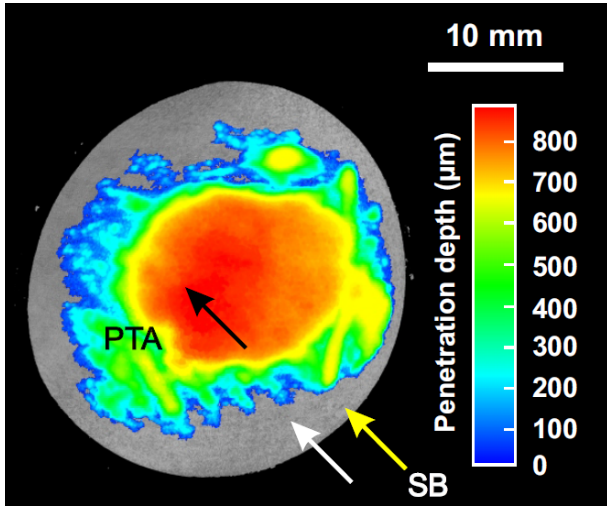
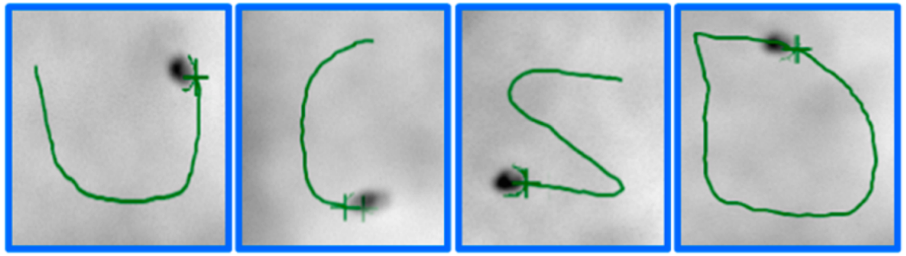
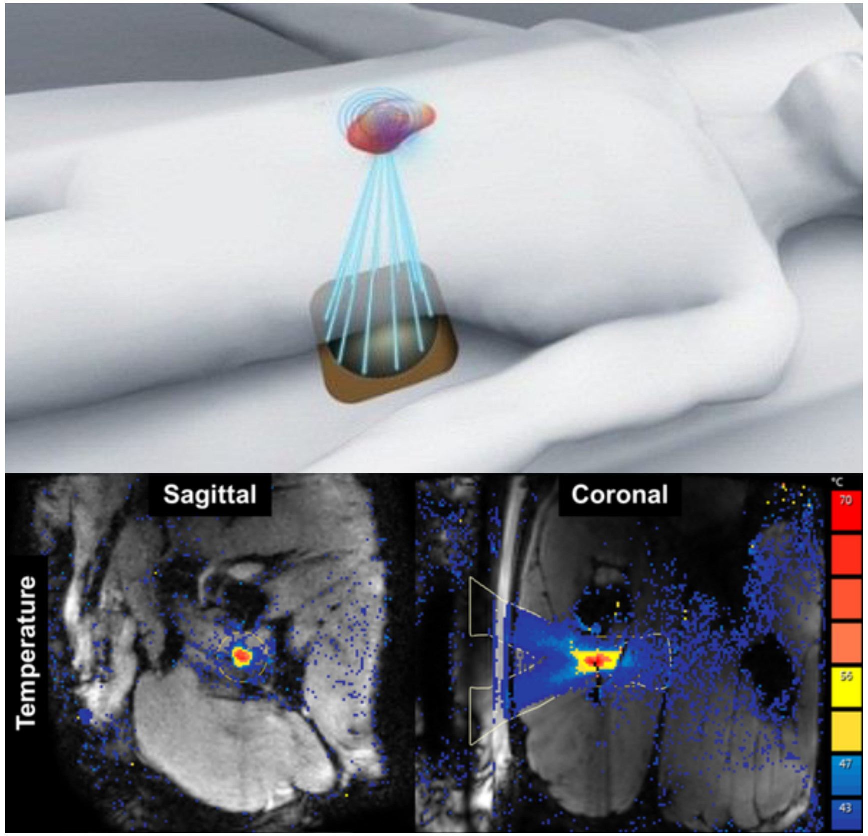
Biomedical Ultrasonics, 5 cr

