Optimal Power Settings for Holmium:YAG Lithotripsy

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Abbreviations and Acronyms

COM = calcium oxalate monohydrate

MAPH = magnesium ammonium phosphate hexahydrate

TF = total fragmentation

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Purpose: We determined the optimal Ho:YAG lithotripsy power settings to achieve maximal fragmentation, minimal fragment size and minimal retropulsion.

Materials and Methods: Stone phantoms were irradiated in water with a Ho:YAG laser using a 365 μm optical fiber. Six distinct power settings were tested, including 0.2 to 2.0 J and 10 to 40 Hz. For all cohorts 500 J total radiant energy were delivered. A seventh cohort (0.2 J 40 Hz) was tested post hoc to a total energy of 1,250 J. Two experimental conditions were tested, including with and without phantom stabilization. Total fragmentation, fragment size and retropulsion were characterized. In mechanism experiments using human calculi we measured crater volume by optical coherence tomography and pressure transients by needle hydrophone across similar power settings.

Results: Without stabilization increased pulse energy settings produced increased total fragmentation and increased retropulsion (each $p < 0.0001$). Fragment size was smallest for the 0.2 J cohorts ($p < 0.02$). With stabilization increased pulse energy settings produced increased total fragmentation and increased retropulsion but also increased fragment size (each $p < 0.0001$). Craters remained symmetrical and volume increased as pulse energy increased. Pressure transients remained modest at less than 30 bars even at 2.0 J pulse energy.

Conclusions: Holmium:YAG lithotripsy varies as pulse energy settings vary. At low pulse energy (0.2 J) less fragmentation and retropulsion occur and small fragments are produced. At high pulse energy (2.0 J) more fragmentation and retropulsion occur with larger fragments. Anti-retropulsion devices produce more efficient lithotripsy, particularly at high pulse energy. Optimal lithotripsy laser dosimetry depends on the desired outcome.

Key Words: urinary calculi; lithotripsy; lasers, solid-state; efficiency; calcium oxalate

The Ho:YAG laser fragments stones through a photothermal mechanism.[1] Photon density (fluence) in the stone correlates with lithotripsy.[2] Ablation crater volume increases as pulse energy increases.[3,4] Since lithotripsy correlates with the photons delivered, a strategy for efficient lithotripsy would be to increase pulse energy (increase power).

However, prior studies of Ho:YAG lithotripsy efficiency favor pulse energy settings less than 1.0 J.[5–7] Increasing pulse energy produces increased retropulsion.[4,8,9] As a stone retropulses, the separation distance decreases between fiber tip and stone surface. Since Ho:YAG energy is well absorbed by water, retropulsion re-

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sults in less energy reaching the stone.[10] Increasing pulse energy also produces larger fragments.[6]

To our knowledge how these combined factors (pulse energy, pulse frequency and retropulsion) work together to impact lithotripsy efficiency is unknown. There are competing interests to deliver more energy per time (more power) and achieve faster lithotripsy but at a potential cost of increased retropulsion and larger fragments.[3–6,8,9,11] To determine optimal power settings for Ho:YAG lithotripsy we studied the effect of power settings on fragmentation, fragment size and retropulsion.

MATERIALS AND METHODS

Experiments

Retropulsion and fragmentation efficiency. Uniform Ultra-cal 30 stones (calcium sulfate dehydrate)[12] 6.35 mm (¼ inch) in diameter were constructed. All phantoms were hydrated overnight in saline before experiments. For all lithotripsy experiments phantoms were positioned in a water bath in a clear plastic cylinder with a diameter of 8 mm that was open at each end. A mm grid was positioned beneath the water bath for retropulsion (phantom displacement) measurement.

All phantoms were irradiated with 100 W Ho:YAG energy using a polished 365 μm Slimline-365 optical fiber (Lumenis®) stabilized in a 5Fr ureteral catheter. The fiber and catheter were hand held. All phantoms received 500 J total energy. Six power settings were tested (see table). A seventh post hoc cohort was tested at 0.2 J and 40 Hz to a total of 1,250 J energy exposure. This increased energy exposure was tested to simulate the same total fragmentation as if 0.2 J pulse energy were used. The objective was to achieve the same total fragmentation as occurs with higher pulse energies since the clinical goal is to fragment a stone to a specific end point. Two experimental conditions were tested, including phantoms irradiated 1) with no stabilization device and 2) with a stabilization device deployed behind the stone to fix the stone in place and prevent retropulsion.

