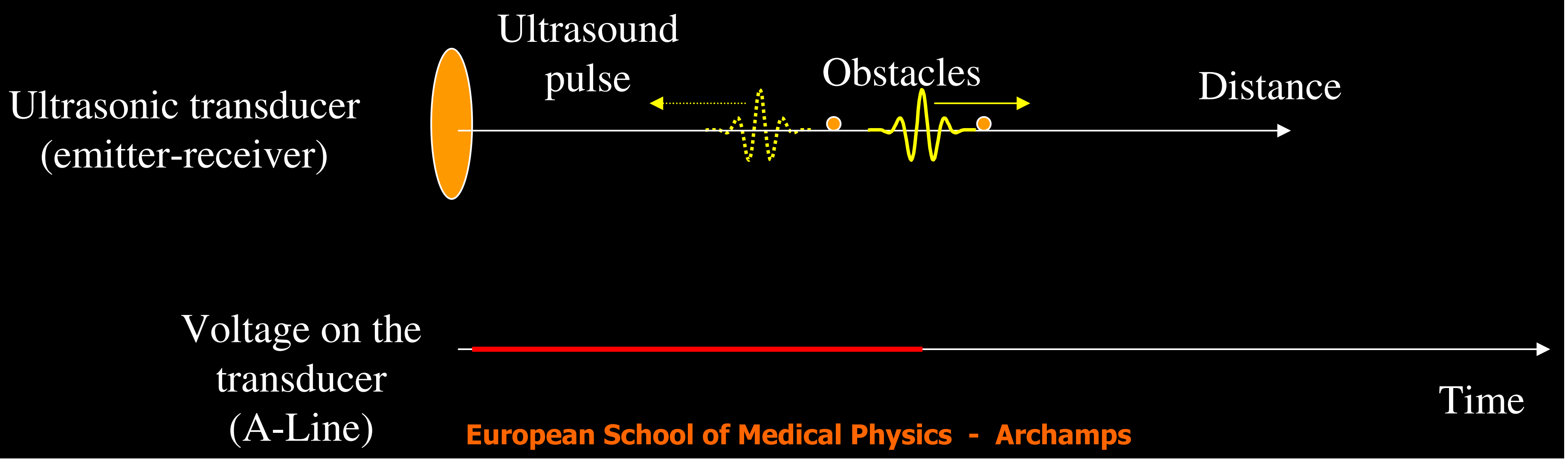

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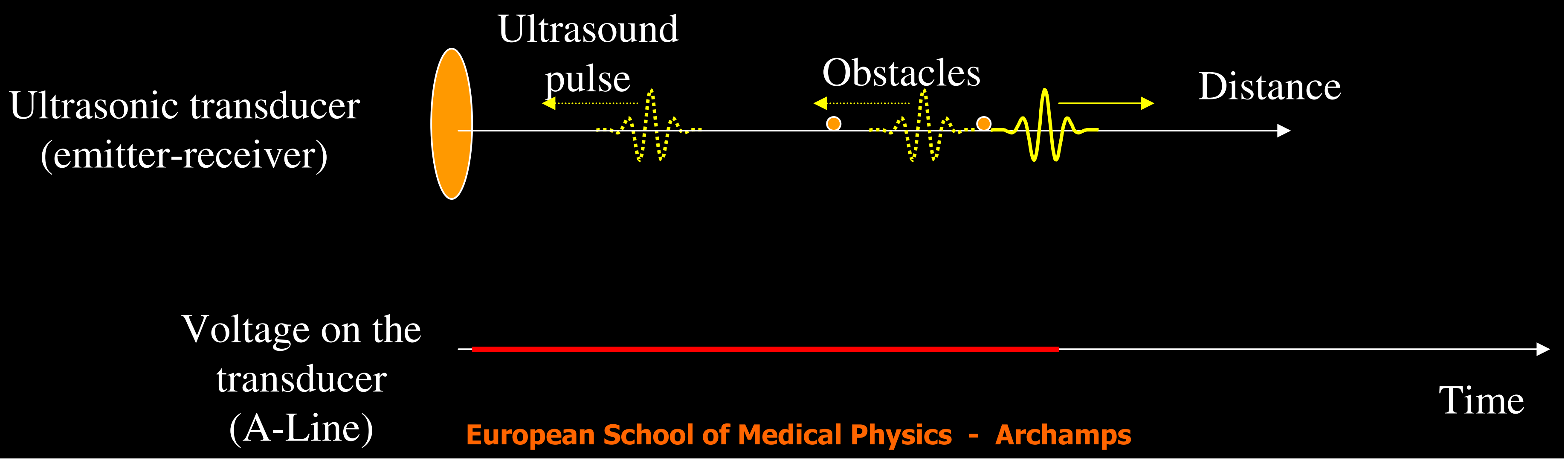

