Surgical Management of Urolithiasis: Mechanism of Stone Damage in a New Era of Laser Lithotripsy

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Improving Mechanistic Understanding and Treatment Efficiency of Laser Lithotripsy

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Urinary Stone Disease (USD)

1. USD: 2\textsuperscript{nd} most costly benign urologic condition in the US (>\$2B/yr)

2. Laser lithotripsy (LL): treatment of choice for USD

3. Despite rapid advances in LL technologies, fundamental knowledge of LL has not changed in the past decades
Stone Damage in LL

(the MOSES Effect)

Conventional Theory: Photothermal ablation dominates; cavitation damage is negligible
New Evidence - Part I

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Fragmenting Mode (0.8 J and 10 Hz)

Dornier Medilas H Solvo 35 Laser

Broadening of crater area in water !!!
New Evidence – Part II

Parallel fiber experiments confirm cavitation damage in LL when the photothermal ablation mechanism is virtually eliminated.

High-Speed Photography

Fragmenting Mode (0.8 J and 10 Hz)

SD: standoff distance

OCT: Optical Coherence Tomography

Crater Volume vs. Pulse Number for Parallel Fiber (n = 5)

- Parallel Fiber, 0.5 mm SD
- Parallel Fiber, 1.0 mm SD
- Parallel Fiber, 2.0 mm SD
- Perpendicular Fiber
Hydrophone measurements show weak shock wave emission upon bubble collapse.

Photoelastic imaging demonstrates stress concentration at bubble collapse site in the stone.
Ho:YAG LL – Energy Transmission
(Fragmenting vs. Dusting)

(a) Glass Slide  LL Bubble  LL Fiber  Fiber SD  Water  Slide holder  To photodetector

(b) Energy Transmission vs SD (n=10)

Fragmenting
(0.8 J, 10 Hz)

Dusting
(0.2 J, 20 Hz)

SD = 0 mm, 40 J
SD = 0.5 mm, 40 J
SD = 0 mm, 40 J

1 mm  1 mm

Depth (µm)
Sliding-Window Passive Cavitation Mapping (SW-PCM)

Shock Wave Lithotripsy (SWL)

Cavitation Bubbles

US transducer array

Verasonics (DAQ)

Triggers

Delay

Reconstruct time origin 88 μs

Normalized Amp.

Time [μs]

0

1

100

110

120

130

US transducer element A-line

Norm. energy density

Time [μs]

0

0.5

1

88

90

92

94

96

98

100

Laser Lithotripsy (LL)

SD: 0.5 mm

Fiber

ACM Bubble

Stone

Fiber

PCM Bubble

Stone

ACM: Active Cavitation Mapping

PCM: Passive Cavitation Mapping
Ultrasonic Detection of LL-induced Bubble *In Vivo*
Conclusions

1. Re-evaluate comprehensively the mechanism of stone damage in LL

2. Besides photothermal ablation, cavitation (asymmetric bubble collapse with microjet impact) plays a significant role in stone damage during LL

3. This paradigm-changing observation opens up opportunities for improving LL treatment efficiency and patient outcomes based on optimization of bubble dynamics, instead maximizing laser energy delivery to the stone

4. A multidisciplinary collaboration is urgently needed to advance the knowledge and technology development in LL to benefit the clinical treatment of USD patients in the new era of LL

Thank You