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Carbon Debris and Fiber Cleaving: Effects on Potassium-Titanyl-Phosphate Laser Energy and Chorioallantoic Membrane Model Vessel Coagulation

Lauren F. Tracy, MD; James B. Kobler, PhD; Jarrad H. Van Stan, PhD; James A. Burns, MD, FACS

Objectives/Hypothesis: Photoangiolytic precision afforded by the 532-nm potassium-titanyl-phosphate (KTP) laser relies on predictable energy delivery. Inadequate energy output can cause vessel rupture, and excessive energy can cause thermal damage. The quality of the cleaved surface and carbon deposits from ablated tissue are two factors that could negatively impact fiber performance. The effects of these on energy output and blood vessel coagulation were assessed using a chorioallantoic membrane (CAM) model.

Study Design: Comparative analysis.

Methods: Laser fibers with carbon debris, optimal fiber cleaving, and suboptimal cleaving were inspected at three times magnification, and the light dispersion pattern of each fiber was rated. The average energy output from consecutive pulses through each fiber configuration was recorded. The effect of these fiber conditions on clinical efficacy was estimated by measuring vessel coagulation versus rupture in the CAM model. Repeated measures analysis of variance compared results.

Results: Carbon debris and suboptimal cleaving resulted in decreased energy output in comparison to optimal cleaving ([−Δ244 mJ, d = 4.31, P < .001] and [−Δ195 mJ, d = 6.04, P < .001]). Optimal cleaving resulted in immediate coagulation of vessels. Fibers with suboptimal cleaving and carbon debris had unpredictable outcomes, requiring multiple pulses for coagulation or causing vessel rupture.

Conclusions: KTP laser fiber function is significantly affected by fiber tip condition. Carbon debris and suboptimal cleaving create significant attenuation of energy, which results in an unpredictable angiolytic effect, as demonstrated by increased vessel rupture in the CAM model. Optimal recleaving of KTP laser fibers restores prior energy output and predictable coagulation. Care should be taken to avoid carbon debris on laser-fiber tips and to cleave fibers properly.


Level of Evidence: NA

INTRODUCTION

The 532-nm potassium-titanyl-phosphate (KTP) laser is frequently used during laryngeal surgery.1 Energy from the laser source is transmitted to the target tissue through silica fibers that range from 300 μm to 600 μm in diameter. Variables that can be adjusted at the laser source include power, pulse width, and pulse rate, and optimal settings for achieving maximum photoangiolyis with minimal thermal damage have been estimated in prior studies.2 In the course of those studies it was observed that lower power output can cause rupture of vessels instead of coagulation, and excessive energy can cause collateral thermal damage.

Additional Supporting Information may be found in the online version of this article.

From the Department of Surgery, Harvard Medical School, Center for Laryngeal Surgery and Voice Rehabilitation, Massachusetts General Hospital, Boston, Massachusetts, U.S.A.

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Send correspondence to James A. Burns, MD FACS, Associate Professor, Harvard Medical School, Center for Laryngeal Surgery and Voice Rehabilitation, One Bowdoin Square: 11th floor, Boston, MA 02114, Phone: [617] 726-1444, Fax: [617] 726-9222. E-mail: burns.jame@mgh.harvard.edu

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Even with optimized laser settings, a common surgical observation is that performance is degraded by carbon debris that has accumulated on the fiber tip, resulting in increased vessel rupture instead of coagulation and increased time to ablate epithelial disease. To correct this, the fiber can be freshly cleaved to restore a clean and relatively flat tip surface that is perpendicular to the fiber axis; however, improper cleaving of the laser fiber tip can produce an irregular surface that negatively affects its optical properties and power output.3–5 The purpose of this study was to better quantify and understand the effects of carbon debris, optimal cleaving, and suboptimal cleaving on power output and beam characteristics and how these effects impact coagulation efficacy in a chorioallantoic membrane (CAM) model.