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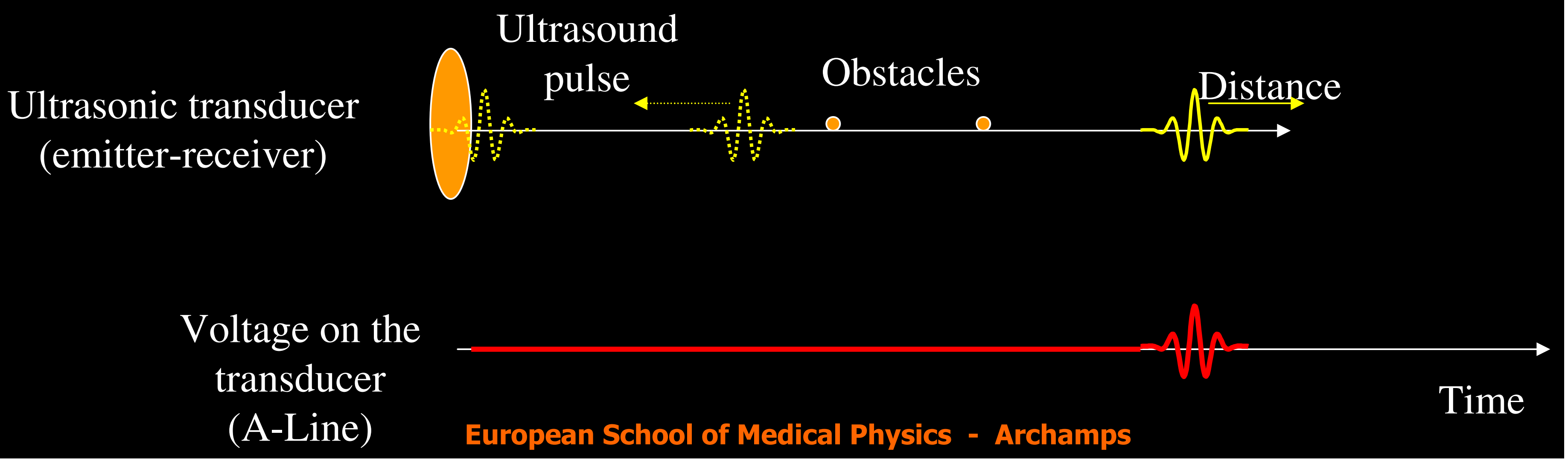

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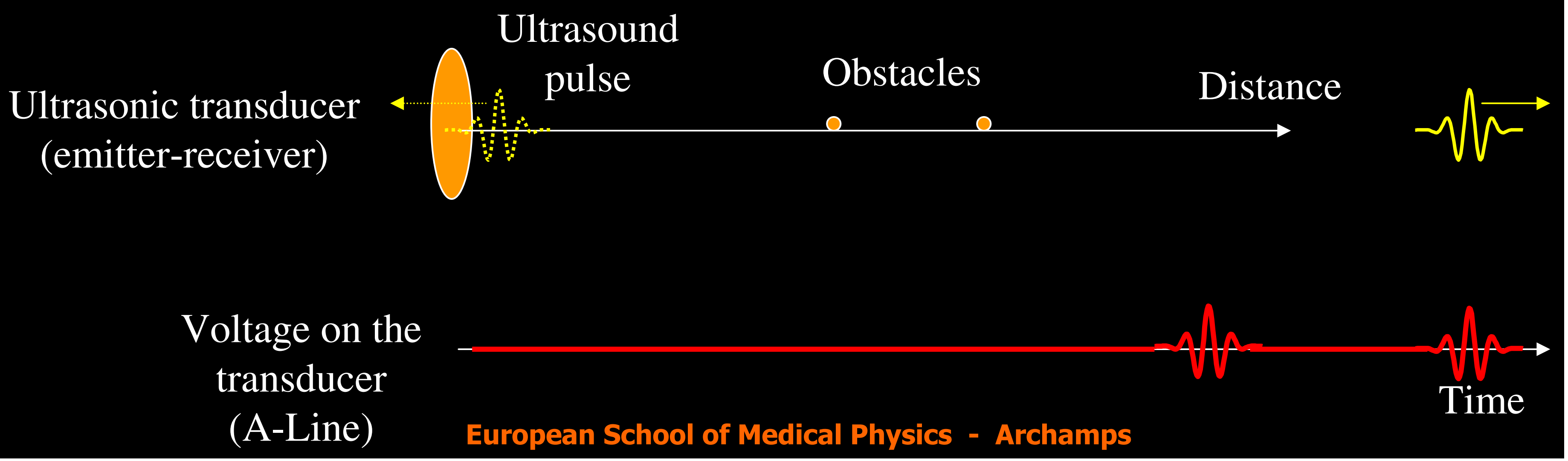