Heikki Nieminen

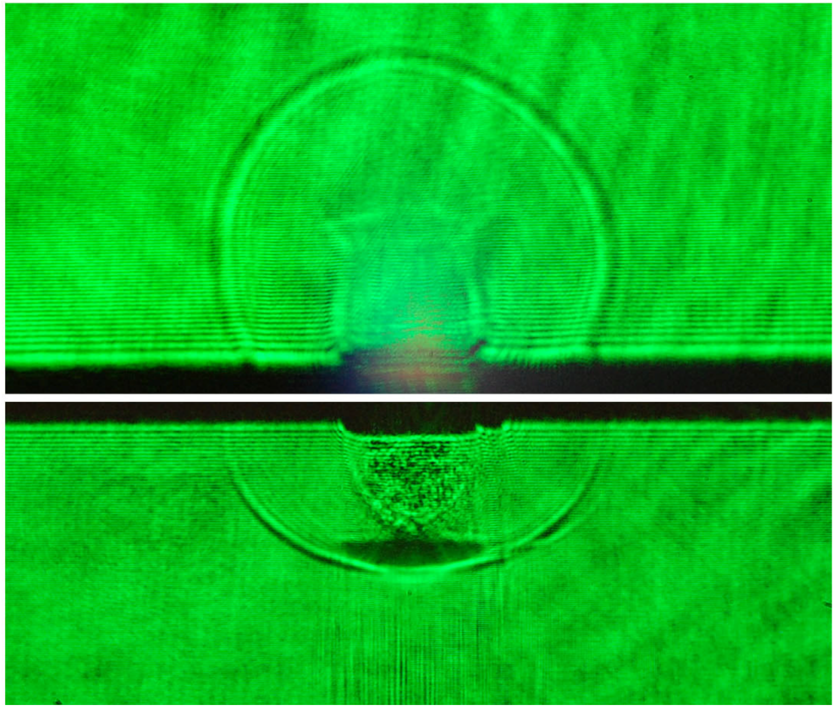
7.1.-31.5.2019



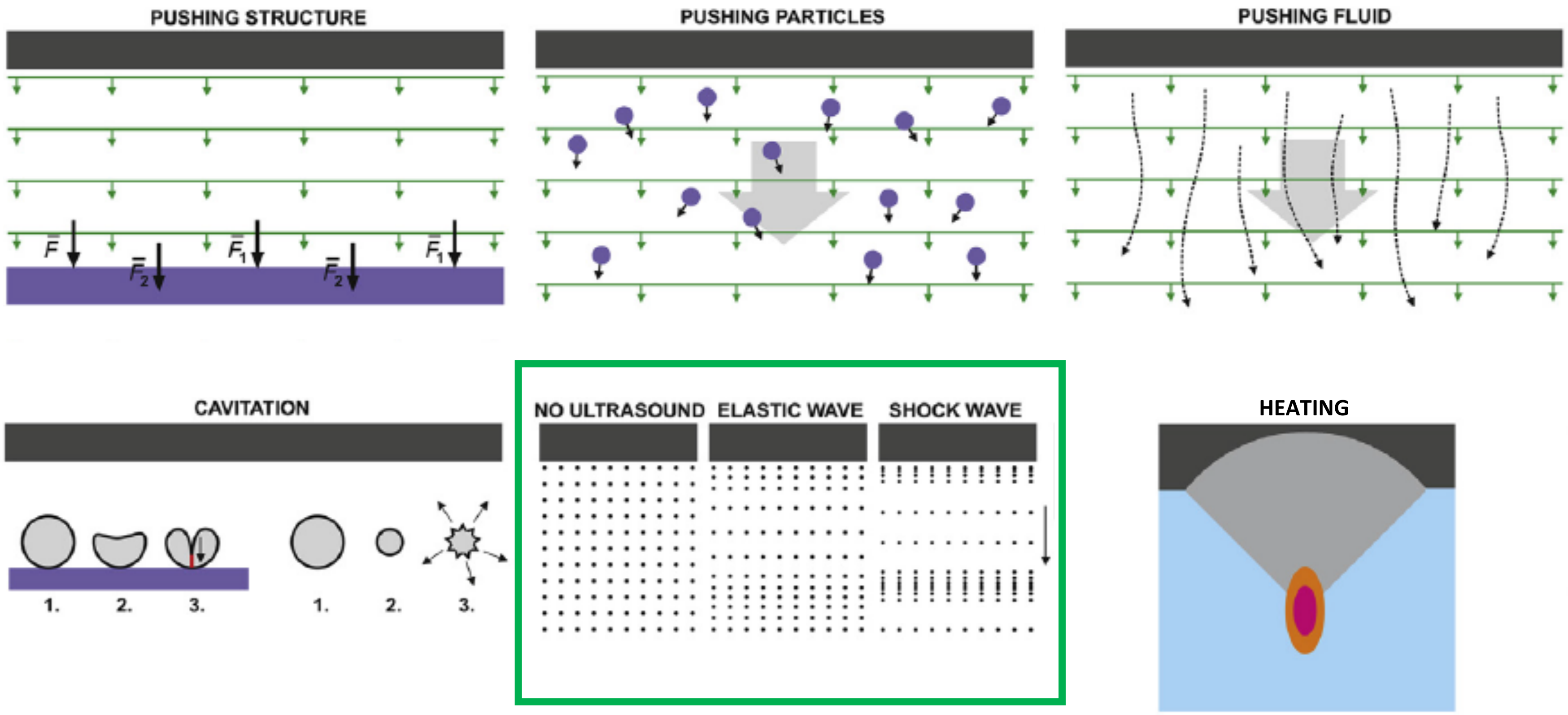




Shock waves

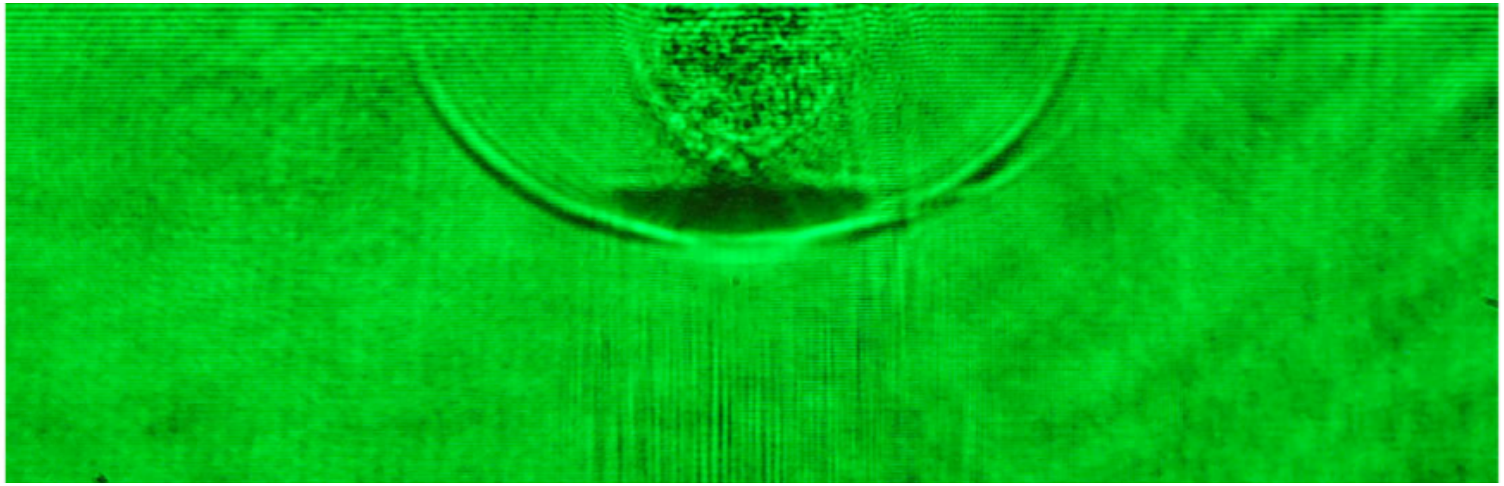


Non-linear ultrasonics



What is a shock wave?

- A travelling discontinuity of density that moves faster than the speed of sound in the material



Strycker et al 2013: http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-21-20-23772

Shock waves

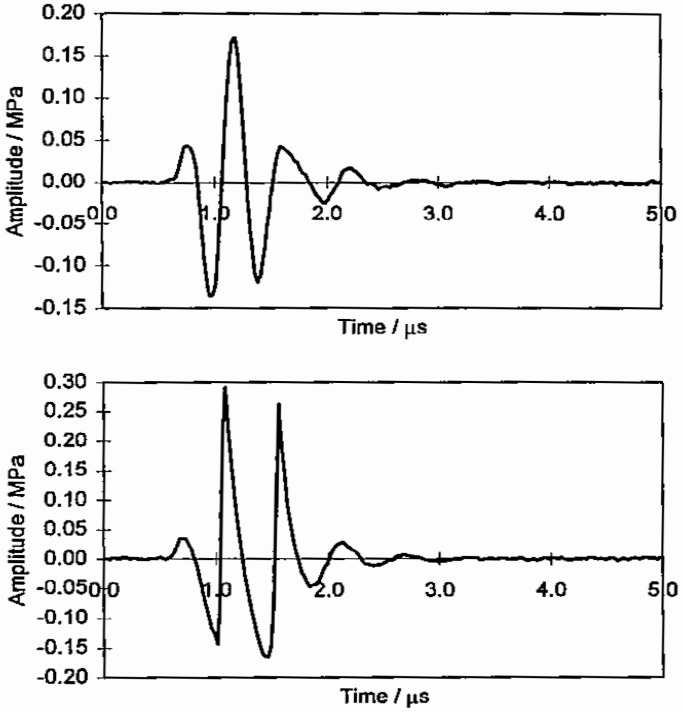
- Submarines during WWII could not detect enemy ships ➔ reason: Pistol shrimps
  - *e.g.* http://www.youtube.com/watch?feature=player_detailpage&v=XC6I8iPiHT8#t=31s

- Other examples: Bombs, jet fighters, lightning etc
- Shock wave generation in fluid:
  - Non-linear propagation of a pulse
  - Bubble implosion
  - Electric spark
  - Laser-ultrasonic
    - Ablation
    - Plasma generation

Shock waves

- Shock wave evolution

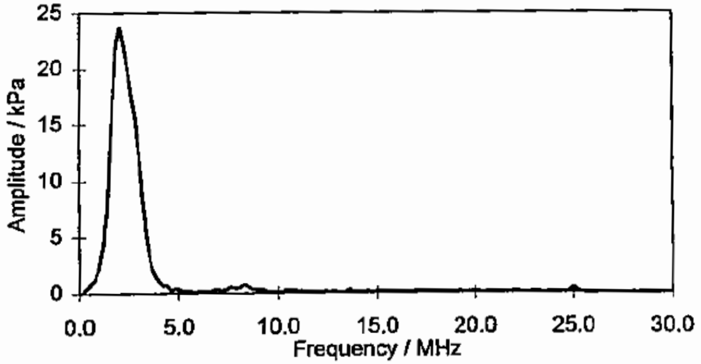
INITIAL



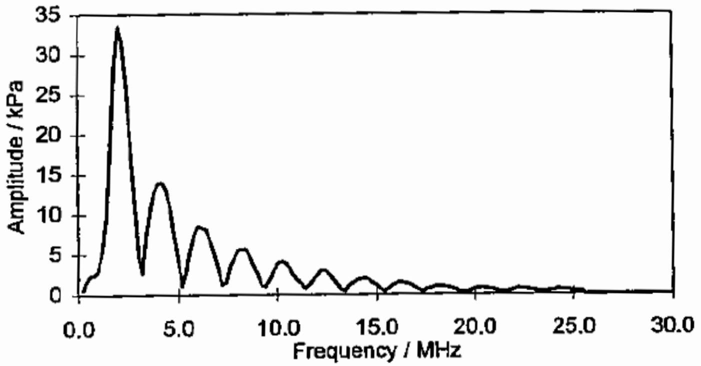
DISTORTED

Figure 2.3. *Initial pulse (top) and nonlinear distortion of pulse (bottom) after propagating 600 mm in water.*

