Are We Cutting Ourselves Short? Laser Lithotripsy Performance Based on Differences in Fiber-tip Preparation


OBJECTIVE
To better understand the impact of laser fiber-tip configuration on lithotripsy performance, we undertook an in vitro study comparing 3 fiber-tip configurations: (1) new (single-use), (2) cleaved (reusable), and (3) coated (cut with scissors).

METHODS
Lithotripsy was performed using a Ho:YAG laser utilizing fragmentation (1 J × 10 Hz) and dusting (0.5 J × 20 Hz) settings. BegoStones were fragmented with a laser fiber advancing at a speed of 1 mm/s (220 seconds of activation). Three fiber-tip configurations were tested: new single-use standard (242 μm core) and cleaved (272 μm core), compared to the same fiber-tip coated/cut flush with scissors, respectively. Study outcome was difference in stone mass before and after each experiment. Power output was measured using a power meter.

RESULTS
Fragmentation for new or cleaved fibers was greater than the coated/cut flush fiber-tip (P < 0.05). For 1 J × 10 Hz and 0.5 J × 20 Hz settings, fragmentation was 59% and 75% higher with new fiber-tip compared to the coated/cut flush fiber-tip, respectively. For 1 J × 10 Hz and 0.5 J × 20 Hz settings, fragmentation was 51% and 45% higher with cleaved fiber-tip compared to the coated/cut flush fiber-tip, respectively. Power output at the end of laser activation was higher for new and cleaved fiber-tips.

CONCLUSION
New and cleaved laser fibers demonstrated superior lithotripsy performance compared to fibers that were coated/cut flush with scissors. Cutting single-use laser fibers risks damaging the fiber-tip which can disperse the energy and reduce lithotripsy efficiency.

U
eroscopy and holmium laser lithotripsy is the most common modality used to treat kidney stones in North America.1,2 Energy is delivered from the laser system to the target tissue through a specially designed fiber made with layers of different material.3 The inner most layer, the core, is made of pure fused-silica and serves to limit strain resulting from bending the fibers. Because the fiber is made of glass, its tip is prone to damage resulting in reduced energy output.4

If the laser fiber-tip becomes damaged, there are several methods to restore its condition and improve energy output; this is important especially for reusable fibers.5,6 First, the fiber jacket is stripped with a laser fiber stripper to expose the transparent core and cladding. Once the jacket is stripped, the fiber tip can be restored using a scribe pen, ceramic scissors, metallic scissors, and blade scalpel. Cutting the fiber-tip with metallic scissors or blade scalpel has been shown to result in inferior power output when compared to cleaving the tip with ceramic scissors or cleaving tool.5,6 It is important to distinguish between cutting and cleaving. Cutting creates a microscopically rough fractured end surface while cleaving is a process of controlled breaking in which an initial scratch is made with a blade, and then tension is applied to separate the 2 pieces producing a tip with a flat microscopically smooth surface.7

In theory, using a new or properly cleaved fiber should result in optimal fragmentation. However, a recent study by Kronenberg et al demonstrated that cutting the laser fiber-tip with metallic (Mayo) scissors before laser lithotripsy results in better fragmentation when compared to stripped fibers.8 They assessed ablation when the fiber-tip was either cut or cleaved, making it flush with the jacket, described as

Disclosures: KRG is a consultant for Lumenis and Boston Scientific. BEK is a consultant for Bard, Boston Scientific, and Olympus. WWR is a consultant for Boston Scientific.

Funding: This study was supported by a scientific research grant from Boston Scientific.

From the Department of Urology, University of Michigan, Ann Arbor, MI; the Department of Urology, Ohio State University, Columbus, OH, MI; and the Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI.

Address correspondence to: Ali H. Aldoukhi, M.B.B.S., M.S., Department of Urology, University of Michigan, Medical Sciences Unit I, Room 4432, 1301 Catherine Street, Ann Arbor, MI 48109-2900. E-mail: ahaldouk@med.umich.edu

Submitted: May 23, 2019, accepted (with revisions): August 20, 2019

https://doi.org/10.1016/j.urology.2019.08.027 0090-4295 79
coated" tip. They reported that a coated fiber provided better ablation than a stripped laser fiber, with no significant difference in outcomes when using metallic or ceramic scissors to make the fiber coated. In light of this evidence, some urologists cut the laser fiber-tip with Mayo scissors at the beginning of laser lithotripsy. When we tried this in clinical practice we noticed suboptimal fragmentation. To better quantify laser lithotripsy performance we undertook an in vitro study comparing in vitro fragmentation outcomes when using "new" and "cleaved" laser fibers (control cohorts) to the same fibers that had their tips cut with Mayo scissors, to make them "coated/cut flush.”