MATERIALS AND METHODS

Standard 400-μm-diameter Endostat laser fibers (Boston Scientific, Boston, MA) were used to study the effects of carbon debris and cleaving configuration on power output and the effect on CAM vessels. Carbon debris buildup was created on the laser fiber tips by touching the tip against the membrane of the CAM model and allowing ablated tissue to adhere to the cleaved surface of the silica fiber. Optimal cleaving was performed with the distal fiber held against the length of a finger and scored perpendicularly with a carbide pen cleaving tool (Sancliff, Inc., Worcester, MA). Then, the

Laryngoscope 129: October 2019

Tracy et al.: KTP Laser Fiber Cleaving and Debris

2244
tip was removed with a gentle bending and breaking motion (see Supporting Video 1 in the online version of this article that shows the technique for achieving an optimal cleave). An irregular, suboptimal cleave was created by cutting the fiber with ceramic scissors. Following each cleave, a 400-μm fiber-stripper (Micro Electronics, Inc., Seekonk, MA) was used to remove 5 mm of the outer nylon jacket. Stripping the fiber only removes the nylon jacket along the sides and does not impact function of the fiber tip. All laser fiber tips were inspected through a stereoscopic microscope (Nikon 1270; Nikon, Tokyo, Japan) at three times magnification and photographed with a Lumix GH4 camera (Panasonic, Kadoma, Japan). To characterize the effect of carbon debris buildup and cleaving configurations on beam properties, the fiber was attached to a three-axis micromanipulator (Fine Science Tools, Inc., Foster City, CA) to precisely position it 5 mm above a flat surface. Using a halogen light source, the resulting pattern of light dispersion through the fiber tip was photographed using a Lumix GH4 camera. Two laryngologists and one laser technician with 28 years of intraoperative laser experience, blinded to the study, rated each image as best, acceptable, or unacceptable according to manufacturer’s recommendations.6

**Effects on Energy Output**

The energy output for each of the testing conditions was measured by connecting fibers to a KTP laser (Aura XP; Laserscope Inc., San Jose, CA) set to deliver 40 W (600 mJ at 15-ms pulse width and 2 pps), which are standard settings for laser-assisted microlaryngoscopy at our institution.2 An Ophir Nova II pulse-triggered energy meter with a pyroelectric power sensor (Ophir-Spiricon, North Logan, UT) was used to measure the energy output of each fiber. The fibers were secured perpendicular to the face of the power sensor at a distance of 1 cm. For each condition the average energy of five consecutive pulses was calculated. The conditions tested first included fibers with carbon debris buildup, optimal cleave, and suboptimal cleave. After measuring energy output through fibers with carbon debris buildup and suboptimal cleave, those fibers were retested after being repaired by cleaving them optimally.

A repeated measures analysis of variance (RM-ANOVA) was used to test any overall differences in energy output across the various laser conditions. Significant main effects were analyzed using Bonferroni-corrected post hoc t tests. The effect size of all significant post hoc comparisons were characterized by the Cohen’s d. The Cohen’s d provides a standardized method to interpret the size of differences between the two groups with effect sizes less than 0.19 interpreted as small, 0.2 to 0.79 as medium, and 0.80 or greater as large. Our institution did not require institutional review board/Institutional Animal Care and Use Committee approval for this study.

**Effects on CAM Vessels**

Three 400-μm-diameter Endostat laser fibers (Boston Scientific, Boston, MA) were used to test the effects of optimal cleave, suboptimal cleave, and presence of carbon debris on CAM blood vessel coagulation. Each fiber tip configuration was tested on seven third-order vessels in the CAM. The CAM model was prepared using research-grade white leghorn chicken eggs at 12 to 14 days postfertilization, as previously described.7,8 Two fellowship-trained laryngologists familiar with the CAM model targeted the CAM blood vessels by placing the laser fiber tip perpendicular to the membrane. The KTP laser parameters were standard for microlaryngeal surgery (40 W, 15-ms pulse width, single pulse). Laser pulses were delivered until the third-order vessel was either coagulated or ruptured. Coagulation was defined as the creation of a sealed bloodless segment, and rupture was defined as the extravasation of blood, which is readily visualized on the membrane (Fig. 1).