INITIAL



DISTORTED



Duck et al 1998: Ultrasound in Medicine

Shock waves

Pulse distortion

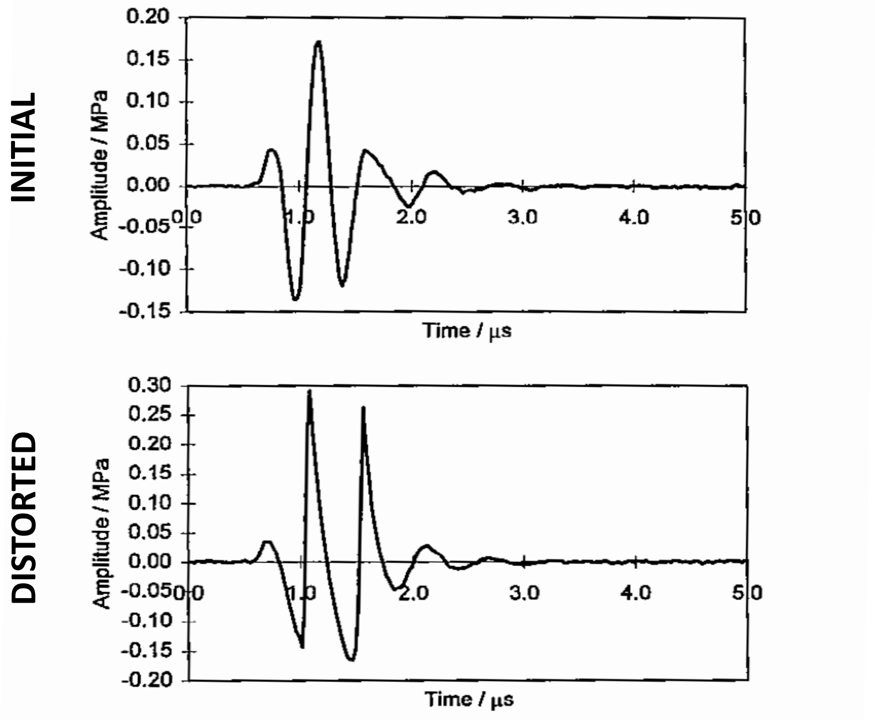


Figure 2.3. *Initial pulse (top) and nonlinear distortion of pulse (bottom) after propagating 600 mm in water.*

Harmonic content with propagation distance

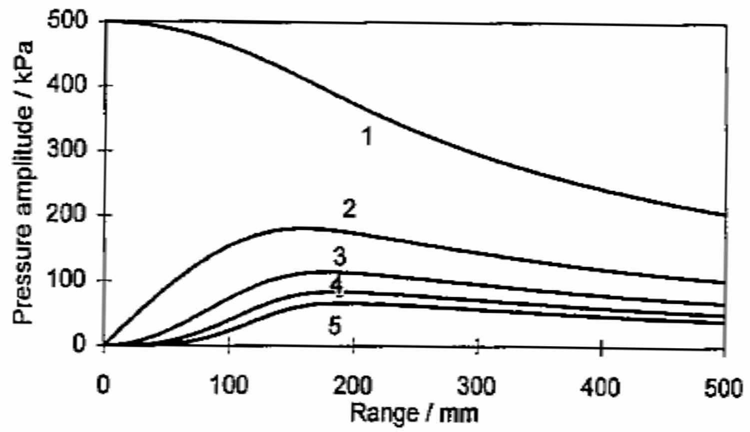
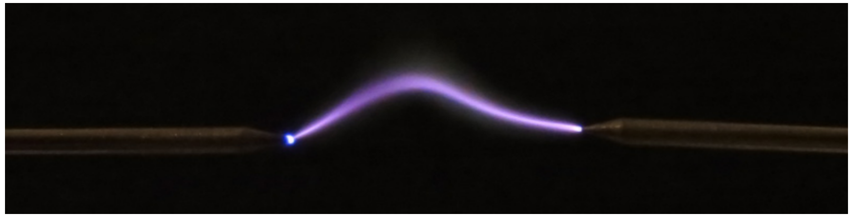


Figure 2.2. *Fundamental and second to fifth harmonics for a nonlinear plane wave in water ($f_0 = 3.5$ MHz, $P_0 = 500$ kPa, $\Gamma = 38$).*

Duck et al 1998: Ultrasound in Medicine

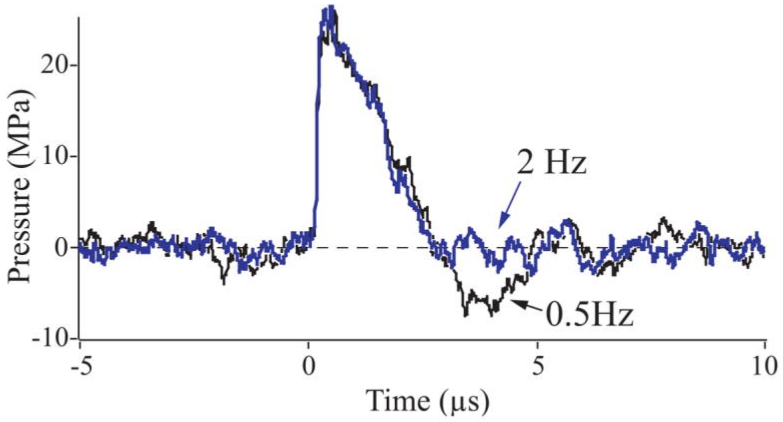
Sound generation with plasma spark

Spark gap



- Spark gap in air or fluid generates plasma ➔ plasma expands ➔ generates sound/cavitation

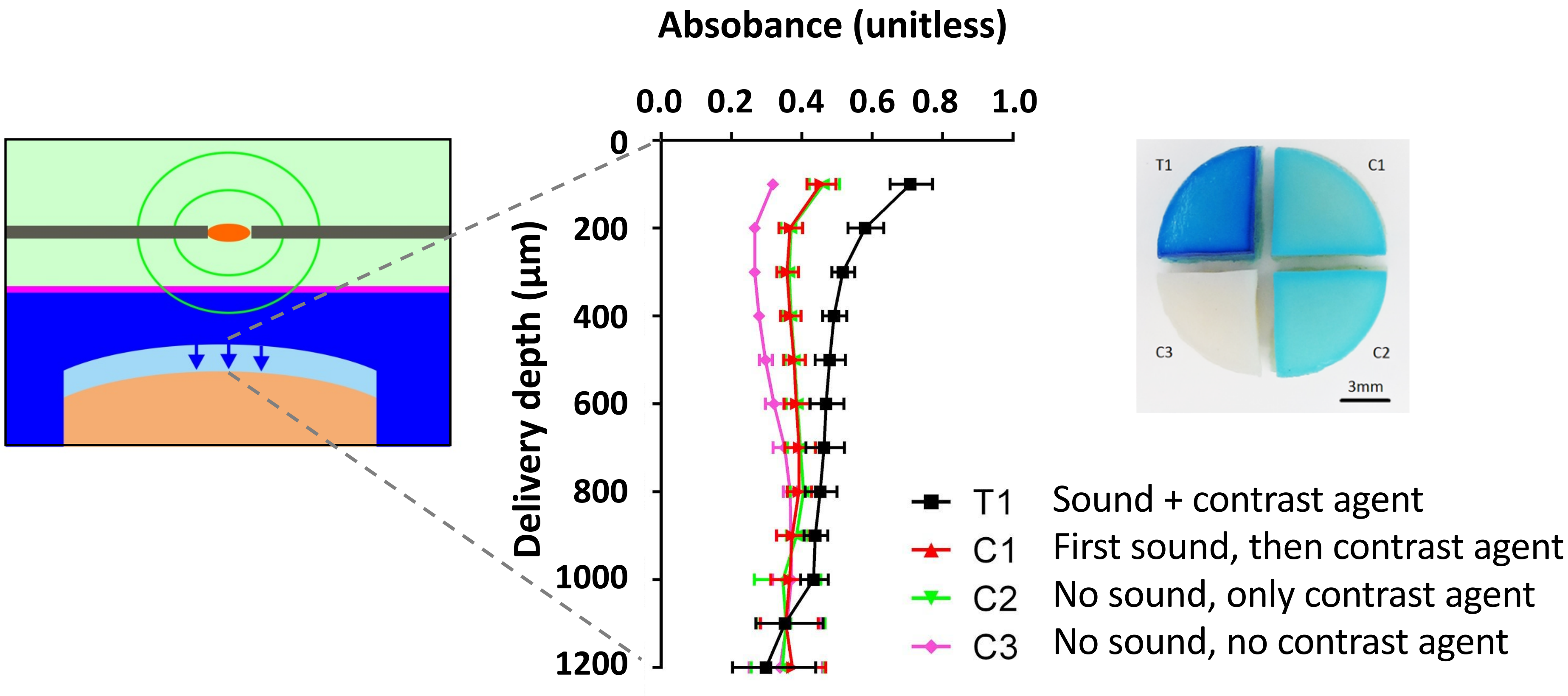
Shock wave signals from lithotripter at different PRF (0.5 or 2 Hz)



