UNIVERSITY OF WASHINGTON

UROLOGY

Fragmentation of kidney stones *in vitro* by focused ultrasound bursts without shock waves

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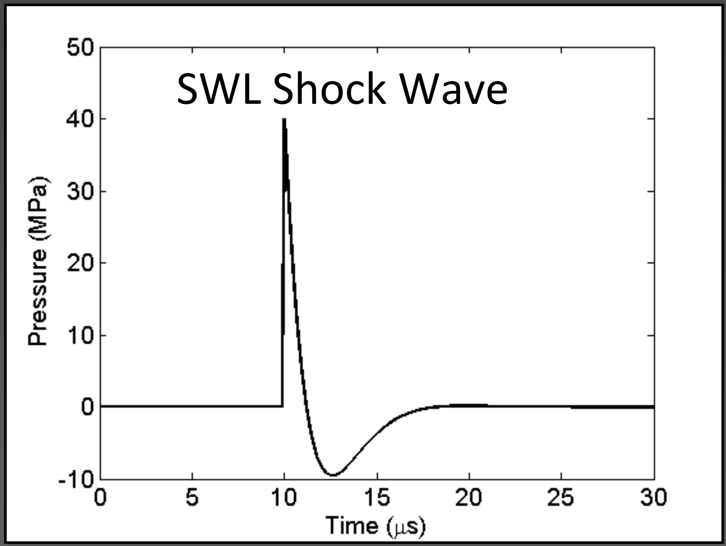
Shock Wave Lithotripsy

- Stone-free rates for shock wave lithotripsy (SWL) have not improved with newer-generation machines[1].

- Variations of shock wave output:
  - Focal width
  - Shock amplitude
  - Method of shock generation



- More invasive techniques such as ureteroscopy[2] are gaining clinical preference

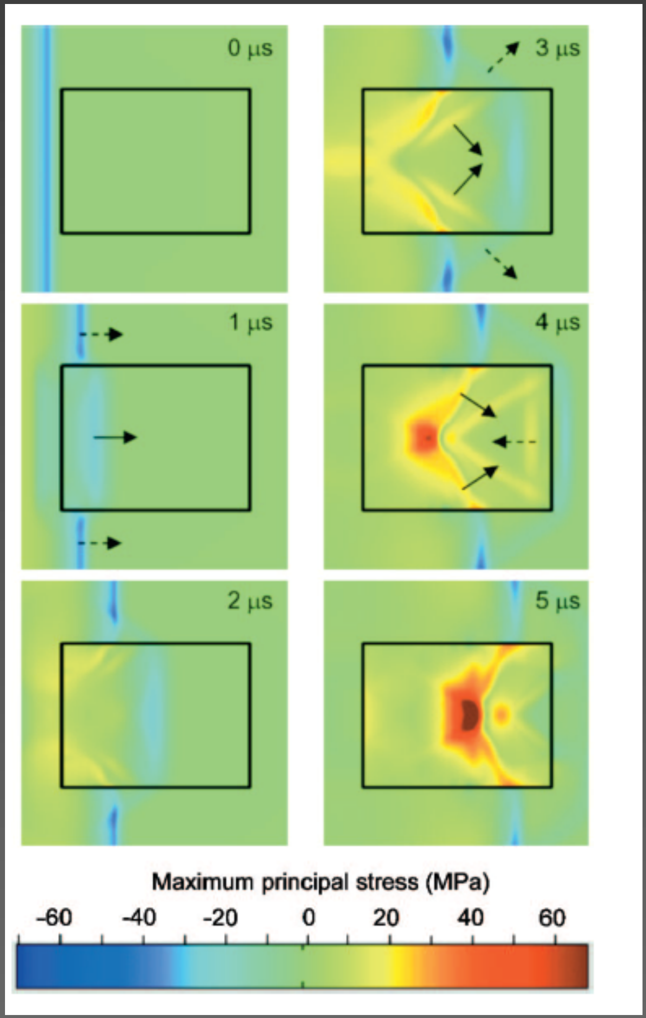
[1]Lingeman JE. J Urol 2004;172:1774.
[2]Matlaga, BR J Urol 2009;**181**:152-2156.

SWL Mechanisms

- Previous studies identified mechanisms of stone fracture[1,2]:
  - Dynamic Squeezing/Shear
  - Cavitation

- Cavitation is a primary cause of tissue injury.