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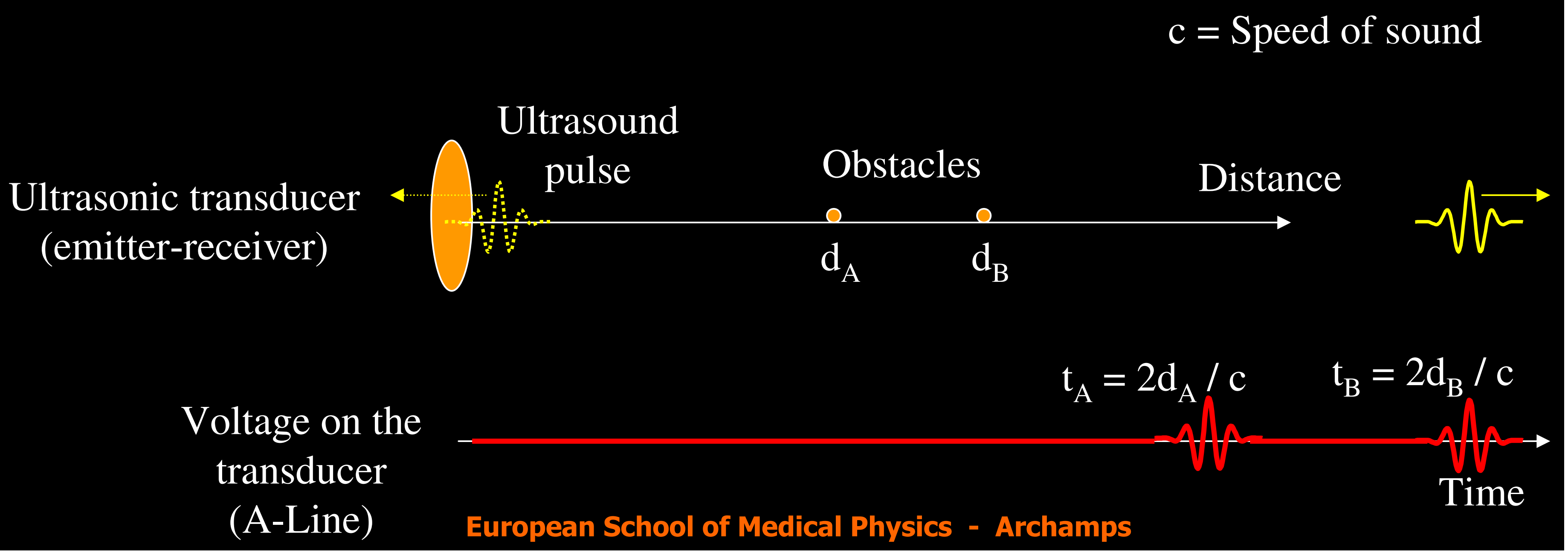

Ultrasonic Elastography

- Principle: Displacement estimation

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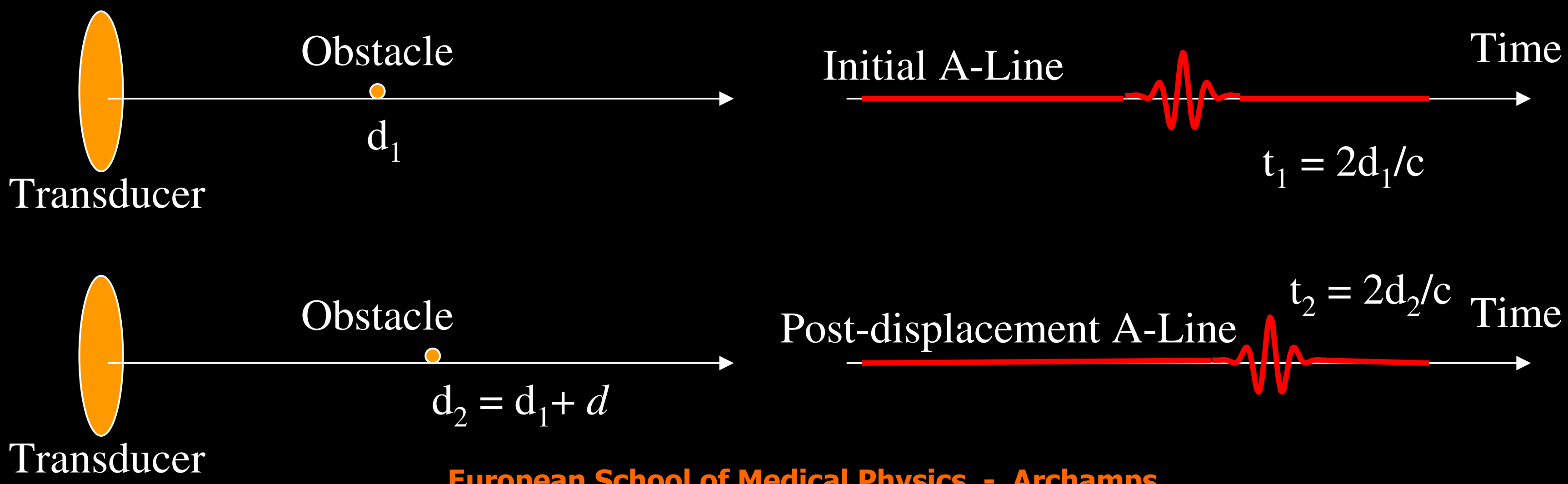
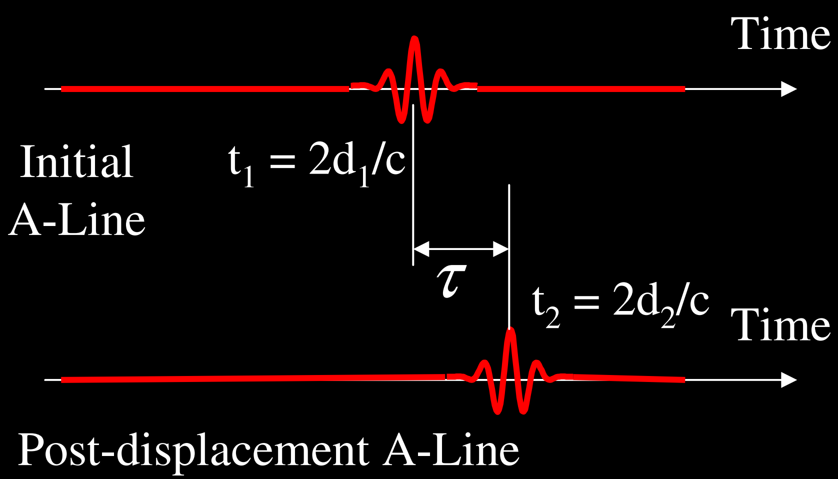