Pishchalnikov et al 2006:
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2442574/

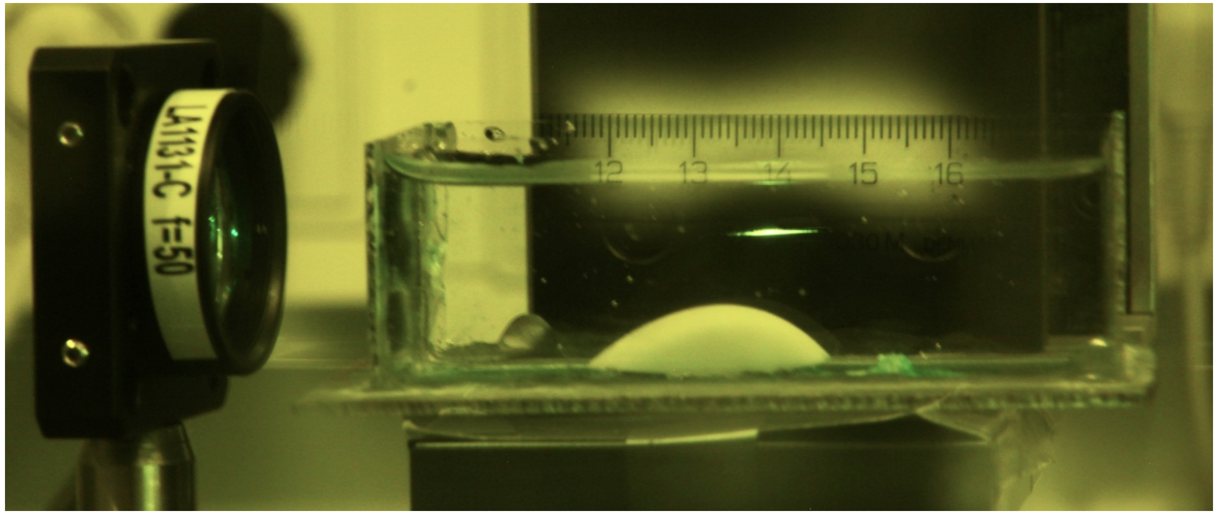
Shock wave drug delivery

- **Delivery of methylene blue (320 Da) to a depth of 0.8 mm in 5 minutes.**



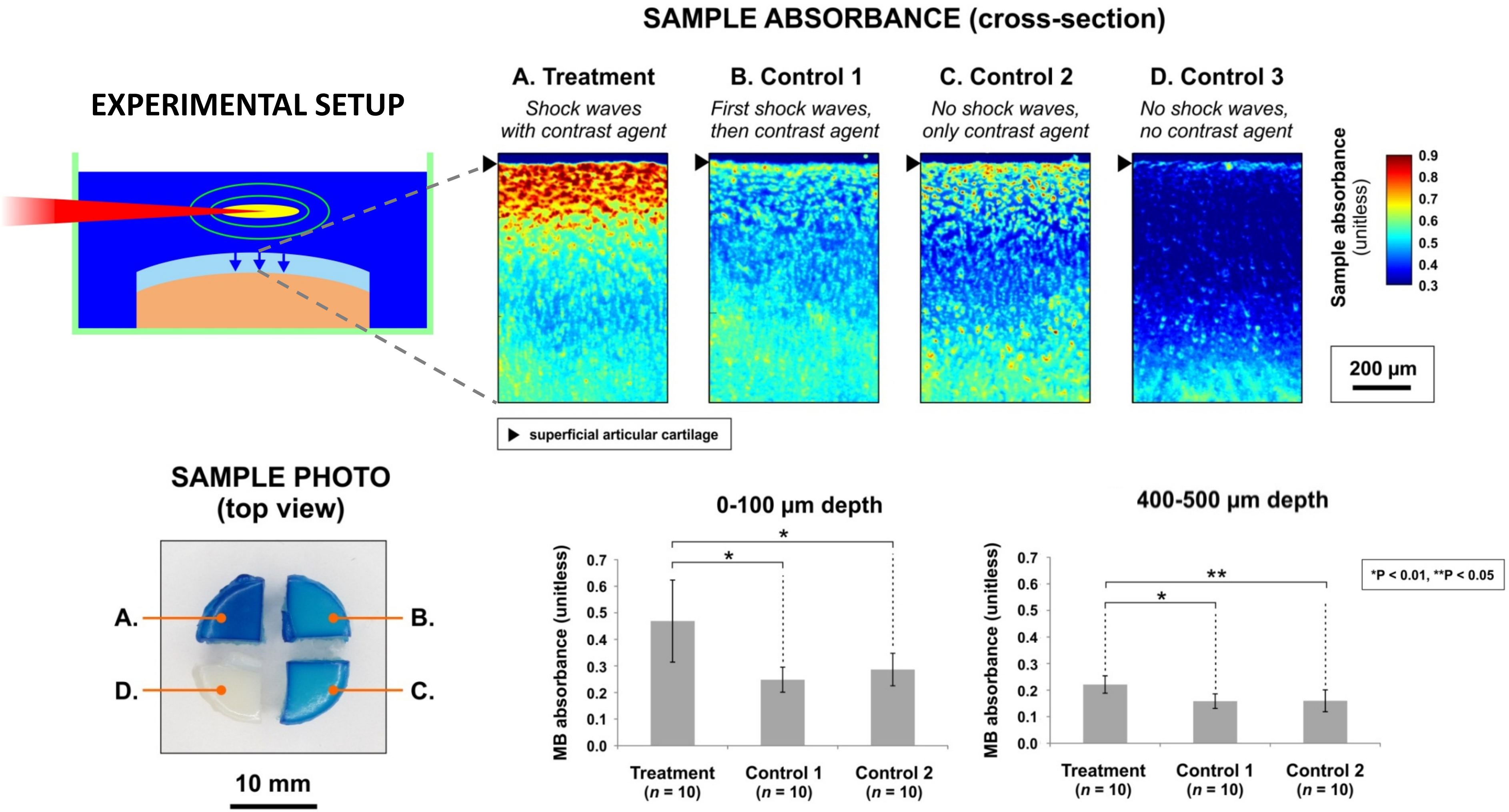
Laser-ultrasonic plasma generation

- Laser pulses can be exploited for ultrasonic drug delivery by generating sound by them by means of:
  - thermoelastic expansion
  - ablation
  - plasma generation (*perhaps the most interesting for ultrasonic drug delivery*)



Laser-ultrasonic delivery

- Delivery of methylene blue (320 Da) to a depth of 500 µm (11 min)



Nieminen et al. doi: 10.1038/s41598-017-04293-5.