Sapozhnikov et al 2007

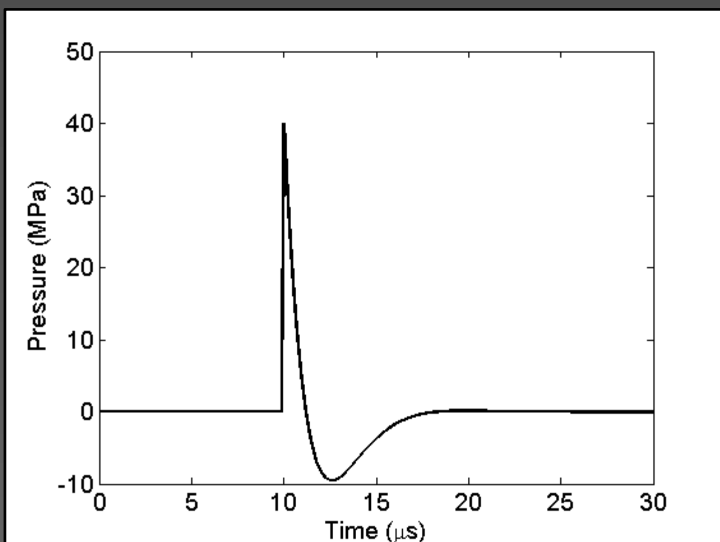


[1]Sapozhnikov et al. J Acoust Soc Am 2007:121;1190-1202
[2]Zhu et al. Ultrasound Med Biol 2002;28:661-671

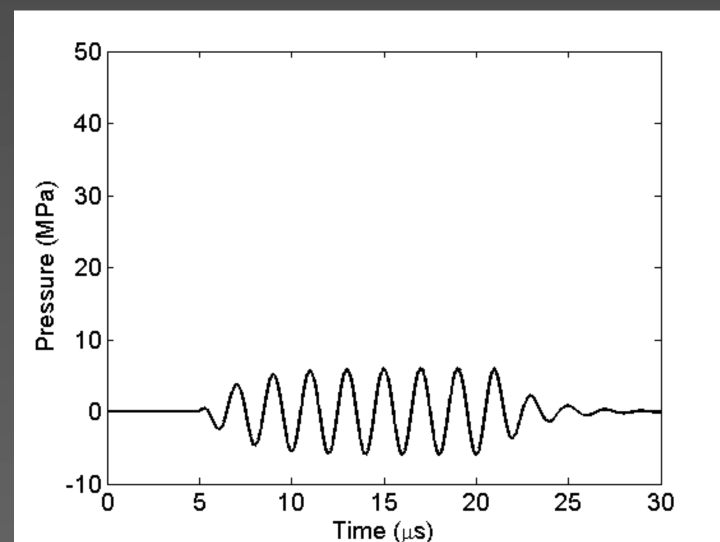
Objective

- **Hypothesis:** Fracture of stones can be effectively achieved by applying ultrasound bursts *without* shock waves:
  - Broadly focused ultrasound bursts
  - Sinusoidal ring-down instead of negative tail to minimize cavitation

SWL Shock Wave



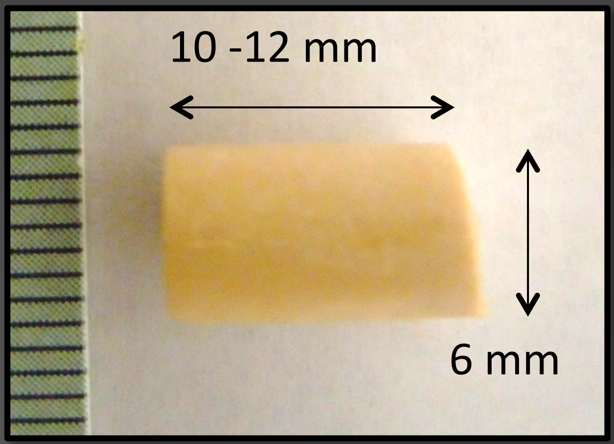
Ultrasound Sinusoidal Burst



- **Experiment:** Determine the exposures needed to fragment stones with burst waves *in vitro.*

Experiment

Cylinder Begostone Model[1]: Similar acoustic properties to COM



- **Tensile Strength:** ~3.5 MPa
- **COM Tensile Strength:** 3.1 – 5.2 MPa

Natural Stones:

- 5-10 mm uric acid, struvite, calcium oxalate monohydrate (COM), and cystine
- Submerged in water ≥ 1 week

[1]Liu Y and Zhong P. J Acoust Soc Am 2002:112;1265

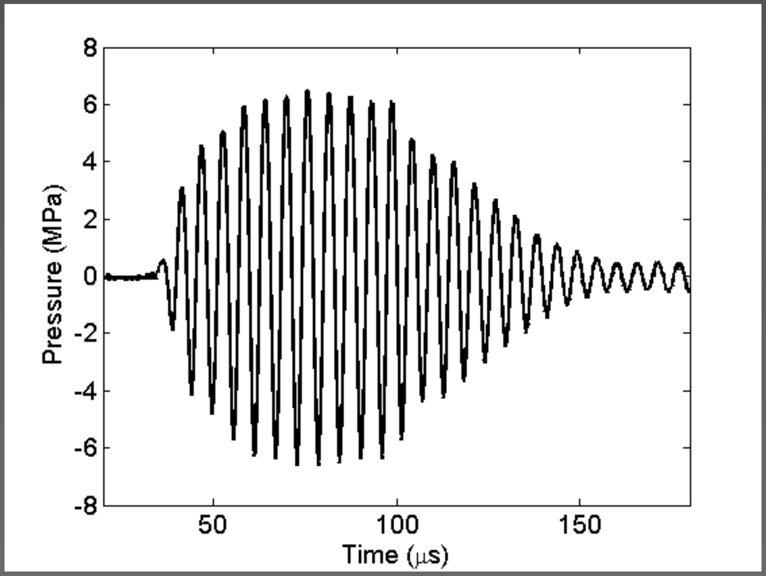
Experiment

170 kHz Transducer

Ultrasound System:

- 170-kHz focused US transducer
- 8.4 cm aperture
- -6 dB beamwidth: 31 x 8 mm
- High voltage RF amplifier