Ultrasonic Elastography

- Principle: Displacement estimation
  - from time-delay estimates t_1 & t_2

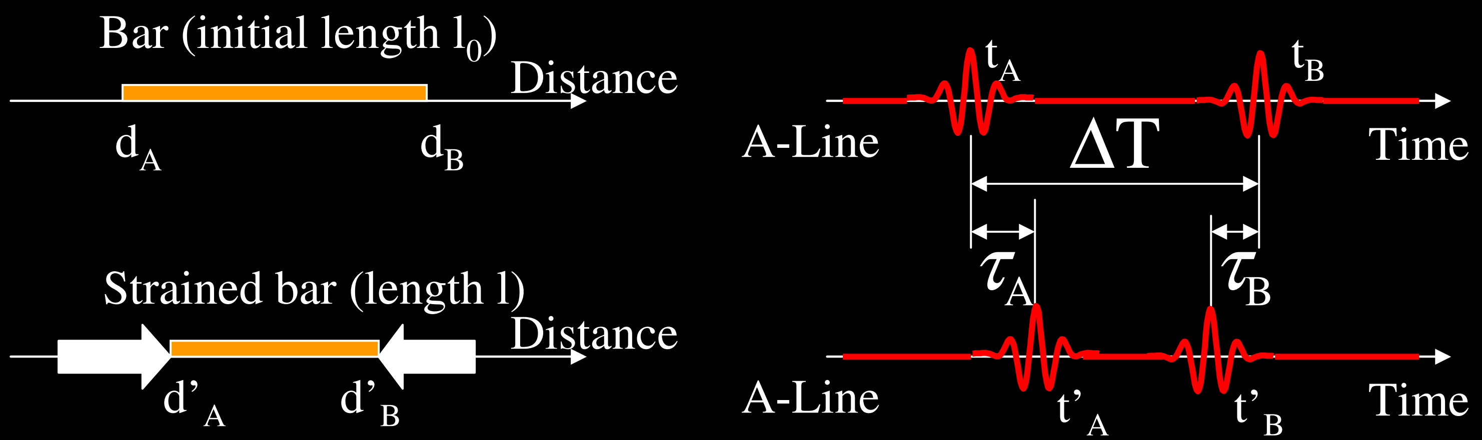
$$d = \frac{c\tau}{2}$$

avec $\tau = t_2 - t_1$



Ultrasonic Elastography

- Principle: Strain estimation



$$l_0 = \frac{c}{2}(t_B - t_A)$$

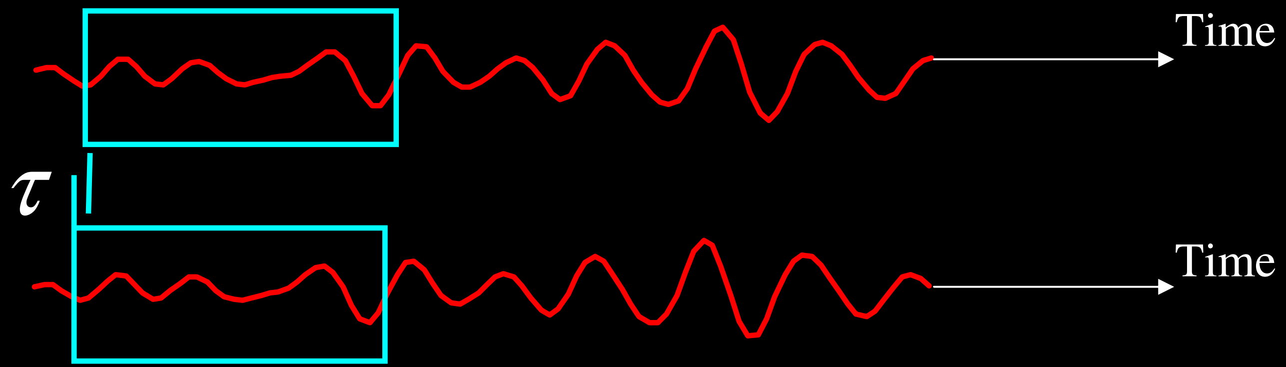
$$l = \frac{c}{2}(t'_B - t'_A)$$

Strain is the relative deformation: $\varepsilon = \frac{l - l_0}{l_0} = \frac{\tau_B - \tau_A}{\Delta T}$