METHODS

Experimental Setup
Artificial stones were created using BegoStones (15:5 ratio) with a completely flat surface measuring 30 × 30 × 3 mm as the stone model for this study. Laser lithotripsy was performed using a 120W holmium laser (P120, Lumenis, CA) utilizing both fragmentation (high pulse energy, low frequency) laser settings (1.0 J × 10 Hz) and dusting (low pulse energy, high frequency) settings (0.5 J × 20 Hz) using short pulse mode. We assessed 2 different laser fibers: a 242 μm core fiber (Flexiva 200, Boston Scientific, MA) and a 272 μm core fiber (Rocamed, Monaco, France). The laser system we have in our laboratory is a research model, so it is able to read and work with both fibers. Laser lithotripsy was performed while the fiber was attached to a 3D positioner system (Velmex, NY). The positioner was programmed to advance the fiber at a speed of 1 mm/s around the stone to perform 10 connected lines that were 20 mm long with 2 mm spacing between each line (Supplementary Fig. 1), equivalent to 3.6 minutes (220 seconds of continuous laser activation).

242 μm Core Fiber: New Vs Coated/Cut Flush Fiber Experiments
Two different conditions, “new” and “coated/cut flush,” were tested using the 242 μm core fiber. For new tip condition, a new single-use fiber with the tip intact as provided by the manufacturer was tested. For the coated/cut flush condition, a new fiber was used but the tip was cut with Mayo scissors without stripping the fiber jacket. New scissors were used in this study. Each tip condition experiment was repeated 5 times with a new laser fiber-tip used for each trial. Table 1 lists the experimental conditions in this study.

272 μm Core Fiber: Cleaved Vs Coated/Cut Flush Fiber Experiments
Two different conditions were tested using the 272 μm core fibers. The “cleaved” condition includes stripping the laser fiber using a fiber buffer stripping tool (T14S21, Thorlabs, NJ) then cleaving it using a ruby scribe to provide a tip with a new-like condition. This method has been shown to contain the entirety of the laser beam. Furthermore, the fiber tip was dried before each measurement. Measurement was not performed before each experiment to avoid burning the sheath around the fiber for the cut fiber-tip condition which could affect the outcome of the study. The fiber-tip was inspected before and after each experiment using optical microscopy to compare the extent of damage before and after each experiment.

Table 1. Summary of experimental conditions and definitions of laser fiber tips in this study

<table>
<thead>
<tr>
<th>Experimental Condition</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>New out of the box laser fiber</td>
</tr>
<tr>
<td>Cleaved</td>
<td>A laser fiber with the jacket stripped then cleaved with scribe pen</td>
</tr>
<tr>
<td>Coated/cut flush</td>
<td>A laser fiber that was cut with Mayo scissors without stripping the jacket</td>
</tr>
</tbody>
</table>

Study Outcomes and Statistical Analysis
Dry mass of the stone was recorded and then stones were hydrated prior to each experiment. Stones were hydrated for 16-24 hours prior to each experiment and were desiccated in dry environment for at least 24 hours after each experiment. Study outcome was difference in stone mass before and after each experiment. Student’s t test was used to compare cohorts mean (R statistical computing v3.4). All testing was 2-sided and the probability of a type I error was set at .05.

RESULTS
Mean initial stone mass for all cohorts was 5.0 g (±0.1; range 4.7-5.2 g). Figure 1 presents fragmentation outcomes comparing the performance of new and cleaved laser fiber-tips with coated/cut flush fiber-tips for each type of laser fiber (230 and 272 core) tested. Regardless of fiber type, the new and cleaved fiber-tip condition resulted in significantly greater fragmentation compared to the coated/cut flush version, for both laser settings tested (P value <.05). New fibers with an intact tip resulted in 59% and 75% more fragmentation compared to the coated/cut flush fiber-tip when using 1.0 J × 10 Hz and 0.5 J × 20 Hz, respectively. Similarly, the cleaved laser fiber-tip resulted in 51% and 45% more fragmentation than the coated/cut flush fiber-tip when using 1.0 J × 10 Hz and 0.5 J × 20 Hz, respectively.