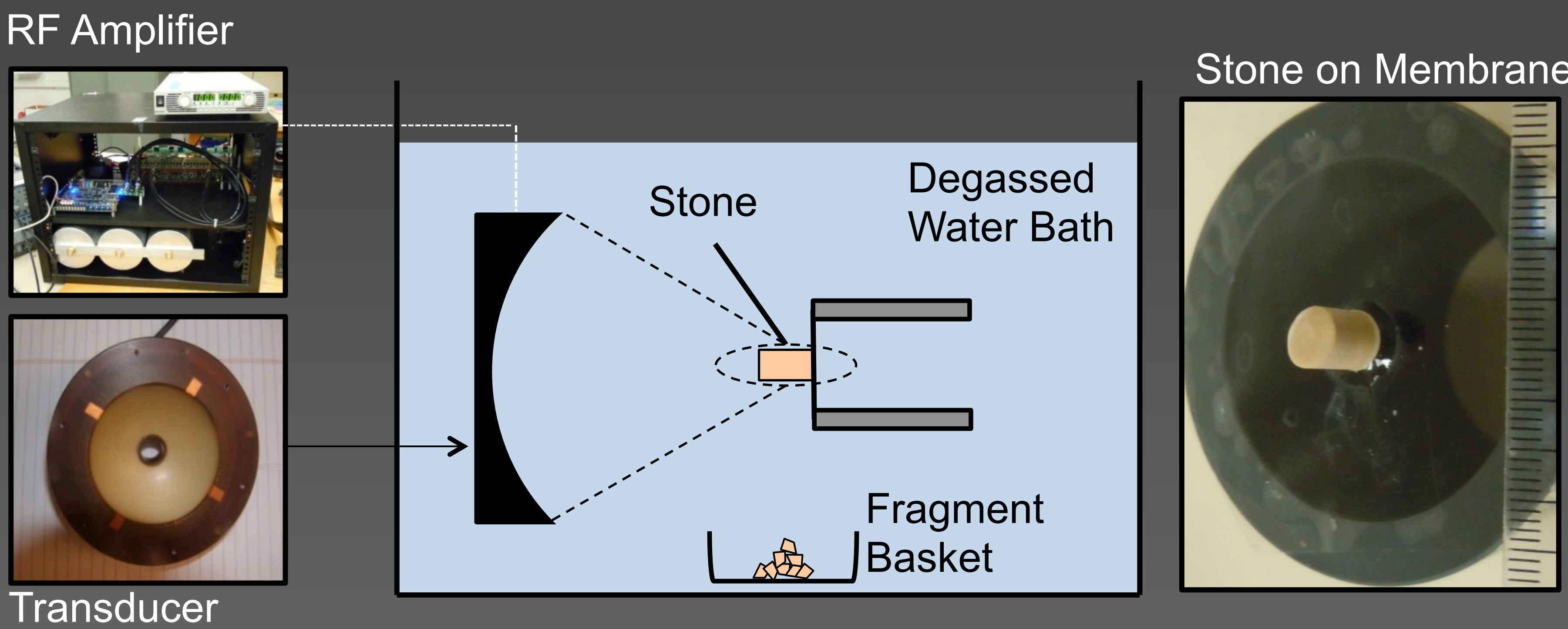
Focal Pressure Waveform



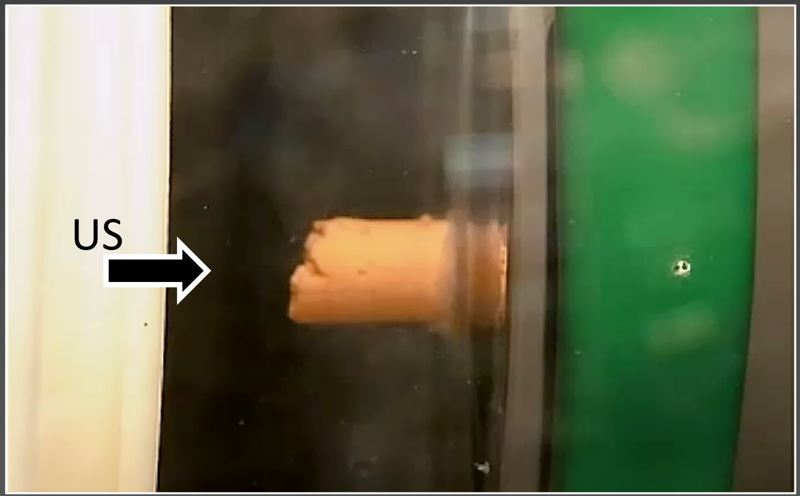
Acoustic Output:

- Focal pressure ampl. ≤ 6.5 MPa
- PRF: 200 Hz
- Burst Length: 10 cycles

Experiment


RF Amplifier
Stone on Membrane
Stone
Degassed
Water Bath
Fragment
Basket
Transducer

