BME2 – Biomedical Ultrasonics

Lecture 8 Bioeffects II- Mechanical Effects

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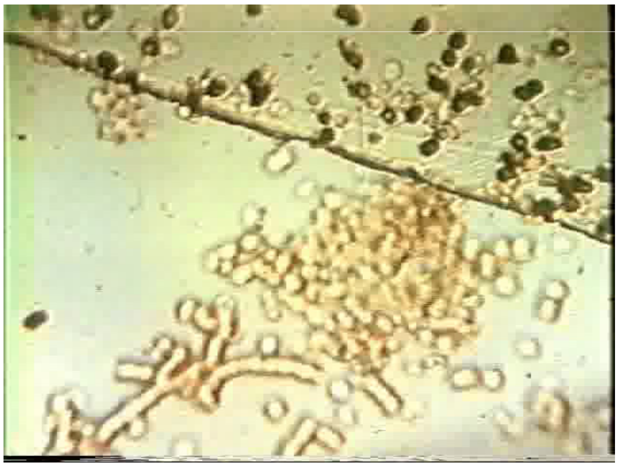
8.1 Acoustic streaming [see Hamilton & Blackstock, Chapter 7]

- In a region of fluid where a sound field exists, the pressure and velocity very with time.

- In general, the temporal averages of these quantities are not zero.

- The average over time of the velocity is called *acoustic streaming*.



- Streaming is strongest
  - At high frequencies
  - In highly attenuative media
  - In highly non-linear media
  - At high pressure amplitudes
  - Under pulsed excitation (for a given acoustic power)

- In water at room temperature, for a diBagnostic ultrasound pulse of centre frequency 3.5 MHz, streaming velocities are about **0.33 mm/s** for a 0.1 W acoustic input.

- By maintaining the same acoustic power input (0.1 W) and by pulsing the ultrasound, the streaming velocity can be increased to 10 cm/s at the focal distance!

8.2 Acoustic Radiation Force

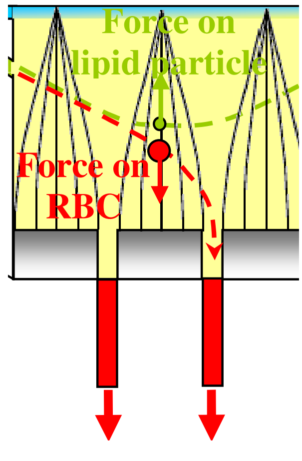
- A particle placed in an ultrasound field will scatter and absorb part of the incident field, resulting in a net momentum loss over the dimension of the particle along the acoustic axis.

- This results in the particle experiencing a net acoustic radiation force, given by

$$F_A = -\left(\frac{\pi p_0{}^2 V_c \kappa_1}{2\lambda}\right).\left[\frac{5\rho_2 - 2\rho_1}{2\rho_2 + \rho_1} - \frac{\kappa_2}{\kappa_1}\right].\sin\left(\frac{2\pi}{\lambda}x\right)$$

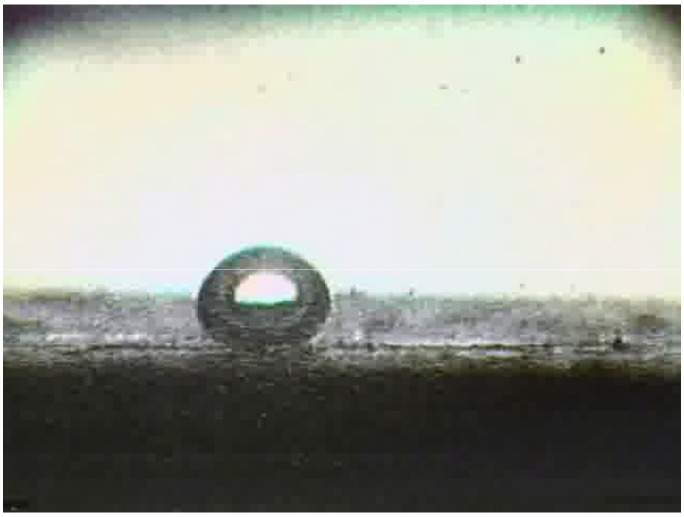
where V_c is the particle volume, λ the wavelength, p_o the pressure amplitude, x the distance along the acoustic axis, and (ρ_2 , κ_2) and (ρ_1 , κ_1) are the density and compressibility of the particle and surrounding medium respectively.