Two stabilization devices were tested, that is the Accordion® and the BackStop™. The Accordion is a hydrophilic catheter that can be passed on a 0.035 or 0.038-inch guidewire. When deployed, it opens a 10 mm diameter occlusion film with multiple folds proximal to the stone.[13] The multiple folds look something like an accordion. It can be collapsed back to its catheter profile. BackStop is a reverse thermosensitive polymer that can be deployed in the ureter via a catheter inserted through a ureteroscope working channel. The polymer forms a gel plug at body temperature that occludes the ureter. At the end of the procedure room temperature irrigation is used to flush the plug and the gel plug liquefies and transports out the ureter.[14] For each power setting and stabilization condition 10 phantoms were tested.

Before lithotripsy each dry phantom mass was measured. After lithotripsy phantoms were dried and fragments were passed through sequential geological sieves to determine fragment size distribution.[15] TF was defined as the initial phantom mass minus the dominant residual

Initial stone phantom mass, retropulsion and stone fragment size increase with pulse energy, and fragmentation by power setting

	Mean ± SD 500 J Total Exposure						Mean ± SD 1,250 J Total Exposure	p Value
Initial stone phantom mass (gm):*	0.2 J 10 Hz	0.2 J 40 Hz	0.5 J 10 Hz	0.5 J 40 Hz	1.0 J 10 Hz	2.0 J 10 Hz	0.2 J 40 Hz	
No device	548 ± 23	563 ± 20	541 ± 23	548 ± 31	539 ± 32	560 ± 23	544 ± 18	0.24
Accordion	544 ± 24	558 ± 27	553 ± 17	549 ± 26	553 ± 17	549 ± 18	544 ± 21	0.79
BackStop	543 ± 35	548 ± 37	546 ± 39	493 ± 39	525 ± 28	530 ± 31	520 ± 23	<0.01
p value	0.43	0.45	0.52	<0.05	0.74	0.71	0.80	
Displacement (mm)†	26 ± 6	22 ± 5	58 ± 15	63 ± 9	98 ± 15	152 ± 38	57 ± 13	<0.0001
Fragmentation by power setting (gm):‡								
No device	11 ± 2	23 ± 5	40 ± 12	20 ± 6	52 ± 12	48 ± 9	36 ± 8	<0.0001
Accordion	13 ± 5	29 ± 5	45 ± 10	50 ± 7	85 ± 34	141 ± 29	68 ± 8	<0.0001
BackStop	25 ± 10	21 ± 4	36 ± 9	47 ± 11	83 ± 13	130 ± 40	43 ± 4	<0.0001
p Value	<0.01	0.92	0.43	<0.001	<0.001	<0.001	<0.02	
Fragment size by pulse energy (% greater than 1 mm):§								
No device	0 ± 0	0 ± 0	5 ± 12	5 ± 2	4 ± 2	1 ± 2	0 ± 0	0.02
Accordion	0 ± 0	0 ± 0	10 ± 4	15 ± 12	37 ± 9	36 ± 8	0 ± 1	<0.0001
BackStop	0 ± 0	3 ± 6	0 ± 0	27 ± 14	31 ± 8	43 ± 11	2 ± 3	<0.0001
p value	0.99	0.43	0.10	<0.01	<0.001	<0.001	0.17	

* Pairwise statistically significant differences for BackStop 0.5 J 40 Hz vs all other cohorts and for 0.5 J 40 Hz BackStop vs no device and Accordion.

† Pairwise statistically significant differences for all comparisons except 0.2 J 10 Hz vs 0.2 J 40 Hz and 0.5 J 10 Hz vs 0.5 J 40 Hz vs 0.2 J 40 Hz (1,250 J total).

‡ Pairwise statistically significant differences for no device 0.2 J 10 Hz vs all other cohorts, 0.2 J 40 Hz vs 0.2 J 10 Hz, 0.5 J 10 Hz, 1.0 J 10 Hz, 2.0 J 10 Hz and 1,250 J total cohorts, for Accordion 0.2 J 10 Hz and 0.2 J 40 Hz vs all other cohorts, 0.5 J 10 Hz vs 0.2 J 10 Hz, 0.2 J 40 Hz, 1.0 J 10 Hz and 2.0 J 10 Hz, 1.0 J 10 Hz vs 0.2 J 10 Hz, 0.2 J 40 Hz, 0.5 J 10 Hz and 2.0 J 10 Hz cohorts, and 2.0 J 10 Hz vs all other cohorts, and for BackStop 0.2 J 10 Hz vs 0.5 J 40 Hz, 1.0 J 10 Hz, 2.0 J 10 Hz and 1,250 J total cohorts.

§ Pairwise statistically significant differences for no device 0.5 J 40 Hz vs 0.2 J 10 Hz, and 0.2 J 40 Hz vs 0.2 J 40 Hz (1,250 J total cohort), for Accordion 0.2 J and all other pulse energy cohorts, and 0.5 J cohorts and all other cohorts, and for BackStop 0.2 J and 0.5 J 40 Hz, 1.0 J 10 Hz and 2.0 J 10 Hz cohorts.