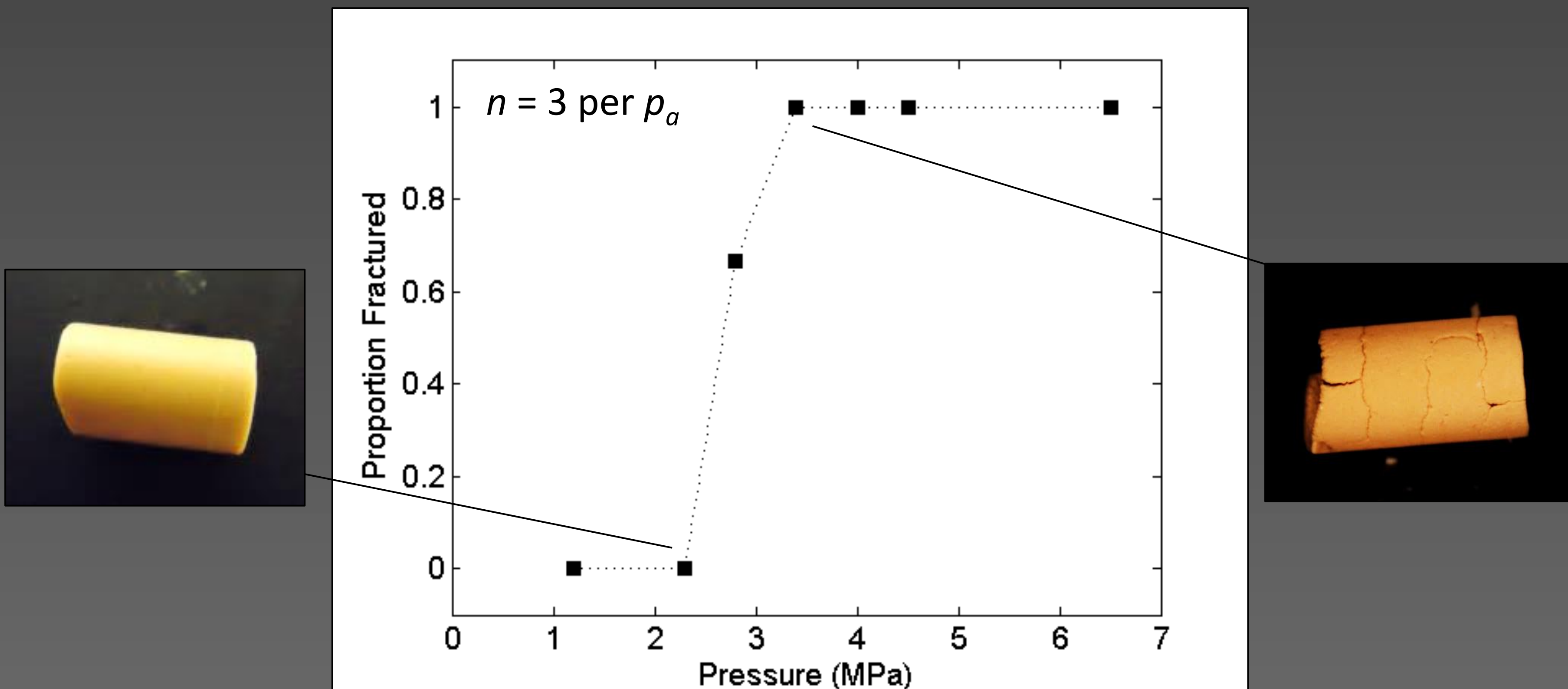
Artificial Stones



- Stones fracture and fragments separate from stone surface proximal to the transducer.
- Time to comminution at f = 170 kHz, p_a = 6.5 MPa:
  9.7 ± 2.8 minutes (n=12)

Artificial Stones

Pressure amplitude to initiate fracture at 170 kHz in 5 minutes:
