

New Technologies in Acoustical Tissue Characterization: Methods Using Acoustic Radiation Force

Dr. Kathy Nightingale

Department of Biomedical Engineering
Duke University

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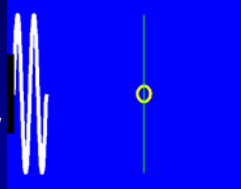
Acoustic Radiation Force
Force generated by a transfer of momentum from an acoustic wave to the medium through which it is propagating, caused by absorption (predominantly) and scattering in soft tissue. Force magnitude typically $\sim 3 \text{ g/cm}^3$

$$F = \frac{2\alpha I_{ta}}{c}$$

α = absorption coefficient

I_{ta} = temporal average intensity

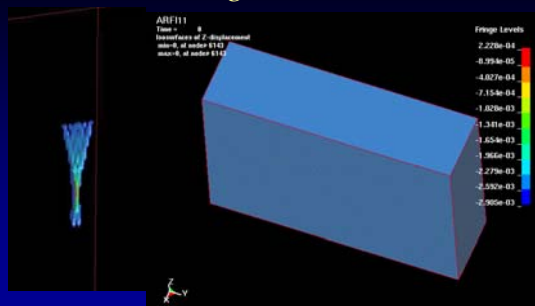
c = speed of sound



Nyborg, W. *Acoustic Streaming*, in *Physical Acoustics* Vol. IIB, editor: Mason W.P., Academic Press, 1965.

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FEM: Homogeneous Medium



$$F = \frac{2\alpha I_{ta}}{c}$$

$\mu = 1 \text{ kPa}$, movie duration = 10 ms

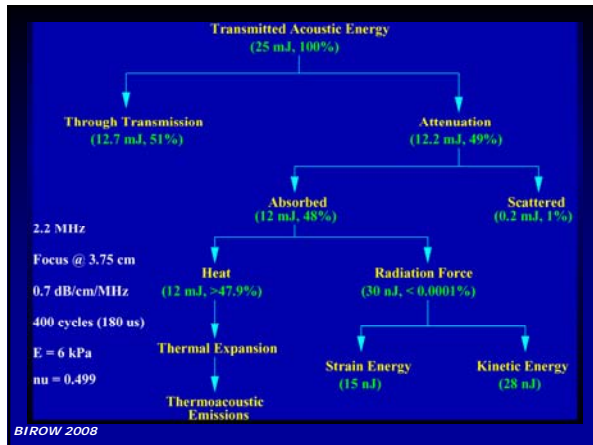
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1. Palmeri et al. "A finite element method model of soft tissue response to impulsive acoustic radiation force". *IEEE UFFC*, 53(10):1699-1712, 2005.

Laboratories investigating Radiation Force Based Imaging Methods:

Sugimoto et al, 1990	Bercoff, Fink, Tanter, et al., 2004
Sarvazyan et al, 1998	Emelianov et al, 2004
Fatemi and Greenleaf, 1998	Barannik et al 2004
Nightingale and Trahey, 2000	Bamber and Duck, 2006
Walker et al, 2000	Gallippi et al, 2006
Negron et al 2002	McLaughlin et al, 2006
Lizzi et al, 2002	McAleavey et al, 2007
Konofagou et al, 2002	Parker et al, 2007
Calle et al, 2003	McDannold et al, 2007

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Occurs with all wave propagation in soft tissue, but requires increased intensity to generate displacements on the order of microns; can be achieved with either diagnostic or HIFU transducers

Typical excitation:

Frequency = 2-6 MHz

Intensity (sppa_s, linear) = 1500 - 3000 W/cm²

Mechanical Index_s = 1.5-3.0

Duration < 1 msec

Temperature rise = 0.03-0.1 °C

Tissue Displacement = 10-15 μm

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Provides localized, focused, internal, mechanical (and thermal) excitation of tissue. What can we do with this?

- Manipulate contrast agents
- Interrogate tissue elasticity

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Elasticity Imaging with Acoustic Radiation Force

Use focused, high intensity, acoustic beams to mechanically excite (push) tissue, and track the resulting tissue response with:

- Ultrasound (most groups) - correlation based displacement estimation methods - tracks displacements to within 0.5 microns axially
 - Can use the same transducer to push and track
- MRI

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Making Images?

Images of relative differences in tissue displacement response:

- Look where you push
- Provides structural information
- Lesion visualization, ablation monitoring

Quantify speed of propagating shear waves, and compute an elastic modulus (Sarvazyan, Fink):

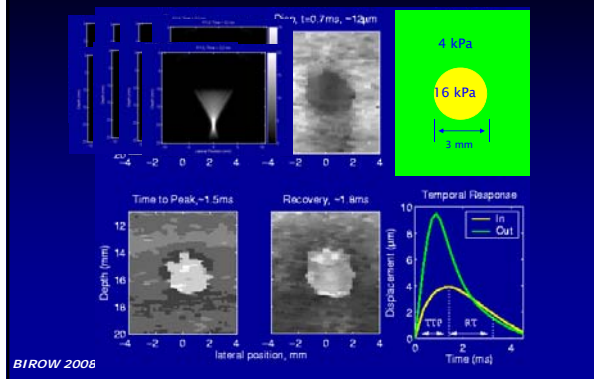
- Look outside ROE, watch wave propagate through
- Facilitates longitudinal monitoring of disease progression (i.e. liver fibrosis)

