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.
SWL Mechanisms

• Previous studies identified mechanisms of stone fracture:\(^1,^2\):
  • Dynamic Squeezing/Shear
  • Cavitation

• Cavitation is a primary cause of tissue injury.

^1^ Sapozhnikov et al. J Acoust Soc Am 2007:121;1190-1202
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

- **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 \(\geq 1\) week

\(^1\)Liu Y and Zhong P. J Acoust Soc Am 2002:112;1265
Experiment

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

Acoustic Output:
- Focal pressure ampl. \( \leq 6.5 \) MPa
- PRF: 200 Hz
- Burst Length: 10 cycles
Experiment

RF Amplifier

Transducer

Stone on Membrane

Stone

Degassed Water Bath

Fragment Basket
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:
  
  $$9.7 \pm 2.8 \text{ minutes (n=12)}$$
Artificial Stones

Pressure amplitude to initiate fracture at 170 kHz in 5 minutes:

\[ p_a \geq 2.8 \text{ MPa} \]
Natural Stones

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

- Communion 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 \( (n=3 \text{ each type}) \)

- Estimated comminution rate: mean 12 ~ 520 mm\(^3/\text{min}\)
Fragment Size

- Stone fragments photographed / sieved to obtain size distribution

Sieved fragment distribution

- Cystine
- COM
- Uric Acid
- Struvite
- COM
- Cystine
- Bego Stone
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 $\geq$ Stone width

170 kHz  

285 kHz  

800 kHz
Fragment Size

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

$D = 0.47 / f(MHz) \ mm$

- 170 kHz
- 285 kHz
- 800 kHz

Ultrasound Frequency (kHz)
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.
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