$p_a \geq 2.8$ MPa



Natural Stones

Stone comminution achieved in all natural stone types treated at f = 170 kHz, p_a = 6.5 MPa

Natural Stones

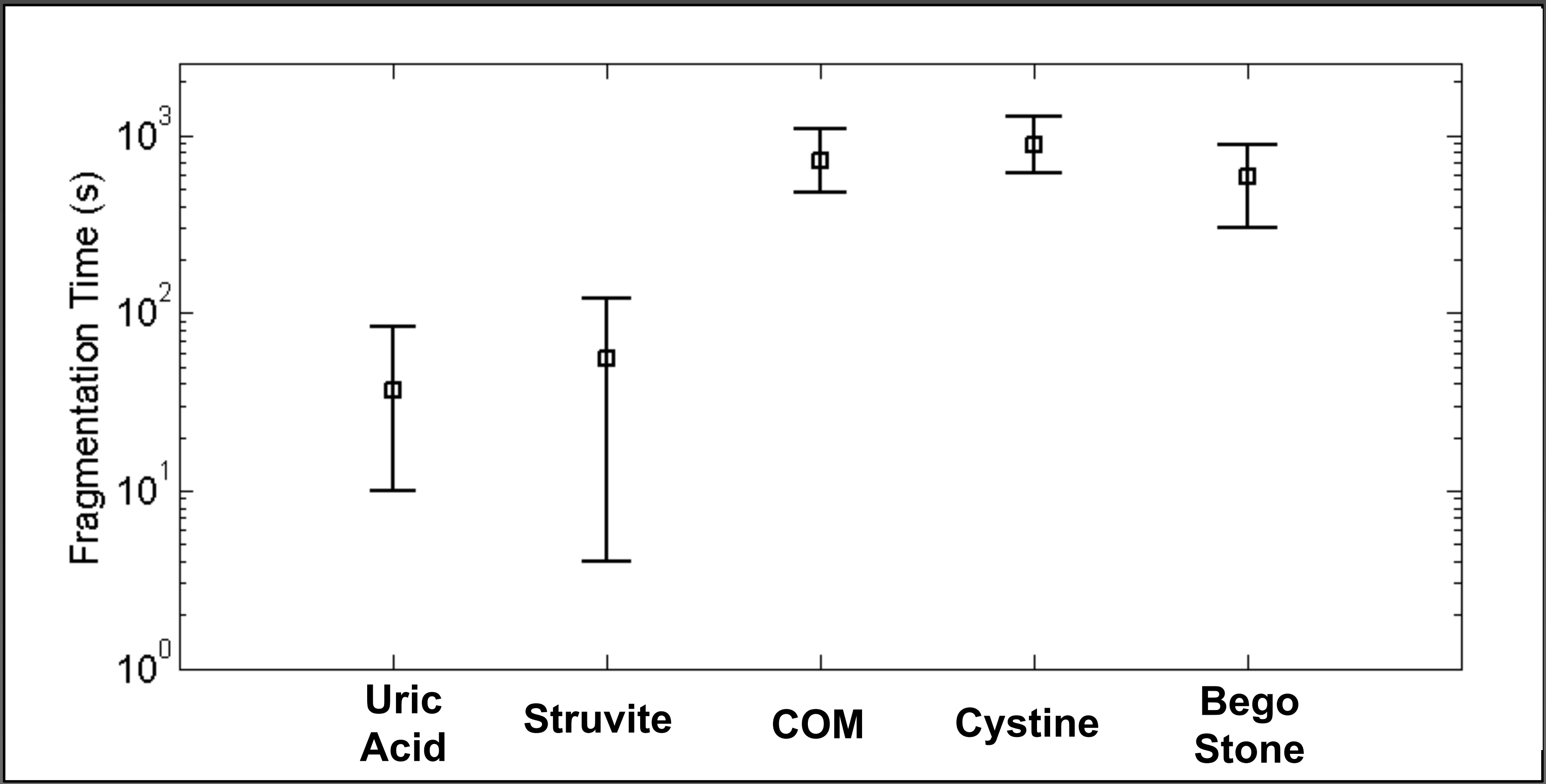
- Comminution time varied dramatically with stone composition: 4 sec – 21 min (*n*=3 each type)

