LABORATORY INVESTIGATION

Inactivation of Bacteria on Explanted Dialysis Catheter Lumens with Fiber Optically Delivered Ultraviolet Light

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ABSTRACT

Purpose: To evaluate the germicidal effect of fiber optically delivered ultraviolet (UV) light on colonized explanted dialysis catheters.

Materials and Methods: Explanted dialysis catheters were screened for intraluminal colonization by culturing 1 mL of a saline flush. Catheters growing >10 colony-forming units were treated with doses of fiber optically delivered UV light (range, 40–1,300 mJ/cm^2). For each UV-treated catheter, an unexposed segment was first cut and set aside as a control sample. A sterile optical fiber was inserted into the catheter hub and advanced to the catheter tip. The fiber was slowly withdrawn at a constant rate while exposing the inner lumen to UV light. A second UV-exposed segment was then removed. The UV-exposed and control segments were split and sonicated to remove the adherent bacteria. The bacteria were counted and identified.

Results: There were 14 colonized catheters treated with UV light. The catheters were primarily colonized with coagulase-negative staphylococci (60%) and *Staphylococcus aureus* (33%). There was a significant reduction in viable bacteria between the UV-treated versus untreated segments of each infected catheter ($P = .04$). In the seven treated catheters with >100,000 colony-forming units per cm^2 of luminal surface area, there was a >99.5% reduction of viable bacteria in all UV-exposed samples, with no residual viable bacteria in four of seven (57%) of the samples.

Conclusions: This study demonstrates the technical feasibility and benchtop efficacy of using fiber optics to deliver UV light into the lumen of a colonized dialysis catheter and inactivating bacteria on the intraluminal surface.

ABBREVIATIONS

CFU = colony-forming units, UV = ultraviolet

When hemodialysis catheters become colonized by bacteria, catheter-related bloodstream infections often result. Catheter infections are difficult to manage because microorganisms form a protective polysaccharide matrix on the catheter surface called a biofilm. This biofilm protects the bacteria from standard antibiotic treatment (1).

Ultraviolet (UV) light has been proposed as an alternative to antibiotics. A particular band with wavelengths 250–270 nm (called the UVC band) is considered germicidal. UV light creates cyclobutane pyrimidine dimers in microbial DNA, which block the progression of replication forks, disrupting the replication process (2). There is some evidence that UV light can induce this DNA damage through a simulated biofilm matrix (3).

Investigators demonstrated the feasibility of delivering UV light into a catheter lumen by exposing the hub to UV light-emitting diodes (4–6). However, it is unclear if this technique can adequately expose the distal parts of the catheter behind curved sections. Other authors proposed using fiber optics to deliver UV light into catheters (7), although, to our knowledge, no experimental work using this technique has been performed. The purpose of the present study was to evaluate the germicidal effect of using optical fibers to deliver UV light directly into infected explanted dialysis catheter lumens.

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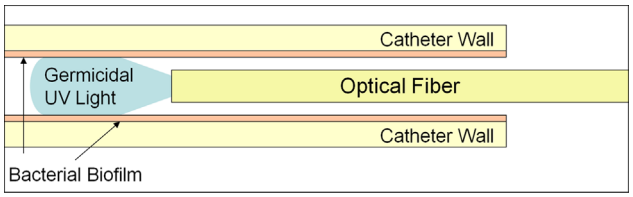
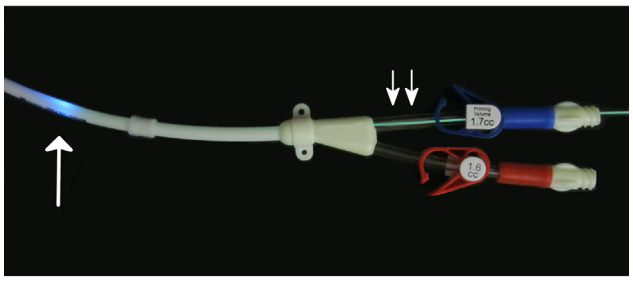
MATERIALS AND METHODS