Femtosecond laser plasma generation

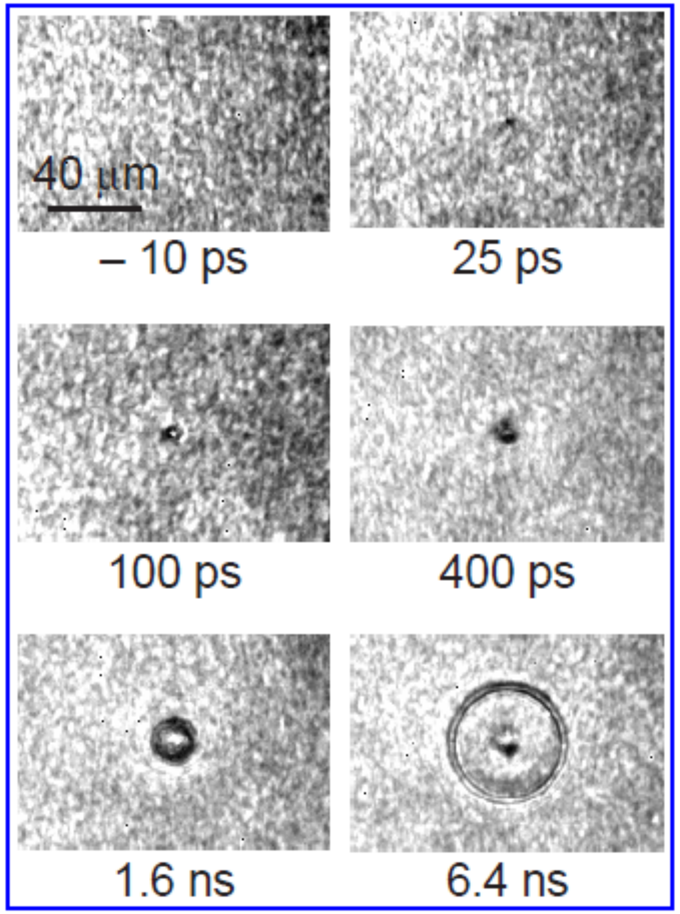
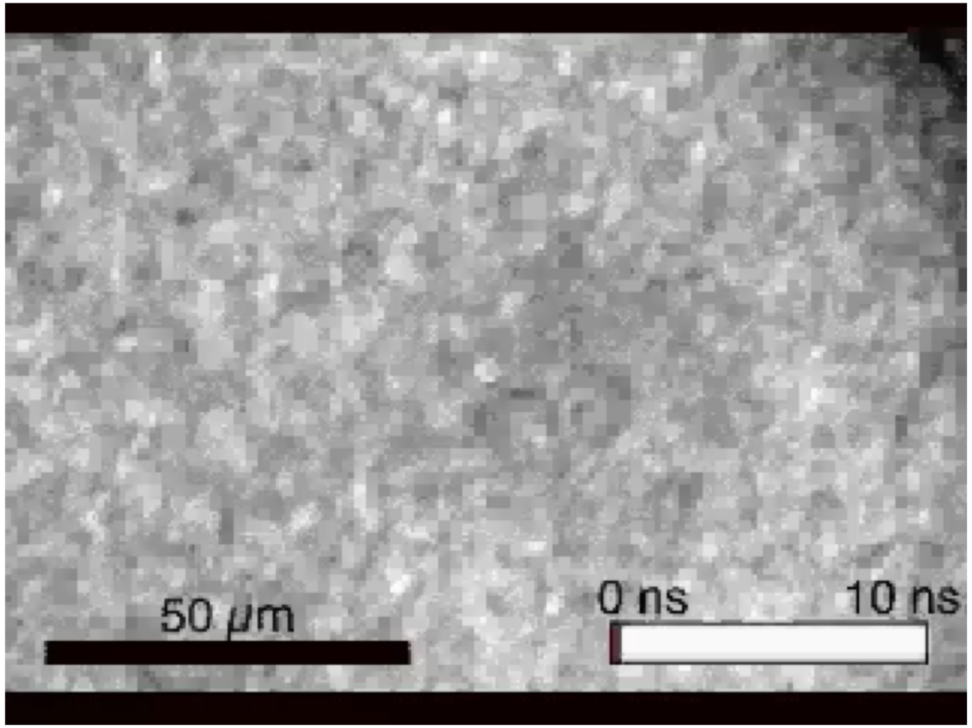


Fig. 2 Images of femtosecond laser-induced breakdown in water obtained for various time delays using the setup shown in Fig. 1. A corresponding quicktime movie shows the first 10 ns of expansion. One second of the movie shows 1 nanosecond of the dynamics.

Video



Schaffer et al 2002: http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-10-3-196

Femtosecond laser pulse at air-water interface

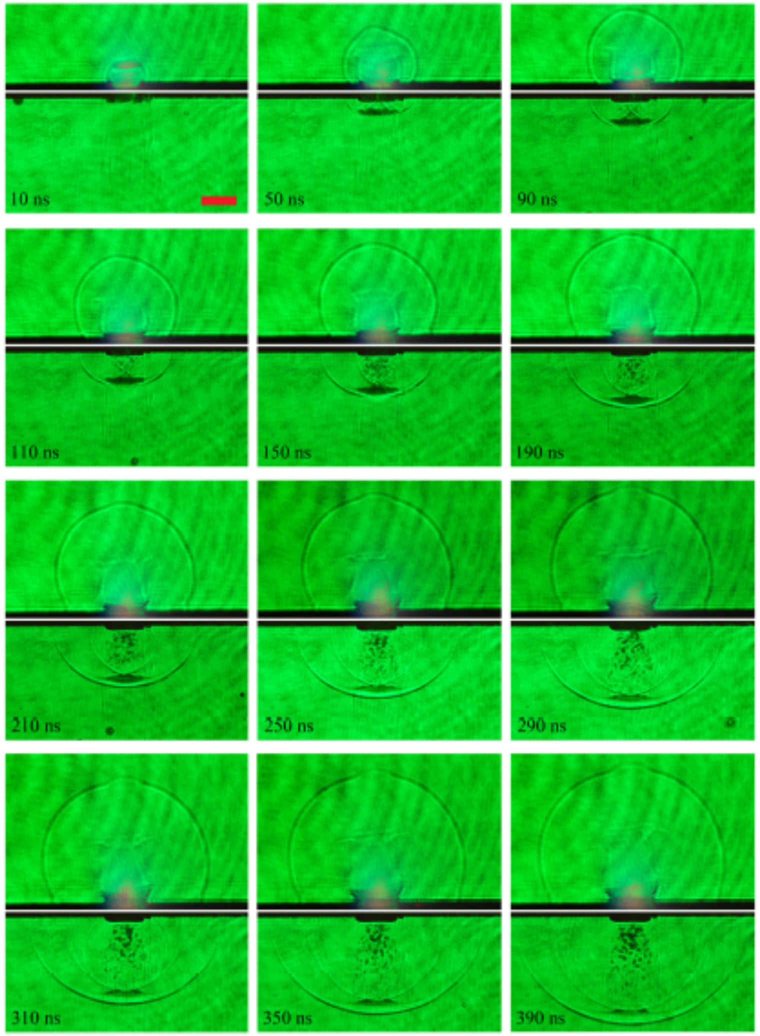


Fig. 3. Temporal evolution of shockwaves in air and water using pulses with about 2.2 mJ energy and 1.25×10^{15} W/cm^2 peak on-axis intensity. The red scale bar in the upper left corner is 200 μm in length.

Strycker et al 2013: http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-21-20-23772

Femtosecond laser pulse at air-water interface

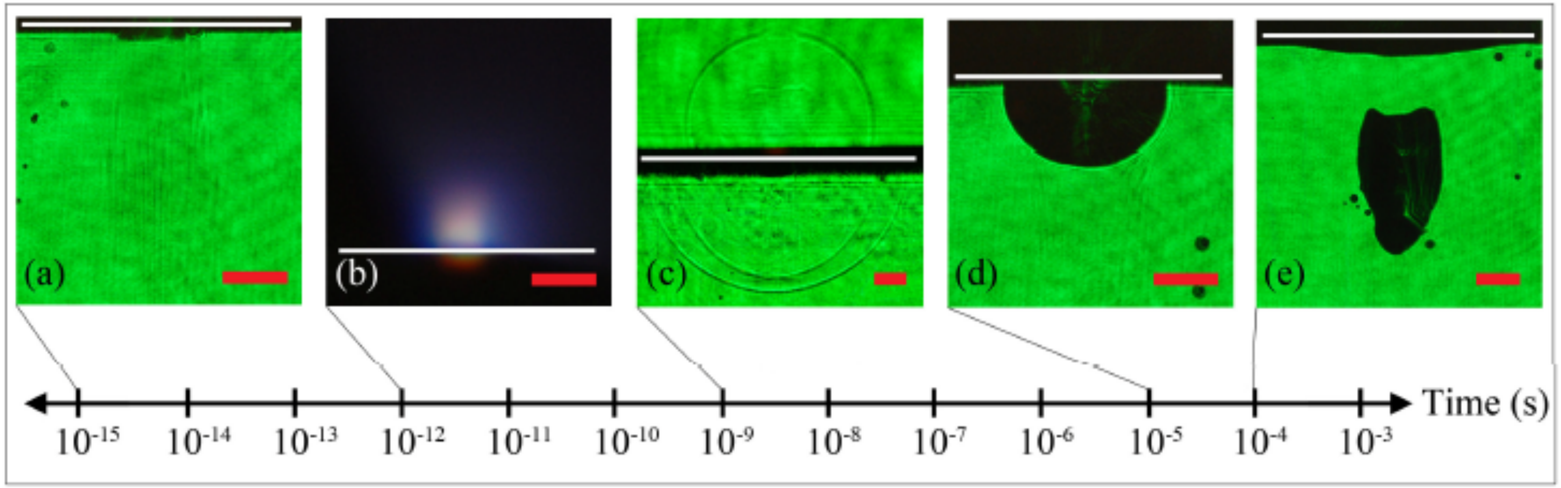


Fig. 2. Outline of events induced by femtosecond laser pulses of few millijoule energies incident on an air-water interface. The red scale bars in the lower right corners are 200 μm in length. The white lines show the approximate position of the air-water interface, with air above and water below. Each picture is shown to be associated with an approximate time scale on which the phenomenon may first begin to be observed. (a) Ionization, plasma generation, and electron-ion thermalization at and beneath the surface, corresponding to the slightly darker region of about 200 μm width in the center of the picture. (b) Plasma expansion from the surface and emission of light. This image was taken without the use of the 532 nm probe pulse. (c) Generation of shockwaves both above and below the surface. Notice the two shock fronts generated within the water sample. (d) Cavity formation at the surface. (e) Cavity closure and bubble formation.