Power output at the end of each experiment is depicted in Figure 2. In general, new and cleaved laser fibers had higher power output at the end of each experiment compared to coated/cut flush laser fiber-tips. The difference in power output was statistically significant when comparing coated/cut flush fiber-tips with new and cleaved fiber-tips, at a setting of 1.0 J × 10 Hz (new, P = .03; cleaved, P = .04). While the power output was lower with coated/cut flush fiber-tips when comparing against new and cleaved fiber-tips at a setting of 0.5 J × 20 Hz, the differences were not statistically significant (new, P = .11; cleaved, P = .06). Microscopic evaluation showed minimal fiber-tip damage after lithotripsy when using both new and cleaved fibers but extensive damage for coated/cut flush fiber-tips.
DISCUSSION

In this study we compared in vitro fragmentation outcomes between different laser fiber-tip conditions. First, we compared fragmentation between new laser fibers with the tip intact against the same fiber converted to a coated fiber, in which the tip was cut with metallic scissors. Comparison between cleaved laser fiber-tip and coated/cut flush laser fiber-tip was also performed. Fragmentation was significantly greater when using both new and cleaved laser fiber-tips compared to the coated/cut flush laser fiber-tip versions. Moreover, power output was higher for new and cleaved fiber-tips compared to coated/cut flush fiber-tip. Microscopic evaluation demonstrated significant damage to fiber-tips that were cut with metallic scissors, compared to new and cleaved laser fiber-tips.

The findings in our study are similar to data reported in the literature.10,11 Yaroslavsky et al compared ablation rates between cleaved fiber-tip prepared with a ceramic scissors and coated fiber-tip cut with metallic scissors. They reported lower ablation rates for the coated/cut flush fiber-tip.11 For instance, ablation rate was 0.2 mm$^3$/s for cleaved fiber-tip compared to 0.09 mm$^3$/s for coated/cut flush fiber-tip when tested at 0.5 J × 15 Hz. Our findings

Figure 1. Fragmentation for new and cleaved fiber tips compared to cut fiber tips following 3.6 minutes of laser lithotripsy at 1J × 10 Hz and 0.5J × 20 Hz. (Color version available online.)

Figure 2. Power output measured for new, cleaved, and cut laser fiber tips following 3.6 minutes of laser lithotripsy at 1J × 10 Hz and 0.5J × 20 Hz.
are in agreement with Yaroslavsky et al, and contrast to those reported by Kronenberg et al. When we tested coated/cut flush laser fiber-tips cut with metallic scissors, lithotripsy performance was inferior to the new or cleaved fiber-tip. One major difference between our study and the study by Kronenberg et al was in laser lithotripsy time. They undertook 30 seconds of lithotripsy time while we performed 220 seconds of laser lithotripsy. Longer laser lithotripsy time might be a factor in highlighting the differences in fragmentation outcomes.

One reason to explain reduction in fragmentation for coated/cut flush laser fiber-tip is due to reduction in energy transmission. Laser fibers are made from fused silica (glass) and they are prepared by manufacturers to have a smooth tip. This is important for optimal energy transmission. New laser fibers produce a beam profile that is equally distributed (near Gaussian) but the beam profile becomes irregular with hotspots once the tip becomes damaged. Lee et al compared ablation for a properly cleaved laser fiber to a fiber that was damaged during lithotripsy after delivering 100 J of energy. They demonstrated that a damaged laser fiber produced a stone crater that was irregular with less ablation compared to a cleaved/undamaged fiber tip; the crater shapes corresponded to the beam profiles for damaged and undamaged laser fibers. Damaged fiber tips demonstrate microfractures that decreases light collimation leading to energy scatter with reduction in forward optical energy transmission. We hypothesize that some of the energy might be reflected back, get absorbed in the cladding, and/or the aberrant trajectories of the laser beam causes some destructive interference; however, this needs further study.