Ultrasonic Elastography

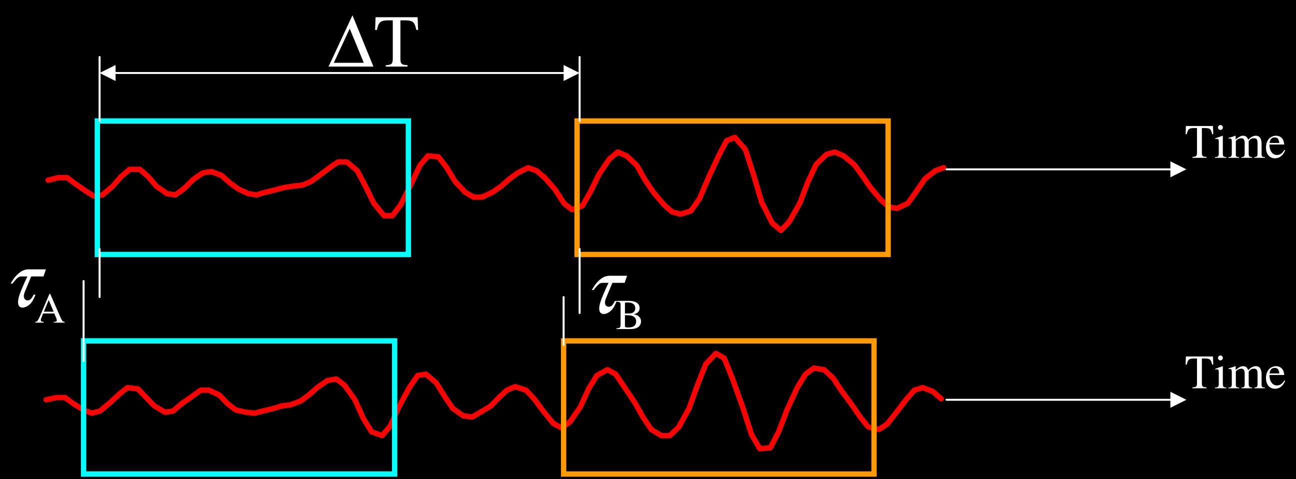
- Principle: Strain estimation
  - In practice individual echoes overlap

- Time-delay estimation based on window match



Ultrasonic Elastography

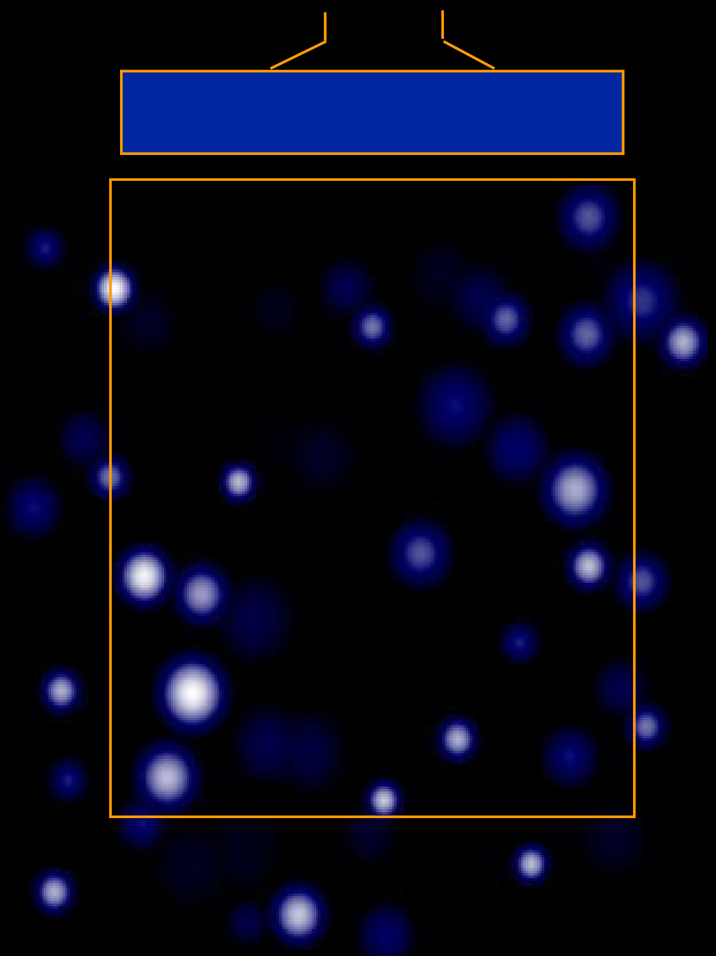
- Principle: Strain estimation
  - In practice individual echoes overlap
    - Strain estimation