Struvite Stone

Cystine Stone

Natural Stones

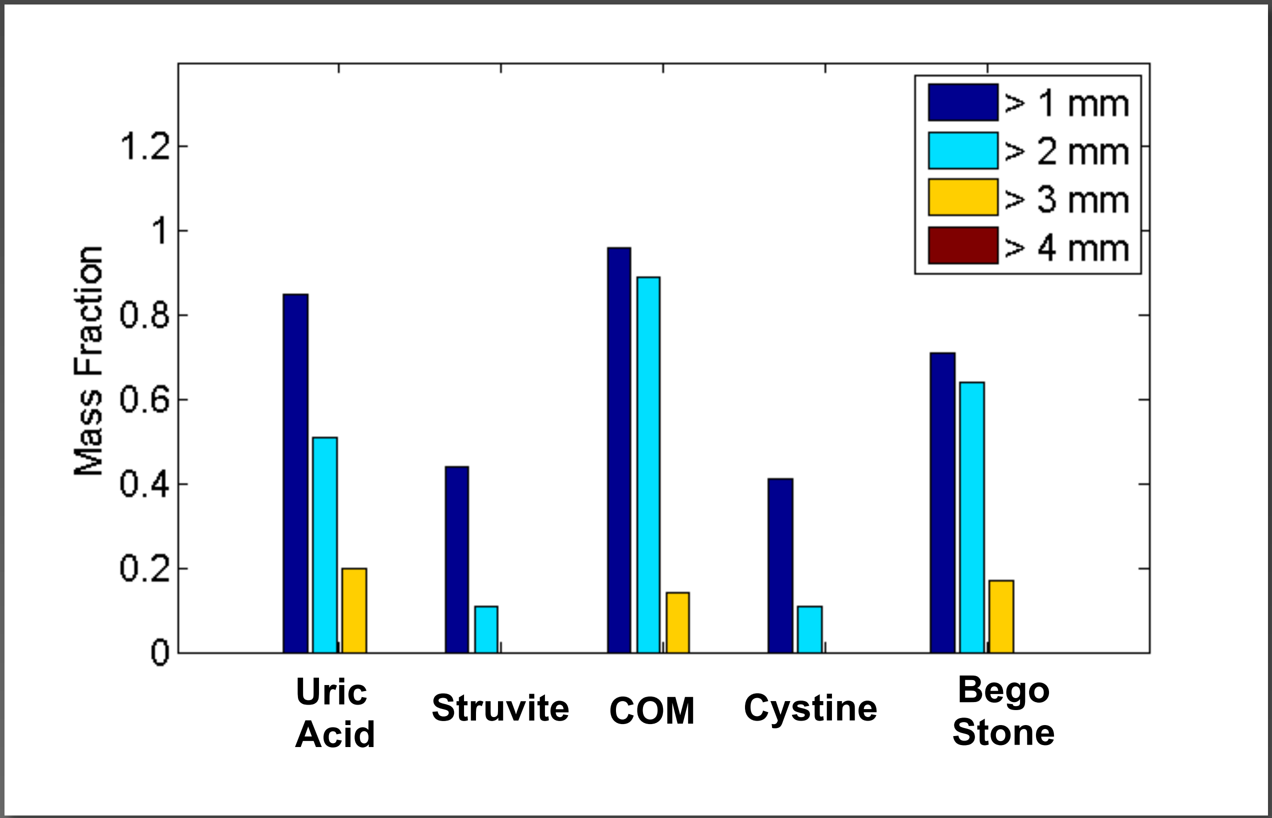
- Comminution time varied dramatically with stone composition: 4 sec – 21 min (*n*=3 each type)
- Estimated comminution rate: mean 12 ~ 520 mm^3/min