Strycker et al 2013: http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-21-20-23772

Shock-wave ”shooting” of tungsten particles into rat liver

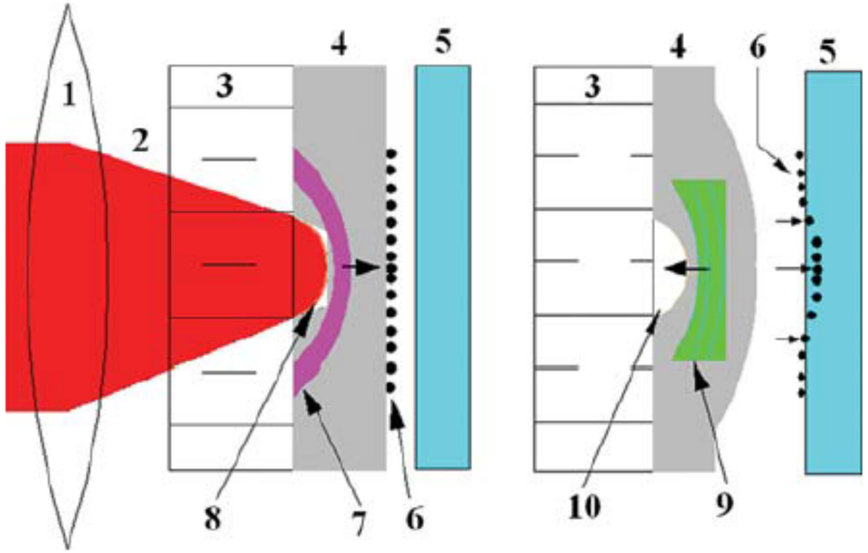


Fig. 2 Illustration of laser ablation assisted particle acceleration (*1* Lens. 2 Laser beam. *3* Glass overlay. *4* Foil. *5* Target. *6* Particles. *7* Shock wave. *8* Confined ablation. *9* Expansion wave. *10* Microcrater due to ablation)

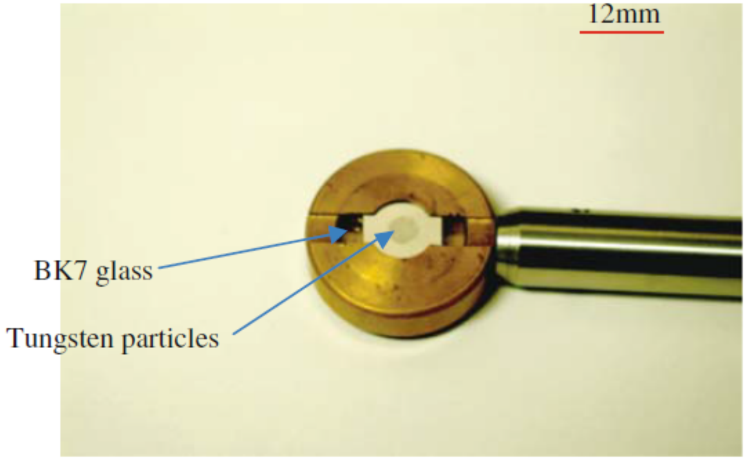
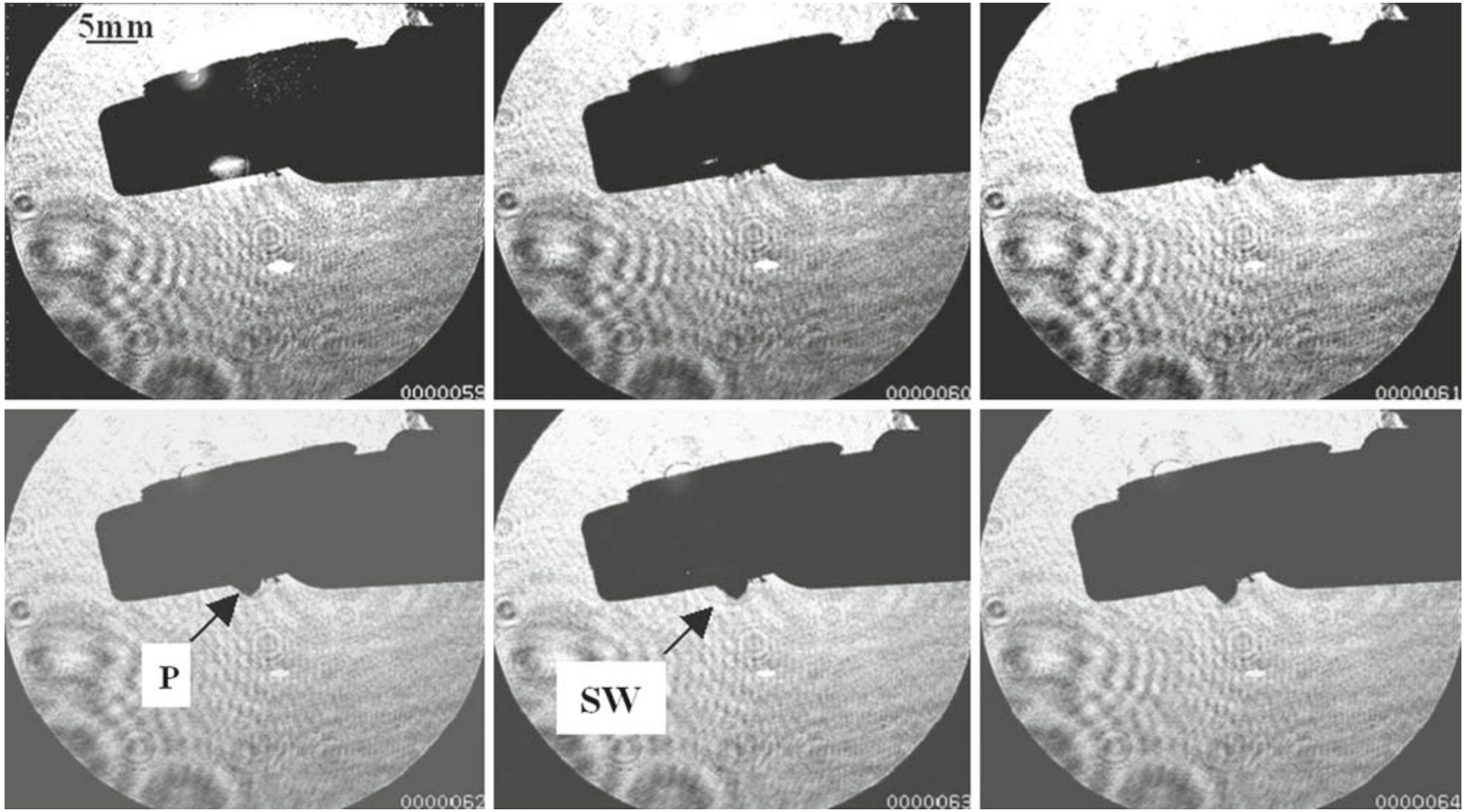


Fig. 3 A layer of 1 μm size tungsten particles deposited on a 100 μm thick Al foil

Menezes 2008: http://link.springer.com/article/10.1007/s00193-008-0163-9

Shock-wave ”shooting” of tungsten particles into rat liver



P = particle cloud, SW = shock wave, 1 µs interval between high-speed camera frames