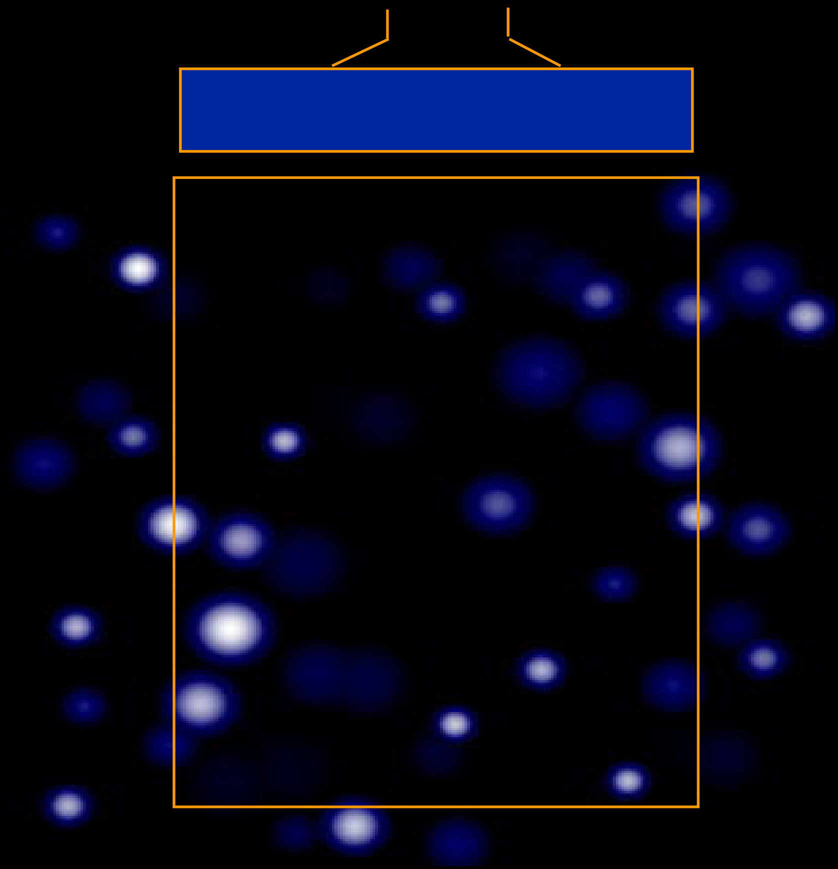
J. Ophir

Tissue Compression Model

Two-dimensional representation/ perfect-slip conditions



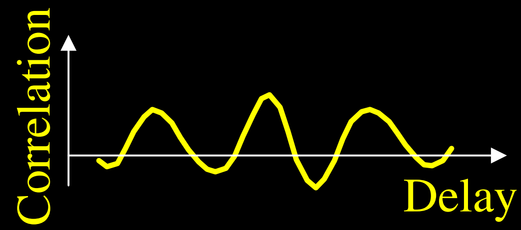
Before compression



After compression

J. Ophir

Elastographic Image Quality



- 3 Types of errors (Walker 1995)
  - False Peaks : large but detectable
    - Large discontinuity errors (typically multiple of λ)
    - Associated with severe decorrelation (typ. < 0.7)
    - Easily identified & removed
  - Jitter : the fundamental limit
    - Uncertainty in TDE (Weinstein 1984)
    - Small errors (typically +/- 1 µm)
    - Not detectable
  - Processing : Interpolation Errors
    - Correlation peak between two samples
    - Systematic bias (Cespedes 1995)

Elastographic Image Quality

- 3 Sources of Errors
  - Strain !
  - Sonographic SNR
  - Out-of-beam Motion

Elastographic Image Quality

- Signal-to-noise ratio (*SNRe*)

$$SNRe = \pi\varepsilon T\sqrt{\Delta T}\sqrt{\frac{(B^3 + 12Bf_o^2)}{3\left[\frac{1}{\rho^2}\left(1+\frac{1}{SNRs^2}\right)^2 - 1\right]}}$$

- Axial Resolution (R_a)

$$R_a = k.\max(T + \Delta T; Pulse\ duration)$$

- Lateral Resolution (R_l)