Excite the tissue at specific frequencies with radiation force, evaluate tissue viscoelasticity (Greenleaf):

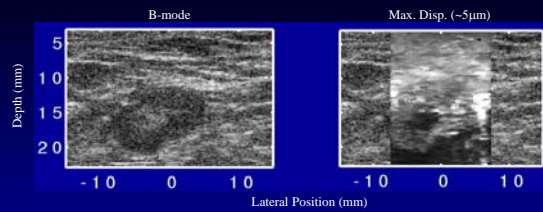
- Can use amplitude modulation to 'drive' tissue at different frequencies with radiation force, evaluate viscoelastic behavior

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Look where you push:



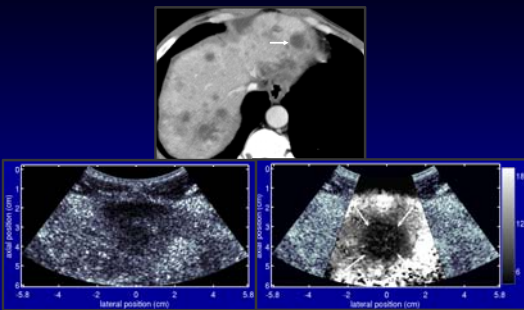
In vivo Breast Lymph Node (Reactive, Benign)



Palmeri ML, Zhai L, Frinkley KD, Gottfried M, Bentley RC, Ludwig K, Nightingale KR. "Acoustic Radiation Force Impulse (ARFI) imaging of the gastrointestinal tract", *Ultrasonic Imaging*, 27:75-88, 2005.

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In vivo Liver Metastasis



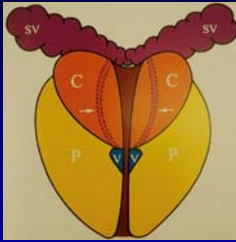
Fahey B, Nelson R, Bradway D, Hsu S, Dumont D, Trahey G. In vivo visualization of abdominal malignancies with acoustic radiation force elastography *Phys. Med. Biol.* 53 (2008) 279-293

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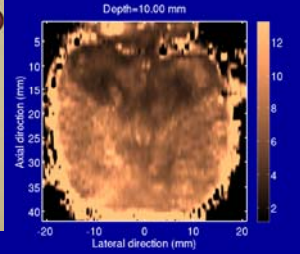
Ex vivo Prostate Anatomic structures

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McNeal's Zonal Sketches



ARFI Coronal Image

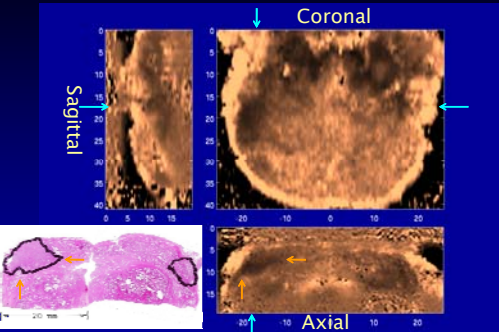


Zhai L, Madden J, Mouraviev V, Polascik T, Nightingale K. Visualizing the anatomic structures of human prostates using ARFI imaging. Proceedings of the IEEE UFFC Ultrasonics Symposium, 2007.

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3D images from excised prostate

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Zhai L, Madden J, Mouraviev V, Polascik T, Nightingale K. Visualizing the anatomic structures of human prostates using ARFI imaging. Proceedings of the IEEE UFFC Ultrasonics Symposium, 2007.

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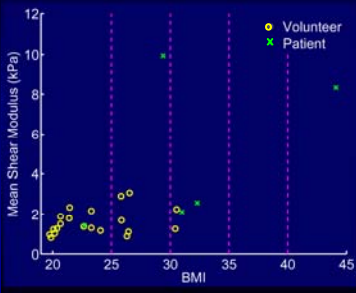
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In vivo Human Liver Stiffness Quantification



- Increased moduli associated with increased inflammation and/or fibrosis
- Feasible in high BMI population

Palmeri et al., "Dependence of in vivo, radiation force derived hepatic shear modulus estimates on imaging approach: intercostal vs. subcostal". *Proceedings of 2007 IEEE UFFC Ultrasonics Symposium*, 2007.

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Radiation Force: Challenges and Opportunities

System Issues:

- Need greater bandwidth transducers – typically want to image at higher frequency than push
- Need more parallelism in receive processing – allows faster frame rates, no repeat interrogations

Acoustic Output:

- Image quality and SNR are improved at depth with greater acoustic output
- Both transducer heating and tissue heating dictate maximum output
- Acoustic output is a regulated parameter

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Radiation Force: Challenges and Opportunities

Image Reconstruction Issues:

- Correlation between parameters (both relative and quantitative) and histology must be performed
- Currently using simple elastic and viscoelastic models

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Acknowledgements

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Tanter, Matthias Fink, Jim Greenleaf,
Armen Sarvazyan

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