A fiber-optic delivery device was constructed for delivering UV light into catheters (Figs 1a, b and 2). The device consisted of an optical fiber optically coupled to a UV laser (MPL-F-266; Information Unlimited, Mont Vernon, New Hampshire) with a center wavelength of 266 nm. The optical fiber had a numerical aperture of 0.48 and a core diameter of 400 μm (BFH48-400; Thorlabs Inc, Newton, New Jersey). The total diameter of the fiber, including the cladding, buffer, and coating, was 730 μm, which was smaller than the inner diameter of a dialysis catheter lumen (approximately 1.7 mm), which allowed for ease of insertion and removal. Optical power measurements were obtained with a UV light detector (Model 2032; New Focus Inc, Santa Clara, California). The power exiting the optical fiber measured approximately 7 mW. The fiber was connected to a computer-controlled translation stage (Sherline Products, Inc, Vista, California), which allowed for precise control of mechanical velocity for controlled fiber withdrawal.



a.



b.

Figure 1. **(a)** Schematic of the UV fiber-optic delivery concept for exposing catheters to UV light. **(b)** Picture of the device within a test catheter. The single arrow indicates the location of the fiber tip and UV light exposure (some blue light is emitted along with the UV light). The double arrows show the green optical fiber within the venous port.

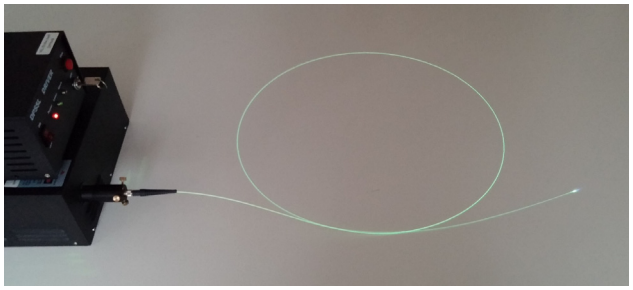


Figure 2. UV device.

Catheter harvesting techniques were adapted from the methods described by Kite et al (8). Discarded explanted catheters were collected and screened for intraluminal infection with the following protocol. The outside of the catheter was thoroughly wiped with 70% isopropyl alcohol to remove any bacteria on the catheter outer surface and to ensure that only luminal bacteria were measured. Each lumen of the catheter was flushed with 4 mL of sterile saline to remove any existing blood, non-adherent planktonic bacteria, and other debris. The catheter lumen was flushed again with an additional 1 mL of saline onto a blood agar plate to collect bacteria that would more likely be sloughed off an adherent biofilm. The plates were incubated overnight at 37°C for 48 hours. The catheters were locked with saline and refrigerated at 4°C. Any resulting microbial growth was noted.

Catheters corresponding to plates growing >10 colony-forming units (CFU) underwent a UV treatment protocol. The outside of the catheter was again thoroughly wiped with 70% isopropyl alcohol. The tip was cut off from each catheter because of variability of tip geometry and so that treated and untreated segments with similar geometries could be compared. A 2-cm untreated segment was cut and set aside as a control sample. A sterile optical fiber was inserted into the catheter hub and threaded through the catheter lumen toward the tip. The fiber was slowly withdrawn through the entire catheter at a constant rate by a computer-driven translation stage while exposing the inner lumen to UV light, allowing for a controlled dose to be applied. UV power was measured before fiber insertion and after removal to assess for any changes in power from occluding debris.

Eleven fibers were withdrawn at a rate of 0.1 mm/s, two fibers were withdrawn at 1 mm/s, and fibers were not inserted in two cases. If the catheter contained multiple inseparable lumens, all lumens were treated. A second 2-cm UV-exposed catheter segment was removed and set aside. Care was taken to ensure that the catheter lumen contained saline during the entire procedure to prevent dehydration. The nonexposed and UV-exposed segments were split lengthwise in sterile fashion and placed in microtubes containing 1 mL of phosphate-buffered saline. The catheter segments in the tubes were sonicated for 15 minutes to remove microorganisms adherent to the catheter lumen. The UV-exposed and the control segments were processed during the same session. The samples were then sent to the clinical microbiology laboratory. Quantification in the microbiology laboratory was performed by plating 0.1 mL on blood, chocolate, and MacConkey agar plates and counting CFU directly. Organism identification and susceptibilities were performed with rapid latex agglutination (Staphaurex; Thermo Fisher Scientific Remel Products, Lenexa, Kansas) and running samples through