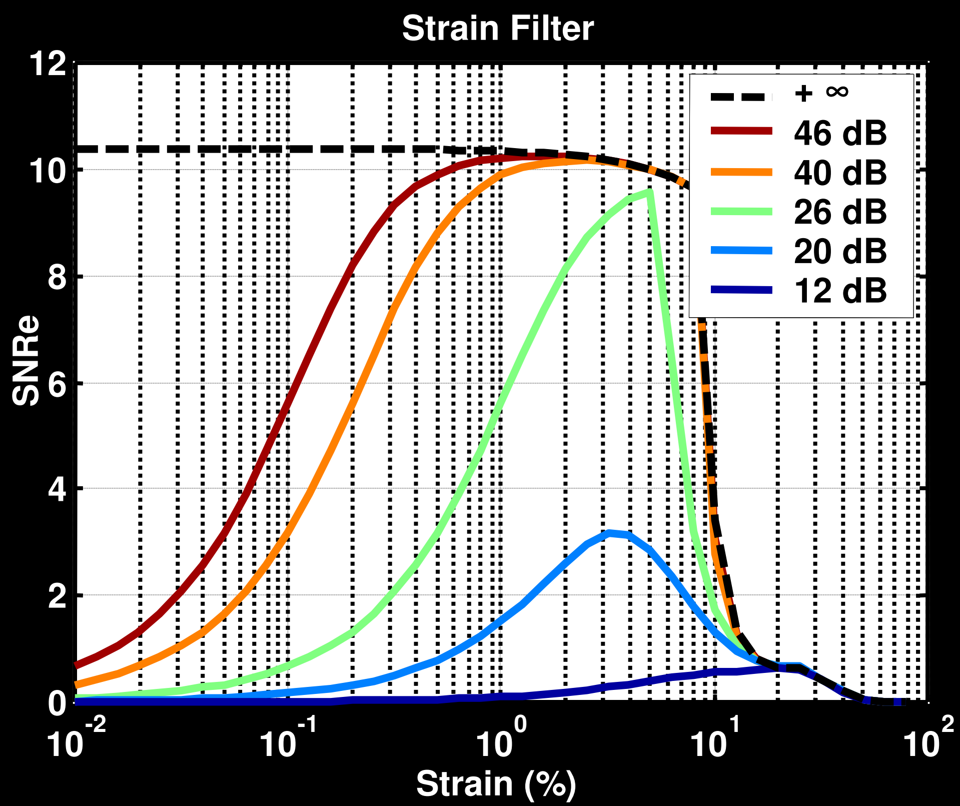
$$R_l = \max(Pitch; Beam\ Width)$$

B	RF signal bandwidth
f_0	Central frequency
T	Window size
ΔT	Window shift
ρ	Cross-corr. coeff.
$SNRs$	Sonographic SNR
ε	Strain
k	Constant

Ref: Walker 1995, Varghese 1997, Righetti 2002 & 2003, Srinivasan 2003

Elastographic Image Quality

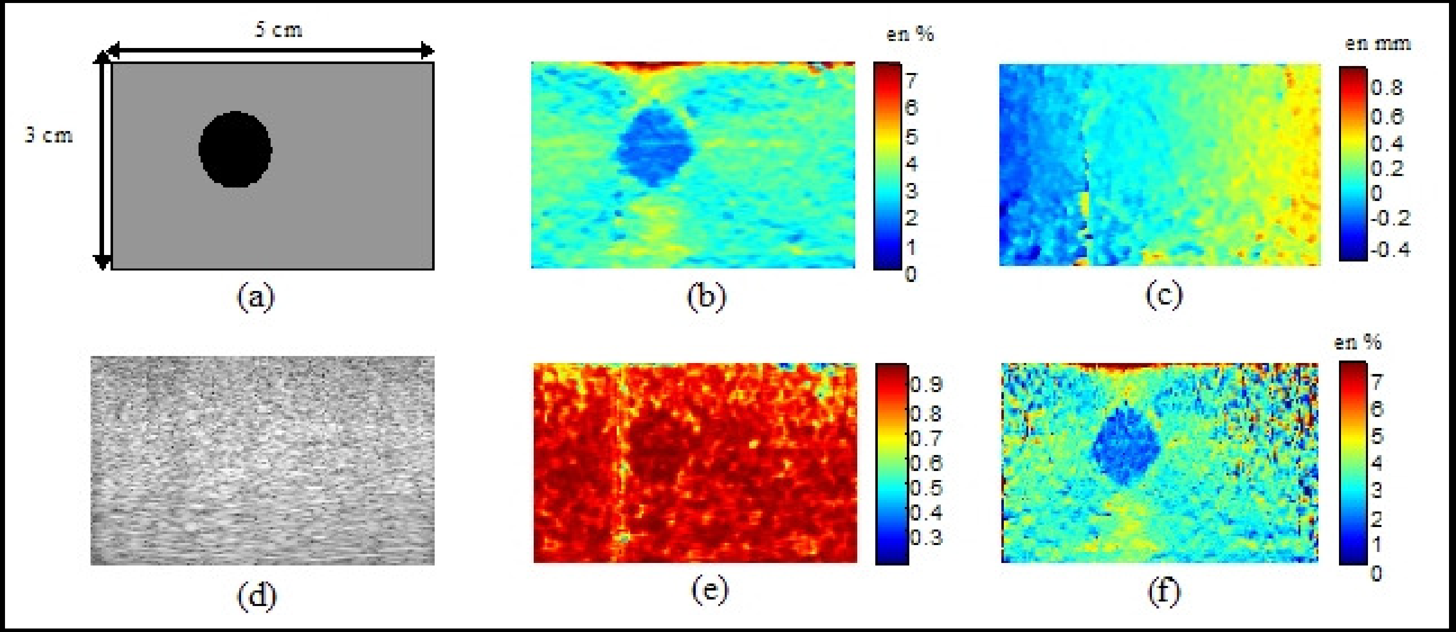
- The Strain Filter (Varghese 1997)



In vivo difficulties:

- Uncontrolled Motion
  - Respiratory
  - Cardiac
  - Patient
- Requirement
  - Fast Acquisition