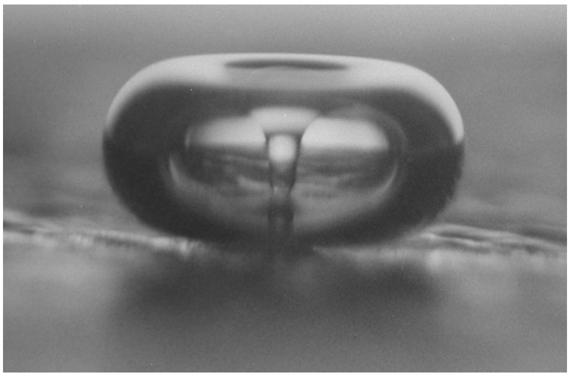
- When harnessed within a standing wave field, acoustic forces can be used to separate biological particles based on their density and compressibility contrast!



8.3 Mechanical effects of inertial and stable cavitation

- A bubble collapsing inertially near a boundary will cause jetting:

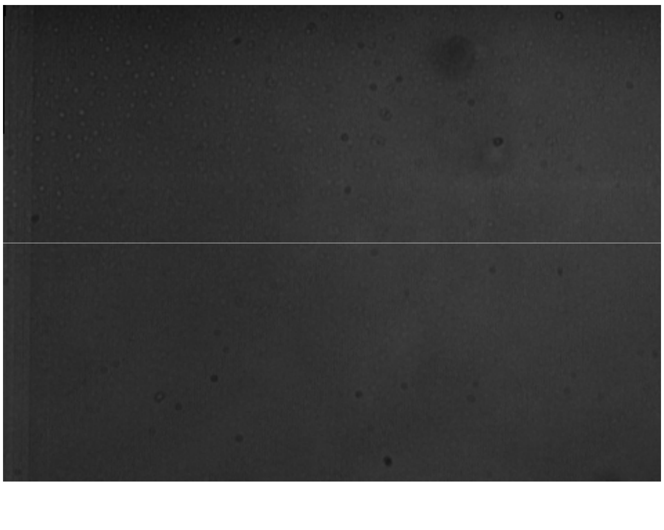




- Such bubble collapses near a cell wall are one of the supected mechanisms for *sonoporation* (increased permeability of cellular membranes to large molecules).

(Photos and video courtesy of Lawrence A Crum, Univ. of Washington)

- A bubble undergoing stable oscillations will generate significant amounts of *microstreaming*