Fragment Size

- Stone fragments photographed / sieved to obtain size distribution

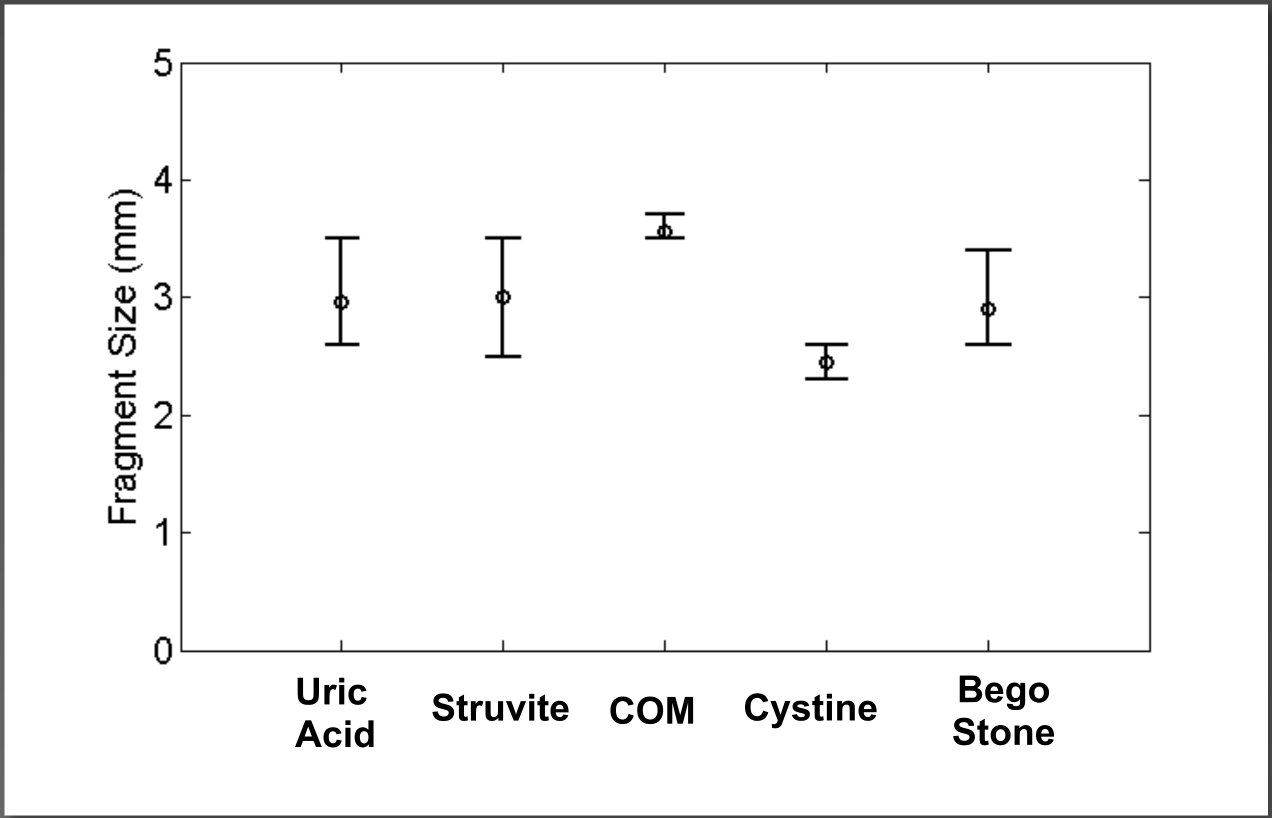
Sieved fragment distribution



Fragment Size

- Stone fragments photographed / sieved to obtain size distribution

Maximum Fragment Size



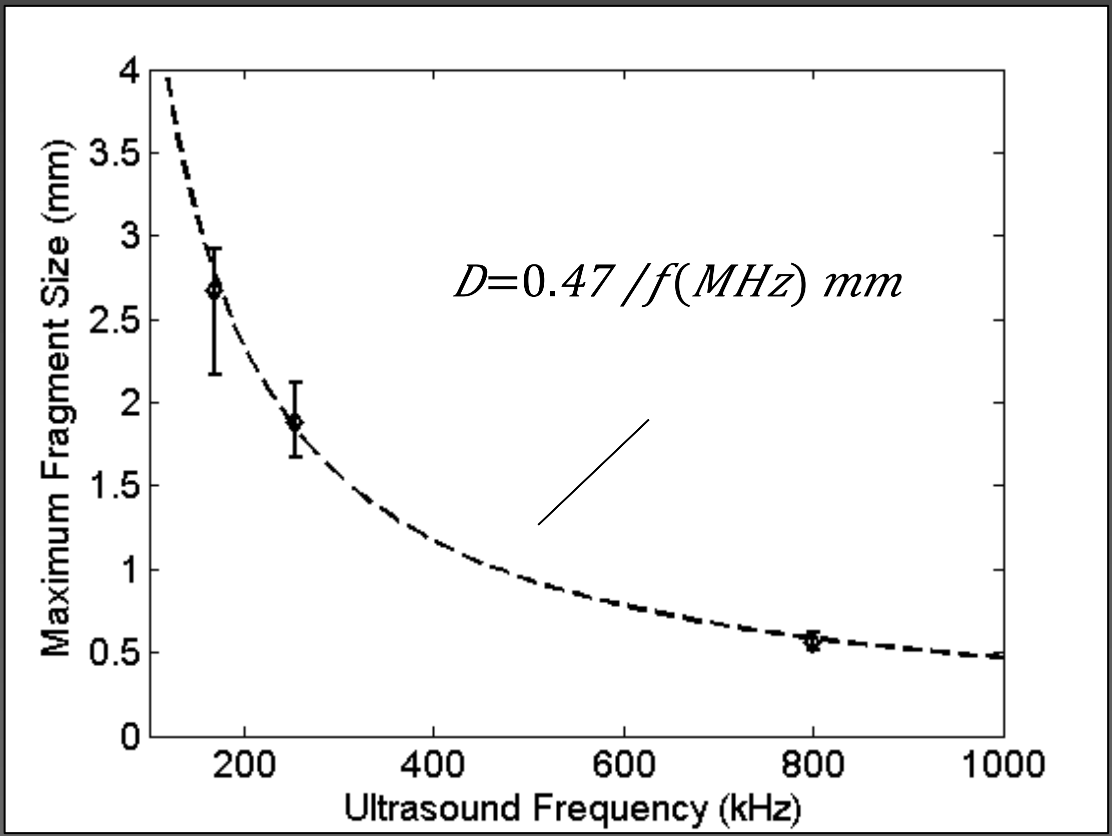
Fragment Size

- Artificial stones treated at different ultrasound frequencies
  - p_a = 6.5 MPa
  - Focal width ≥ Stone width

170 kHz **285 kHz** **800 kHz**

Fragment Size

Maximum fragment size $\propto f^{-1}$



Conclusions

- Focused ultrasound bursts without shock waves can fragment natural and artificial calculi.
- Comminution can be achieved over time frame similar to SWL and possibly faster for certain stone types.
- Fragment sizes are consistent and may be controlled by selection of ultrasound frequency.

Acknowledgments

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