**RESULTS**

Optimal cleaving with the scribe pen created a relatively flat surface perpendicular to the length of the fiber with a slight facet at the site of cleaving, as seen under microscopic visualization. Suboptimal cleaving with ceramic scissors resulted in more irregular tips with multiple facets. Carbon debris was readily visualized adhering to the laser fiber tip and was variable in appearance.

Dispersion of light from the fiber tips correlated with laser fiber tip appearance under three times magnification. All blinded reviewers rated light dispersion from optimally cleaved fibers as acceptable (50%) or best (50%). Suboptimal cleaves were rated unacceptable 100% of the time. Light dispersion from debris-coated fibers was variable, ranging between unacceptable (50%) and acceptable (50%). Figure 2 shows the fiber tip configuration under three times magnification and the corresponding light dispersion pattern.

**Power Output**

The variations in fiber tip configuration tested herein produced significant changes in laser energy output (RM-ANOVA, $F_{[3,12]} = 196.75, P < .001$. The average energy produced by optimally cleaved fibers was significantly greater than suboptimally cleaved fibers ($P < .001$). Carbon debris contributed to further reductions in energy output ($P < .001$).

**Fig. 1.** Third-order blood vessels within the chorioallantoic membrane. (A) Coagulation after energy delivery with optimally cleaved laser fiber. (B) Rupture after energy delivery with suboptimally cleaved fiber. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]
energy output the fiber with optimal cleave was 544 mJ (standard deviation [SD] = 31 mJ), when the laser was set to deliver 600 mJ (40 W, 15-ms pulse width). Carbon debris buildup significantly reduced the average energy output from 544 mJ to 300 mJ (−Δ244 mJ, d = 4.31, P < .001). Suboptimal cleave fibers also had significantly reduced average energy output to 350 mJ (−Δ195 mJ, d = 6.04, P < .001). The energy output for fibers with carbon debris or suboptimal cleave that were repaired with optimal cleave improved to 555 mJ (SD = 24 mJ), similar to the optimally cleaved fibers. Figure 3 depicts the average energy output through these four KTP laser fiber testing conditions in graph form.

![Image of laser fiber tip under 3x magnification and associated light dispersion](image)

Fig. 2. Laser fiber tip under 3× magnification (top row) and associated light dispersion (bottom row). Light dispersion from the OC fiber represents best, whereas light dispersion from the DC fiber is acceptable, and SC fiber is unacceptable. OC = optimal cleave; DC = debris coating; SC = suboptimal cleave. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

![Box and whisker plot of energy output](image)

Fig. 3. Box and whisker plot of energy output through four tested potassium-titanyl-phosphate laser fiber conditions. Power settings of 40 W and 15-ms pulse width predict an energy output of 600 mJ per pulse. The optimally cleaved fibers (OC1, OC2) delivered ~90% of predicted energy. Fibers with suboptimal cleave and carbon debris delivered significantly less energy. The center line denotes the median value (50th percentile), and the box contains 25th to 75th percentiles. The whiskers mark the 5th and 95th percentiles. OC = optimal cleave; DC = debris coating; SC = suboptimal cleave.
Effects on Coagulation

All seven CAM vessels treated with the optimally cleaved fibers were coagulated with a single pulse of energy without rupture. The fiber with a suboptimal cleave ruptured two blood vessels and coagulated five vessels, requiring between one and seven pulses to achieve an effect. The fiber coated with carbon debris ruptured one vessel and coagulated six vessels, requiring between three and six pulses to achieve an effect.