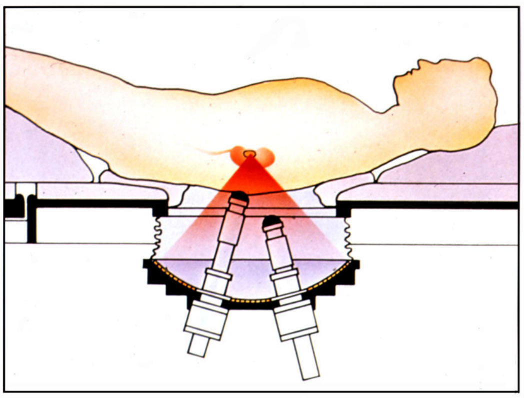


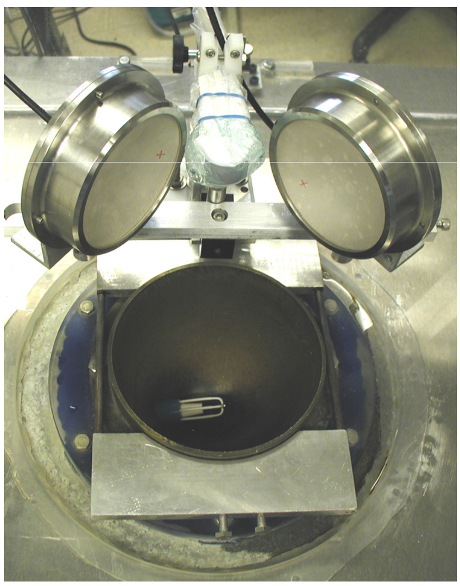
(Video courtesy of Eleanor Stride, Univ. College London)

➢ CASE STUDY I:

EXTRACORPOREAL SHOCK-WAVE LITHOTRIPSY

– Jetting from a cavitation cloud!
– One of several physical mechanisms for kidney stone destruction





(Photos and video courtesy of Michael Bailey, Univ. of Washington)

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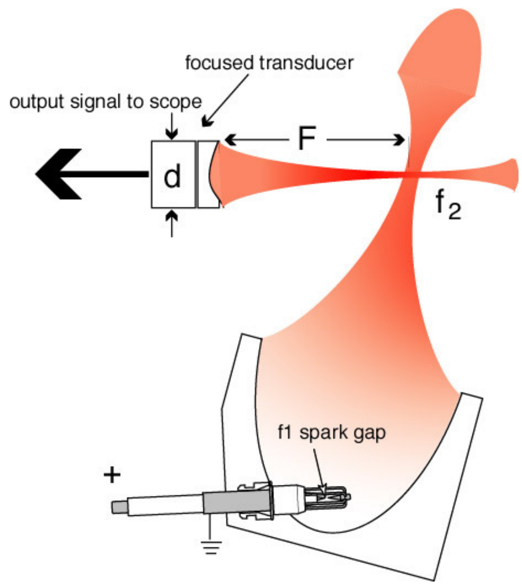

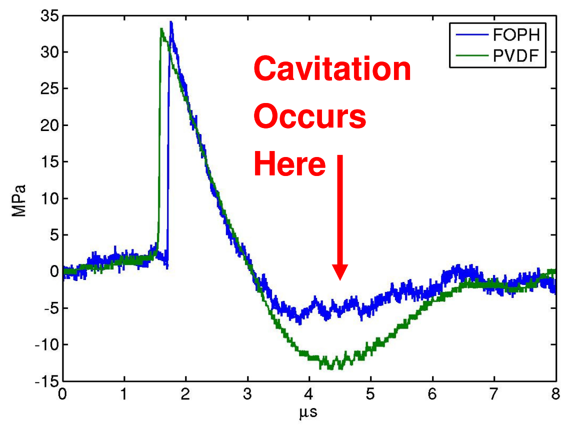

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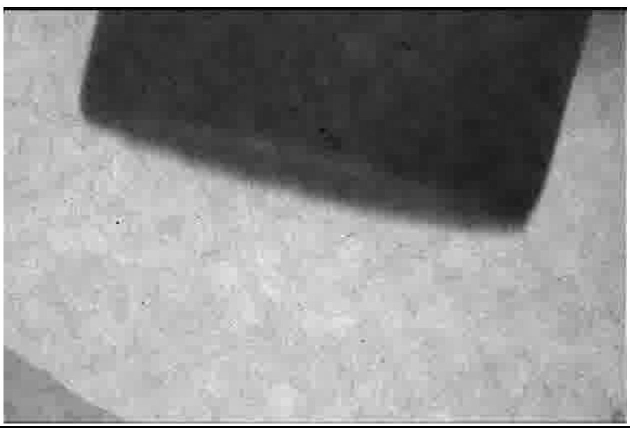
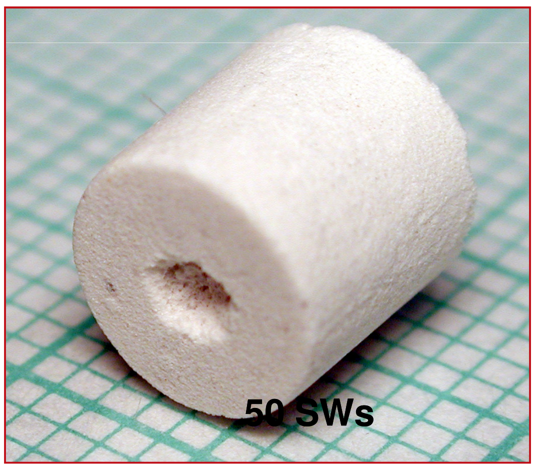