Menezes 2008: http://link.springer.com/article/10.1007/s00193-008-0163-9

Shock-wave ”shooting” of tungsten particles into rat liver

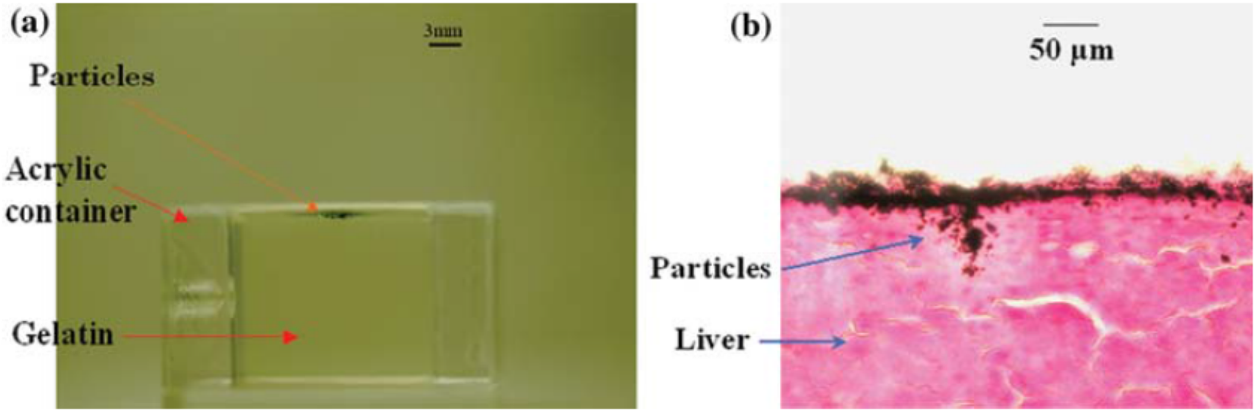
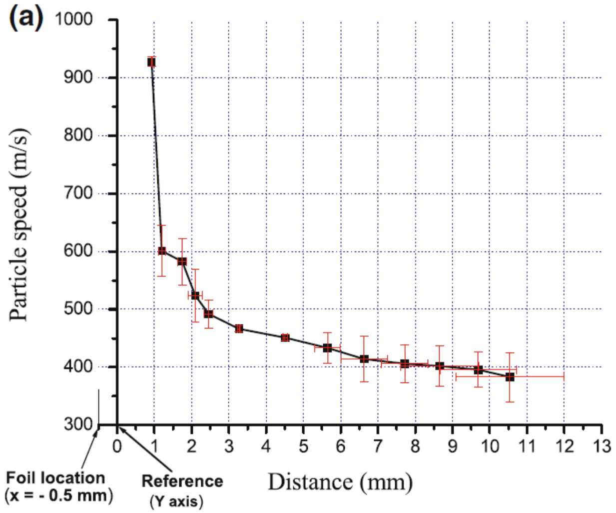
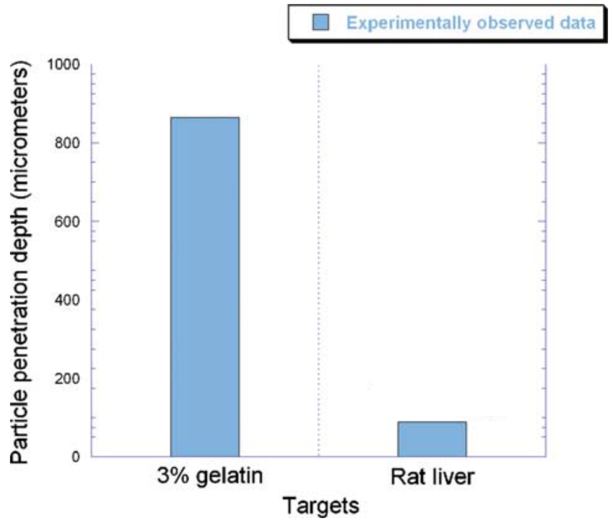


Fig. 8 1 µm tungsten particles delivered into **a** 3% gelatin and **b** liver tissue of Sprague Dawley male rat





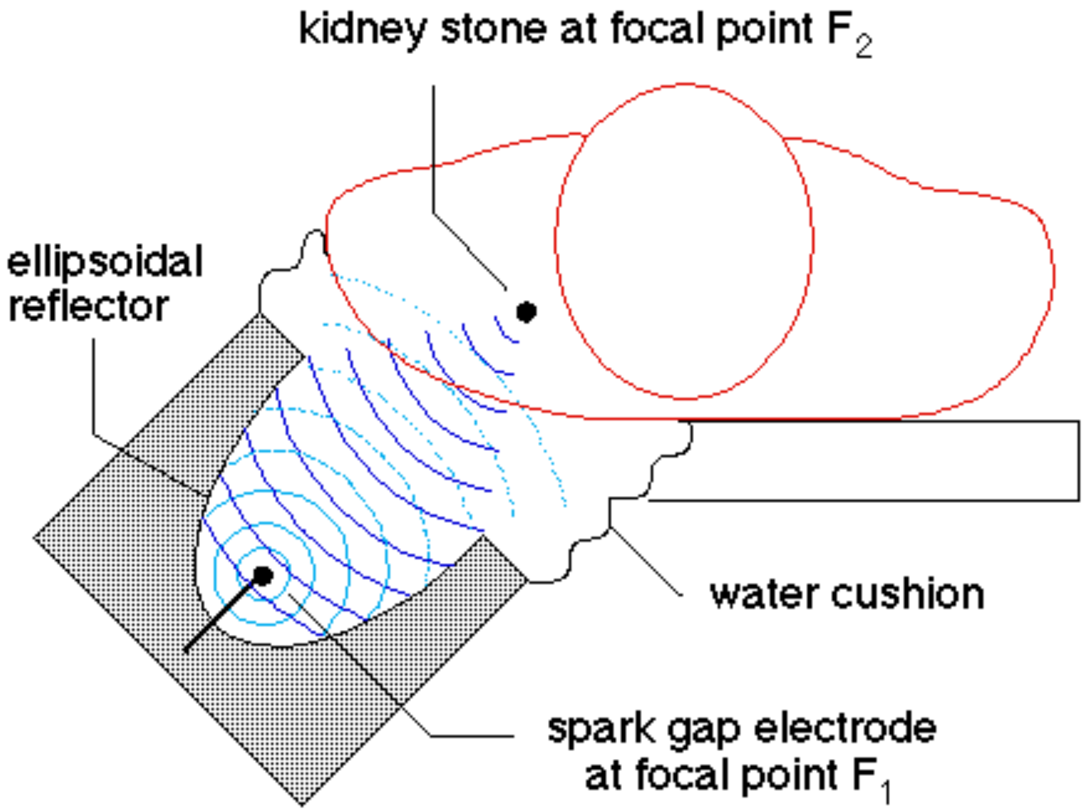
Menezes 2008: http://link.springer.com/article/10.1007/s00193-008-0163-9

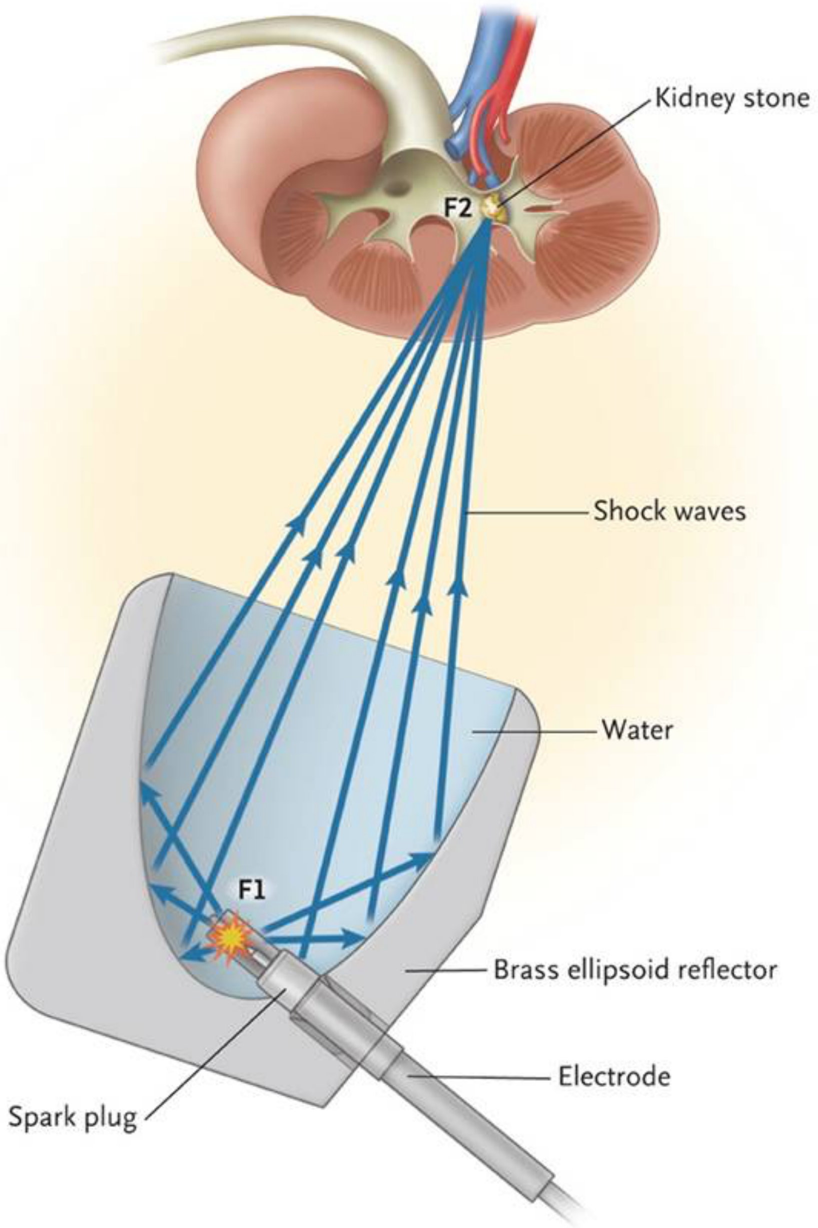
Breaking the bone

FIG. 4. Complete fractures of the bones occurred after 10,000 shock waves at maximum energy density (0.60 mJ/mm²). This photograph shows two femurs.