Cutting the fiber-tip with metallic scissors damages the tip and can decrease energy transmission by approximately 33%. If one cuts the laser fiber with metallic scissors and then sets the power setting to 10 W, the fiber will emit only 6.7 W. The reduction in power output would diminish fragmentation as demonstrated by the data in our study. Moreover, the condition of the scissors might affect the outcomes. Using old scissors with dull blades might worsen the power output even further because of the irregular surface created from the old blades.

Another explanation for the reduction in fragmentation for coated/cut flush laser fiber-tip is the increase in working distance created by the fiber jacket. This was demonstrated in a recent study by Ritchie et al. They assessed the effect of stripping laser fiber-tips on fragmentation. They compared fragmentation between 2 laser fiber-tip conditions, stripped and coated/cut flush (not stripped); laser fiber-tips were cleaved with ceramic scissors for the 2 cohorts. They found 25% higher fragmentation when using a stripped laser fiber compared to a coated/cut flush tip. They attributed the reduction in fragmentation for coated/cut flush tip to the coating itself, as it acts as a buffer increasing the distance between the fiber-tip and the stone. An increase in fiber-tip to stone distance results in less fragmentation. It is also possible that power loss may occur because the jacket blocks some of the laser beam.

The difference between new and coated/cut flush laser fiber-tips in this study ranged between 59% and is more pronounced than the 25% difference reported in the study by Ritchie et al for similar laser setting. One major difference between our study and Ritchie et al is the fact that they cleaved the laser fiber with ceramic scissors for both study cohorts. However, in our study the fiber was cut with metallic scissors in the coated/cut flush cohort which further worsens power output.

Our data do not support cutting the laser fiber-tip at the beginning of ureteroscopy and laser lithotripsy. When using single-use fibers, laser lithotripsy is more efficient if the fiber is used as provided by the manufacturer. When using reusable fibers, cleaving and stripping the fibers before they are used is advocated. One advantage of using a coated/cut flush fiber-tip over a cleaved and stripped fiber is the improved visibility that a coated/cut flush fiber provides. Some surgeons do not like to use the aiming beam during lithotripsy, and in this situation, a transparent fiber-tip is difficult to see. In the future, this issue may be overcome if manufacturers are able to provide urologists with colored tips that are easier to see eliminating the surgeon’s need to cut the fiber-tip to improve visibility.

In this study we did not assess the best option for reconditioning the fiber-tip once it burns back to the jacket during laser lithotripsy. Data in the literature supports stripping and cleaving the tip with ceramic scissors. However, this depends on the availability of sterilizable ceramic scissors and strippers in each institution. The best option currently is to use laser settings with low pulse energy and long pulse mode laser to reduce fiber burnback.
This study has several limitations. First, only artificial stone models with 1 composition were used in this study. However, using BegoStone provides consistent and reproducible data, and was used in all other studies evaluating fiber-tip configuration performance. Also, we did not test 365 core fiber size in this study. We selected the 242-272 core fibers as they are the most commonly used sizes for ureteroscopic laser lithotripsy. A major strength of our study is that when we assed single-use fibers, we tested a brand new fiber for each experiment, thus at considerable cost. Another limitation of this study is that we tested laser fibers from 2 manufacturers only. The outcomes might be different for other laser fibers. Also, only short pulse mode was used in this study. We used short pulse because it is the default mode in all laser systems. Earlier studies have not specified which pulse mode was used. Nevertheless, we would expect the trend to be the same between new and cleaved and coated/cut flush regardless of pulse duration. However, further studies are needed to confirm this. Long pulse mode is known for its protective effect on fiber tip degradation compared to short pulse.

Finally, we used a laser that is compatible with both Boston Scientific and Rocamed laser fibers because it is a laboratory system. The use of Rocamed fibers is not possible on next-generation commercially available Lumenis lasers.

In conclusion, fragmentation during holmium laser lithotripsy is significantly affected by the fiber-tip condition. Using a new, or cleaved and stripped laser fiber-tip, results in much better fragmentation compared to coated/cut flush laser fibers that have been cut with metallic scissors. Cutting the laser fiber-tip reduces energy output and risks damaging the tip.

Acknowledgments. The authors would like to acknowledge Adam Nodiff, a senior product manager at Boston Scientific, for his advice on laser fiber technology.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.urology.2019.08.027.

REFERENCES