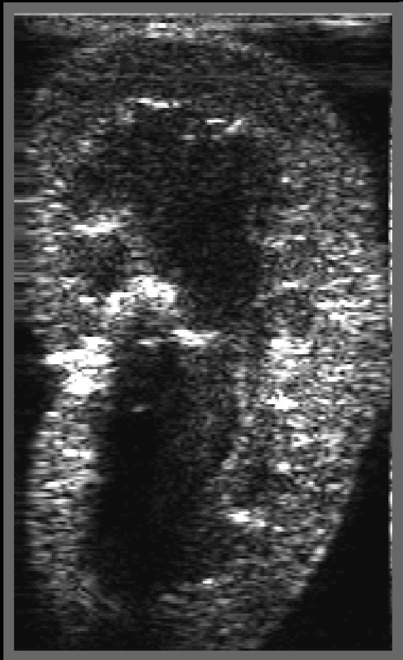
Basic example: wonders of elastography



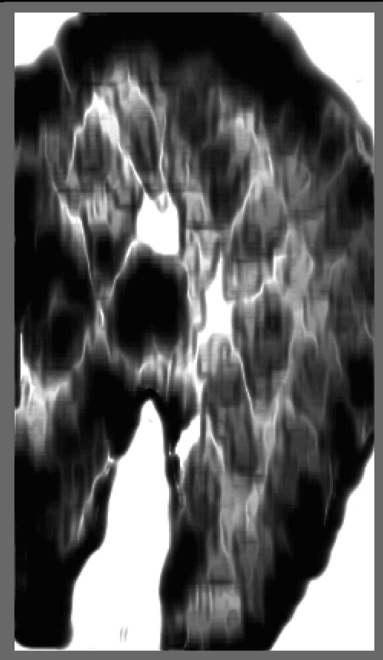
Result of the 2D algorithm for estimating the deformation of a test object made of soft cryogel containing a harder cylindrical inclusion. (a) diagram of the medium to be characterized, (b) axial deformations in %, (c) lateral displacements in mm, (d) standard ultrasound image, (e) maps of the correlation coefficients between the initial image deformed locally compensated for by the estimated deformation parameters, (f) axial deformations estimated with a mono-dimensional method.

Creatis, Lyon

Example: Ovine Kidney in vitro

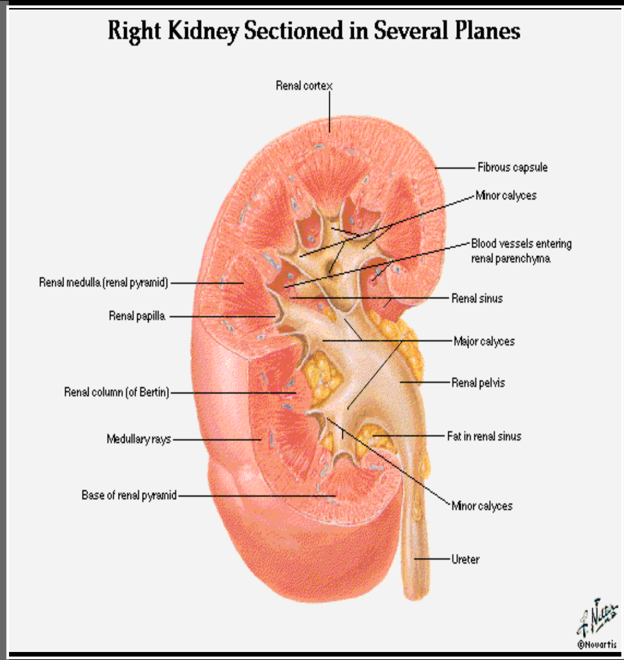


Sonogram



Elastogram

Photograph



Anatomy

Kallel & Ophir 97

Conclusion

- New & Clinically Important Information on Normal and Pathologic Tissues
- Breast, Prostate, Liver, Vasculature, Thyroid, Therapy Monitoring and Follow-Up
- Today, at least 3 major ultrasound companies are at various stages of commercializing a machine
- Happy birthday Elastography !

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  - University of Texas Medical School, Houston, Texas, USA
  - www.elastography.com

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Elastography

Tissue Elasticity Imaging

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References

Methods (Elastography)

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Methods (Sono-elasticity & Others)

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  - Yamakoshi et al., IEEE UFFC 37(2) (1990)
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References

Applications (Elastography)

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- Intravascular Elasticity Imaging using Ultrasound - Feasibility Studies in Phantoms
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- A New System for the Acquisition of Ultrasonic Multicompression Strain Images of the Human Prostate In Vivo
  - Lorenz et al., IEEE UFFC 46(5) (1999)
- Elastographic Characterization of HIFU-Induced Lesions in Canine Livers
  - Righetti et al., UMB 25(7) (1999)
- Visualisation of HIFU lesions using elastography of the human prostate in vivo: Preliminary results
  - Souchon et al., UMB 29(7) (2003)

References

Applications (Sono-elasticity & Others)

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- Reconstructive ultrasound elasticity imaging for renal transplant diagnosis : kidney ex vivo results
  - Emelianov et al., Ultrasonic Imaging 22(3) (2000)
- Sonoelasticity Imaging of Prostate Cancer : in vitro Results
  - Rubens et al., Radiology 195 (1995)
- Detection of high-intensity focused ultrasound liver lesions using dynamic elastometry
  - Shi et al., Ultrasonic Imaging 21 (1999)

Web Sites

www.elastography.com

University of Texas in Houston

J. Ophir

www.lp-it.de/LP-IT-strainImaging.html

Real-Time Strain Imaging of the Human Prostate

A. Lorenz & A. Pesavento