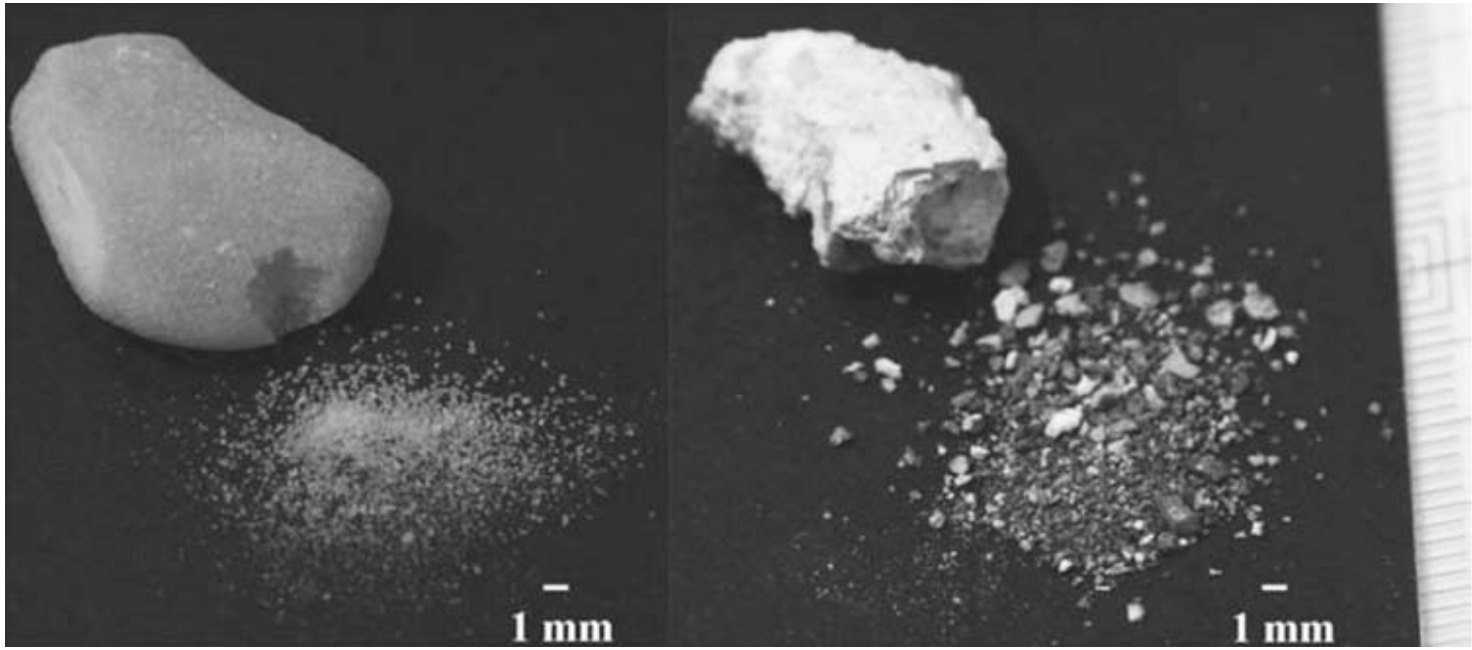
Kaulesar Sukul et al 2002: http://www.sciencedirect.com/science/article/pii/S0022480483710085

Lithotripsy



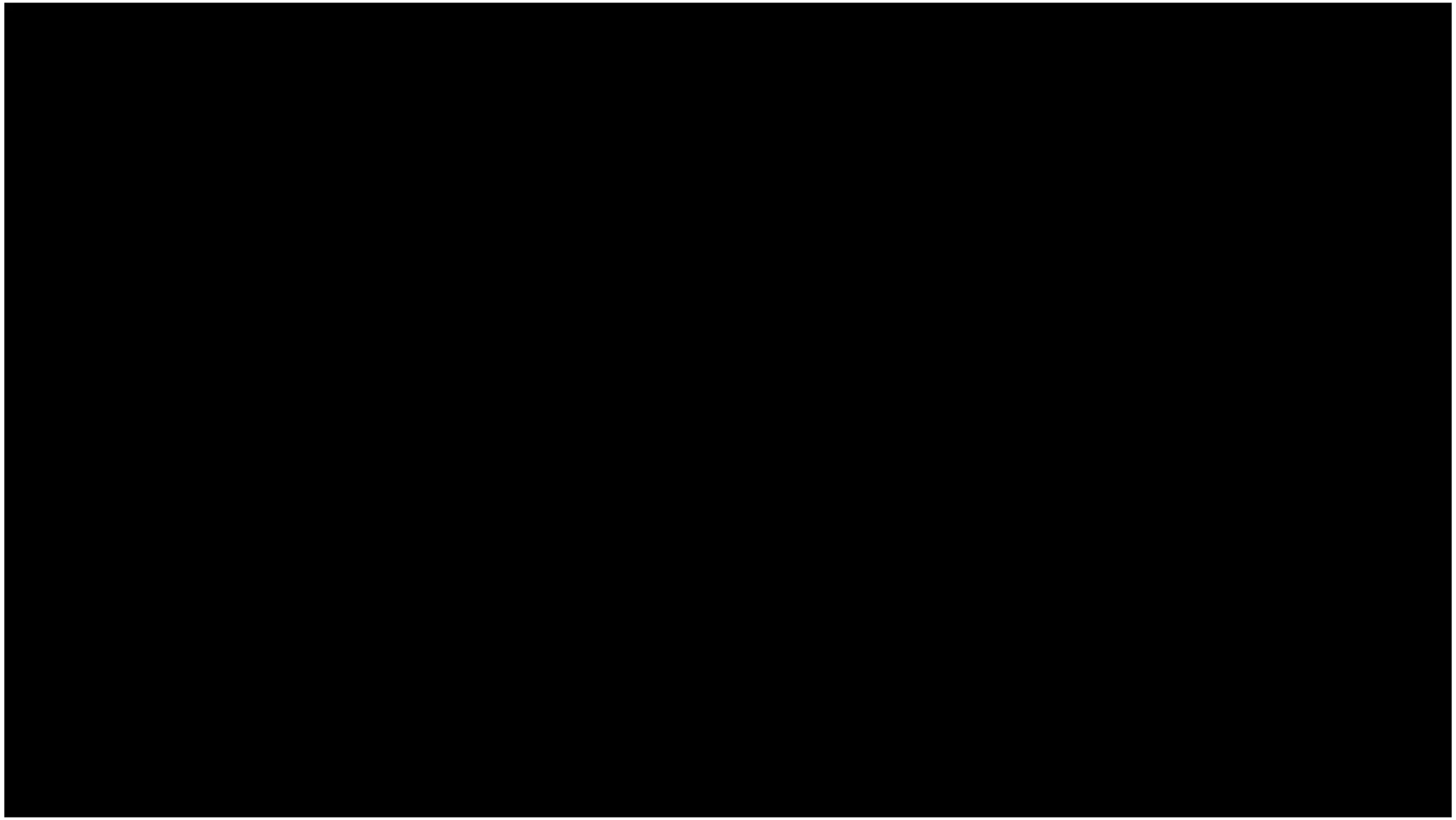


Breaking calculi with shock waves



Yoshizawa et al. 2009: http://link.springer.com/article/10.1007/s11517-009-0471-y

Commercial lithotripter



https://www.youtube.com/watch?v=qnVqSAX-GlU

Burst wave vs. shockwave lithotripsy

https://www.youtube.com/watch?v=8EJ9vqLsI_Y