DISCUSSION

The KTP laser is now used for a variety of indications and has become a useful surgical tool during laryngeal surgery.\textsuperscript{3–12} All aspects of KTP laser function, including knowledge of fiber maintenance, are critical for maximizing surgical precision and efficacy. During microlaryngoscopy, carbon debris from laser-tissue interaction can accumulate on the fiber tip. Additionally, the fiber tip may not have the optimal configuration due to improper cleaving or chipping. In this investigation, we found that carbon-debris buildup and suboptimal cleaving decrease average energy output from the expected output by 50% and 58% of the predicted output, respectively. The clinical consequence is that the laser may deliver reduced and unpredictable energy to the tissue, resulting in less selectivity and precision. This was demonstrated by more frequent CAM vessel rupture and variability in the number of pulses required to achieve a tissue effect when fibers were improperly cleaved or had carbon debris at the tip.

The CAM model simulates the microcirculation within the superficial lamina propria and has been previously used as a model for analysis of the photoangiolytic effects of lasers on vocal fold microvasculature.\textsuperscript{1–3} Debris and suboptimal cleaving resulted in variable angiolytic effect and occasionally caused rupture of blood vessels. This difference may not be significant during ablation of extensive papillomatosis or carcinoma; however, when precise photoangiolyis is the goal, close evaluation and maintenance of the fiber tip can improve expected laser function. The effectiveness of several fiber-cleaving devices has been evaluated in the urology literature\textsuperscript{3–5} relative to holmium:yttrium aluminum garnet lasers. Vassantachart et al.\textsuperscript{4} compared different cleaving tools, and found the pen cleaving tool and scalpel resulted in better power output as compared to metallic scissors and a cleaving wheel. This study also showed that the use of the scribe pen for cleaving resulted in power output comparable to that of new fibers. Haddad et al.\textsuperscript{5} evaluated the effects of different laser cleaving techniques on lithotripsy and found no significant clinical difference between techniques after 1 minute of lithotripsy. In a similar study, Peplinski et al.\textsuperscript{3} noted variable initial power output with different cleave techniques; however, this difference disappeared after 3 minutes of use. In that study, larger fibers were noted to have more durable power output with time. Because the use of these fibers in urology involves high energy ablation in a nonspecific manner, the findings from these studies are not necessarily relevant to microlaryngoscopy, which utilizes much less energy in a more selective and precise manner. To our knowledge, this is the first study to evaluate the effect of fiber cleaving and carbon debris buildup on power output and photoangiolyis for the KTP laser during microlaryngoscopy.

For intraoperative fiber care, manufacturers recommend cleaning off foreign material and recleaving or stripping if there is laser fiber damage encountered during surgery.\textsuperscript{6} Following cleaving, it is advised to inspect the distal fiber tip under magnification and evaluate the quality of light dispersion. In this investigation, the light patterns from the fibers were highly characteristic for the cleaving categories of optimal versus suboptimal, with optimal fibers producing smaller, more circular spots. The light patterns from debris-coated fibers were more variably rated as acceptable or unacceptable. This is not surprising, because carbon debris was not deposited uniformly on the fiber tips. This study, therefore, supports the manufacturer’s recommendation of close evaluation of both fiber tip and resulting light pattern.

This study only reported results for the 400-μm diameter fiber because the 400-μm fiber is used most commonly in our practice, even though other sized fibers are available (300 μm and 600 μm). Also, carbon debris does not build up uniformly on the fiber tip. This variability, which was readily observed during visual inspection, could not be controlled, and it is likely that a greater amount of debris would result in diminished energy output. Additional studies to extend these observations to other fiber diameters and variable degrees of carbon deposits would improve the generalizability of our conclusions.

CONCLUSION

KTP laser fiber function is significantly affected by distal tip configuration. Carbon debris and suboptimal cleaving significantly decrease energy output, which results in an unpredictable angiolytic effect as demonstrated by increased vessel rupture rate in the CAM model. Fibers in these conditions can be recleaved optimally to achieve maximal energy output and predictable coagulation of blood vessels. During photoangiolytic KTP laser surgery, care should be taken to avoid carbon debris buildup on laser fiber tips and to cleave the fibers properly.

BIBLIOGRAPHY