Eroding an artificial kidney stone...



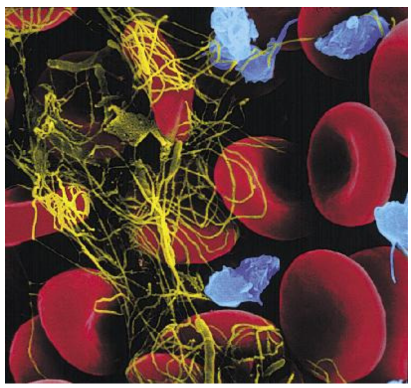
(Photos and video courtesy of Michael Bailey, Univ. of Washington)

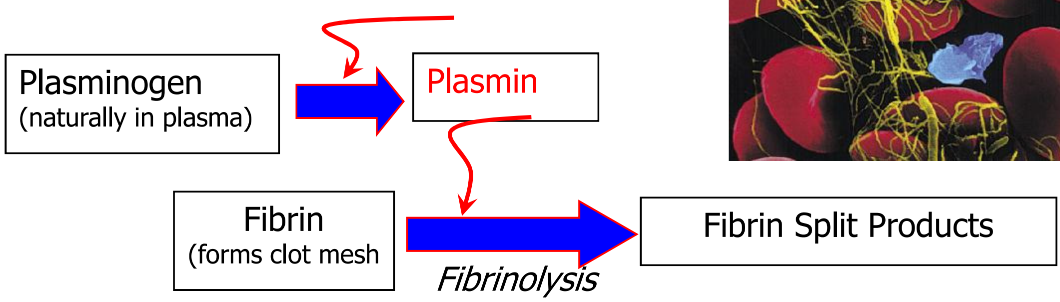
➢ CASE STUDY Ii:

ULTRASOUND-ENHANCED THROMBOLYSIS

Ultrasound-Enhanced Thrombolysis: Clinical Motivation

- Blood clots and thrombi are largely responsible for ischaemic stroke thrombotic events.
- Thrombolytic action of rt-PA

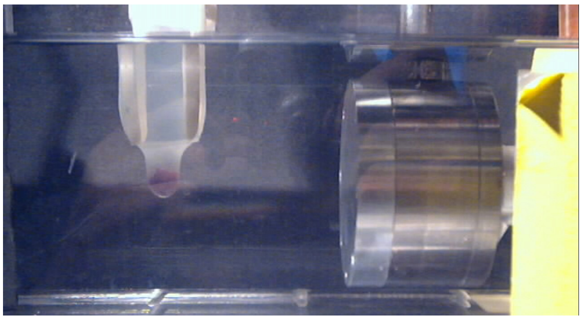




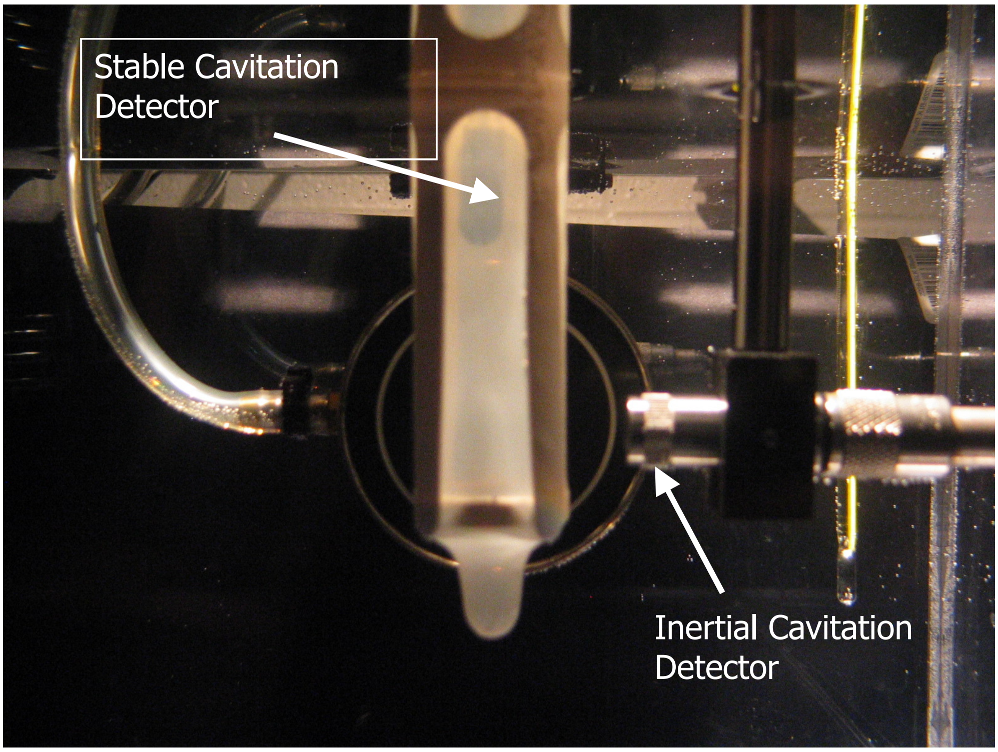
- Systemic delivery of rt-PA can cause internal bleeding.
- ***Localized activation key to successful & safe clinical use.***

Thrombolysis Study: Clot Formation & Exposure

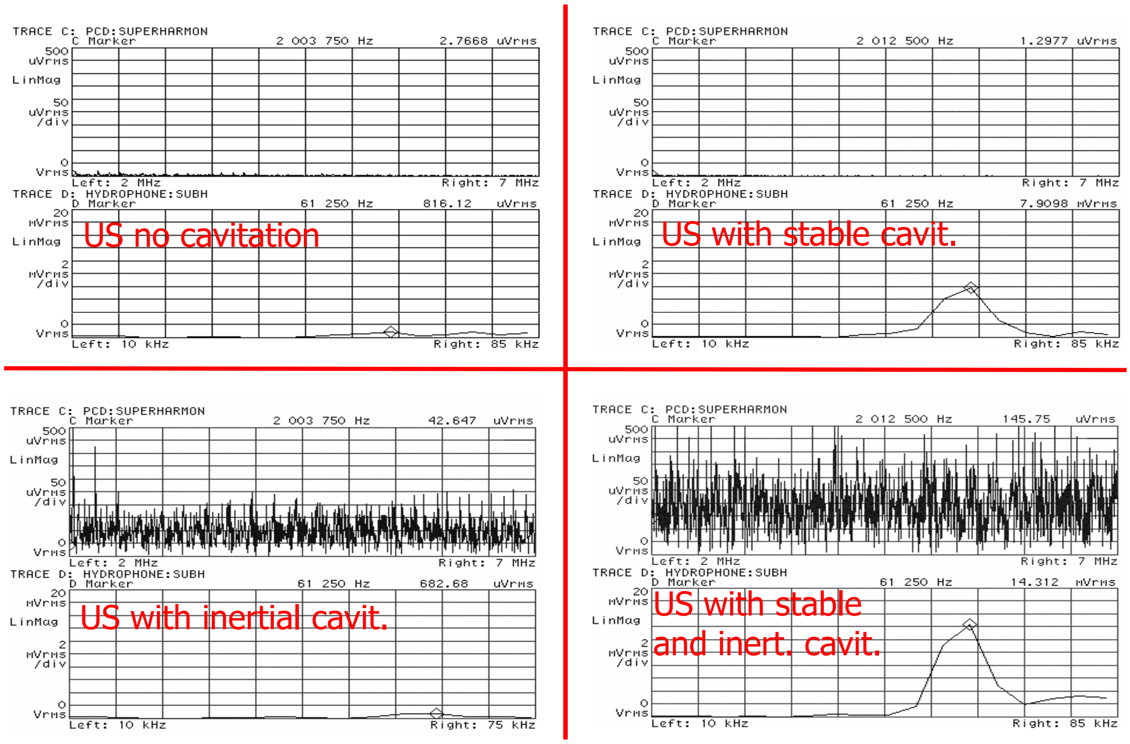
- Whole Blood Clots:
  - 2-3 ml aliquots of whole pig blood clot in test tube
  - Incubated at 37 C for 3 hours
  - Refrigerated 3 days prior to use
- Pulsed or CW Ultrasound Exposures
  - 120 KHz center frequency
  - PRP = 600 μs
  - Exposure Duration = 30 min.
  - Duty Cycle from 0% to CW
- Clot added to rt-PA + Plasma
- Weighed before & after exposure



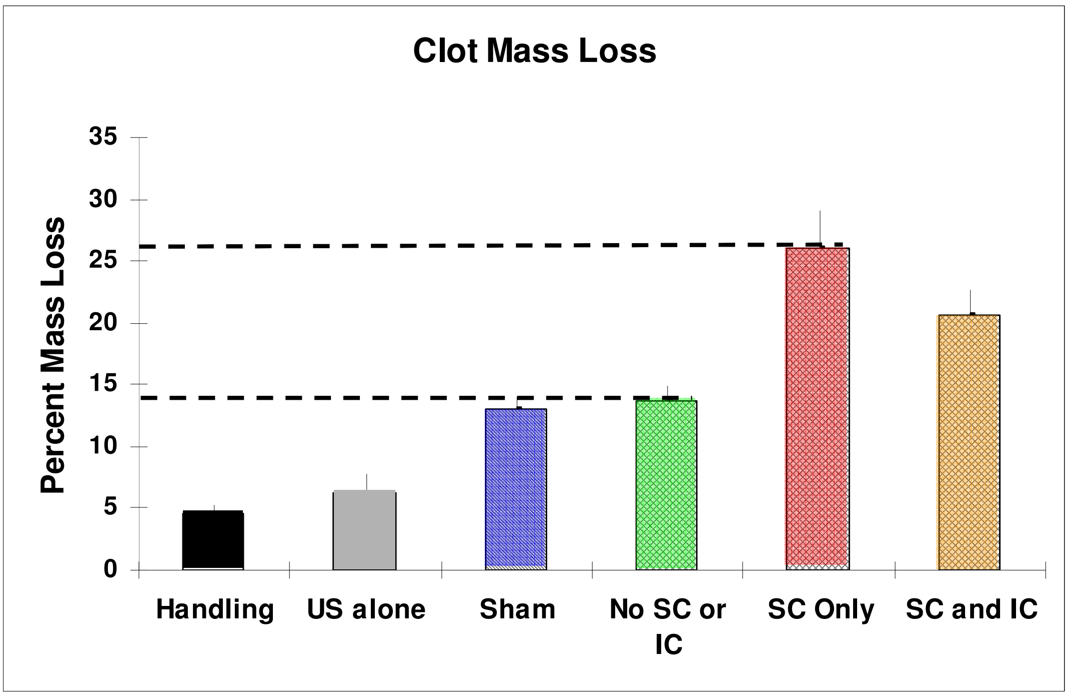
Apparatus for Cavitation Detection



Excitation regimes – cavitation study

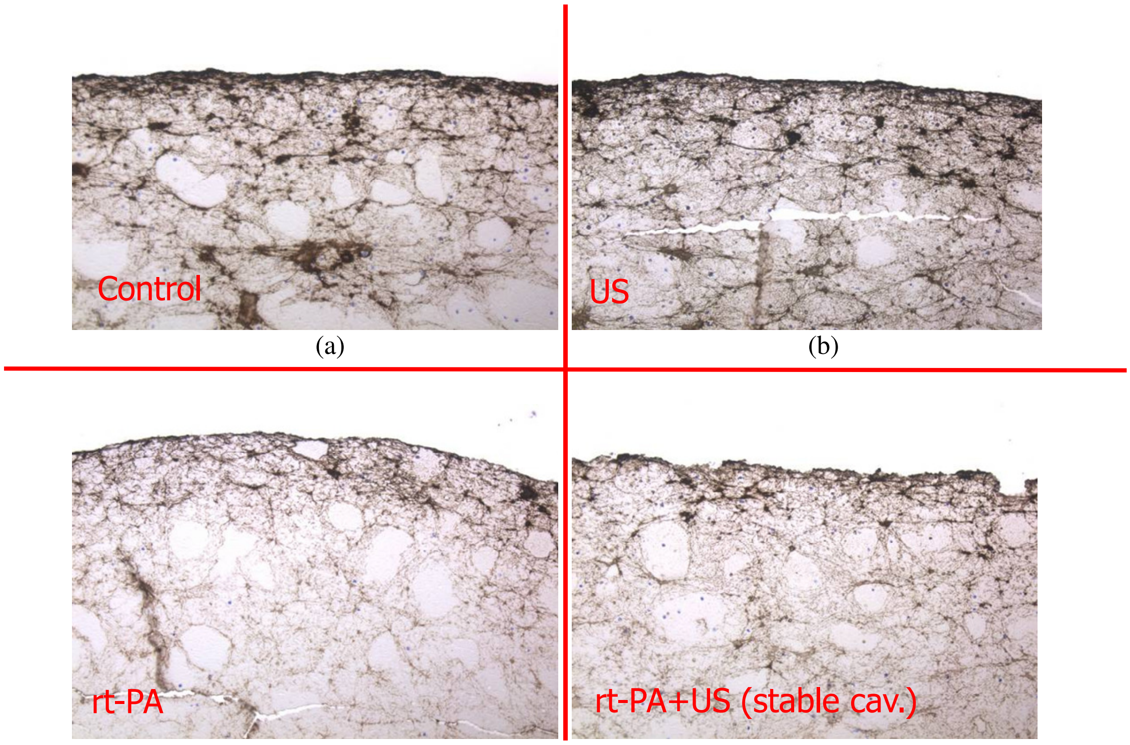


Correlation of cavitation with thrombolysis



Datta S, Coussios C-C et al., Ultrasound Med. Biol, 2006 (in press).

Observations of clot surface



Labeled with mouse anti-fibrinogen antibody and stained with horseradish peroxidase-linked goat anti-mouse IgG

Conclusions: the future of biomedical ultrasound

- Ultrasound is cheap, portable, presents no risk to the user and little or no risk to the patient.

- Ultrasound imaging has become widely accepted in the clinical arena and is especially well-suited to imaging of high acoustic contrasts (suffers by comparison to MRI for image resolution).

- The future of ultrasound applied to therapy is bright: there are numerous emerging and under-explored applications, requiring deeper understanding of the interactions of sound (and bubbles) with tissue and cells