Available online at www.sciencedirect.com

ScienceDirect

Optics and Lasers in Engineering 45 (2007) 495–502

OPTICS and LASERS in ENGINEERING

Fiber photo-catheters for laser treatment of atrial fibrillation

Igor Peshko[a,*], Vladimir Rubtsov[b], Leonid Vesselov[c], Gennady Sigal[a], Hillel Laks[d]

[a]*Department of Chemical and Physical Sciences, University of Toronto at Mississauga, 3359 Mississauga Rd, North Mississauga, Ont., Canada L5L 1C6*
[b]*Intelligent Optical Systems, 2520 W, 237th Street, Torrance, CA 90505, USA*
[c]*Walsh Medical Devices Inc., 1200 South Service Road, West Unit 3, Oakville, Ont., Canada, L6L 5T7*
[d]*Heart and Heart-Lung Transplant Program, David Geffen School of Medicine at University of California, Los-Angeles, 10833 Le Conte Ave., Rm. 62-182 CHS, Los Angeles, CA, 90095, USA*

Received 15 June 2006; accepted 4 October 2006
Available online 22 November 2006

Abstract

A fiber photo-catheter has been developed for surgical treatment of atrial fibrillation with laser radiation. Atrial fibrillation (AF) is a heart rhythm abnormality, which involves irregular and rapid heartbeats. Recent studies demonstrate the superiority of treating AF disease with optical radiation of the near-infrared region. To produce long continuous transmural lesions, solid-state lasers and laser diodes, along with end-emitting fiber catheters, have been used experimentally. The absence of side-emitting flexible catheters with the ability to produce long continuous lesions limits the further development of this technology. In this research, a prototype of an optical catheter, consisting of a flexible 10-cm fiber diffuser has been used to make continuous photocoagulation lesions for effective maze procedure treatments. The system also includes a flexible optical reflector, a series of openings for rapid self-attachment to the tissue, and an optional closed-loop irrigating chamber with circulating saline to cool the optical diffuser and irrigate the tissue.

Keywords: Atrial fibrillation treatment; Fiber diffuser; Photo-catheter; Laser surgery

1. Introduction

In recent years, laser and optical fiber technologies have grown to become increasingly important in the medical instrumentation market. Procedures such as cancer treatments, cosmetology, skin treatment, laser acupuncture, and surgery have benefited greatly from the use of red, near-infrared (IR) and middle IR radiation. Optical fiber technologies can be used for power delivery, to act as sensors, and as multifunctional devices, controlling the laser's radiation and the transfer and processing of data. Unfortunately, the currently available optical energy delivery devices are limited in their effectiveness because their inherently large illumination areas can cause tissue damage outside the desired treatment area. Also, the large bend radii of currently available devices prevent them from being used in some endoscopic and cardiovascular applications [1]. The solution to this is to create a miniature, flexible probe of relatively long length, which can precisely deliver a narrow strip of light and can be operated with different light sources. Such a device would have a wide range of uses, including therapeutic applications such as irradiation of the brain [2] or the liver [3].

In this paper, we present a novel catheter based on a flexible side-emitting optical fiber that can be used for making continuous photocoagulation lesions for effective maze procedure treatments. This innovative, side-emitting, fiber optic, high-energy delivery platform uniformly emits optical energy over its entire 10-cm length. Long period gratings (LPGs) imprinted in the multimode optical fiber provide the basis for the technology behind this proposed catheter.

LPGs are induced periodic changes in the refractive index of optical fibers. The period of these induced changes is many times higher than the wavelength of the light in the fiber [4,5]. These gratings couple light effectively from the core mode to the cladding modes. The general view of the mode envelope and exact spectral positions of the mode

*Corresponding author. Tel.: +1 905 569 4488; fax: 1 905 569 4488.
E-mail addresses: i.peshko@utoronto.ca, ipeshko@gmail.com (I. Peshko).

0143-8166/$ - see front matter
doi:10.1016/j.optlaseng.2006.10.003

lines depend on the parameters of the fiber and the LPG. LPGs have applications like strain, bend, temperature, and refractive index change sensors [6–8]; light diffusers for medical applications [9]; and chemical sensors [10,11]. Hence, a fiber with an LPG may be used to monitor a patient's temperature and pulse, and could potentially be used to analyze the patient's blood chemical content levels. Therefore, this technology has the potential to be a "universal" multifunctional catheter that can be used both as a surgical instrument, and as a patient monitoring device.

2. Atrial fibrillation problem

During atrial fibrillation (AF), rapid and irregular electrical impulses cause erratic and incomplete activation of the atria, which in turn leads to the loss of normal sinus rhythm. Over time, this condition can contribute significantly to the likelihood of cardiovascular disorders and even death. Each year, a considerable amount of money is spent on the diagnosis and treatment of this disorder. The surgical maze procedure was the first treatment that offered a permanent solution for maintaining a normal sinus rhythm in patients with AF [12,13]. This procedure involves the creation of a maze-like series of incisions in the left atrium, resulting in isolation of the pulmonary vein and removal of the left atrial appendage. The scarring resulting from the incisions permanently blocks the path of the erratic electrical impulses, thereby eradicating the arrhythmia.

To simplify the procedure, make it less time consuming, and in some cases to make it less invasive by eliminating the need for cardiopulmonary bypass, a so-called partial maze procedure has been developed [13]. Further improvements have been achieved by replacing the traditional scalpel-performed incisions with thermoablative, cryoablative lesions formed by alternative energy sources such as radiofrequency, cryothermy, microwave, and ultrasound.

In current practice, a radio frequency probe or cryoprobe is used to create rings of scar tissue around each of the four pulmonary veins: around the left atrial appendage, around the mitral valve annulus, along the route of the coronary sinus (which carries blood back to the heart from the cardiac veins), and along a line connecting the pulmonary veins and the mitral valve annulus. This effectively isolates the sources of the chaotic electrical signals.

Many studies have extensively investigated the use of lasers for cardiac ablation and have shown them to be a promising alternative to RF and microwave energy sources for creating deep, continuous transmural lesions. However, in the majority of these studies, the optical fiber was oriented normal to the tissue's surface, and the radiation was delivered through the fiber's tip. This configuration produces high irradiance near the output end of the fiber, which increases the probability of tissue vaporization, creates a char layer that decreases the probe's depth of penetration, and can even result in fiber damage. Furthermore, to produce a continuous linear lesion, such a probe must be drawn along the tissue's surface, which is highly undesirable in a transcatheter ablation procedure. To avoid these problems, it is necessary to develop a light source that will create a deep homogeneous, electrophysiologically inactive scar with a controllable lesion size, and a clear-cut lesion border in a single application. In this paper, we describe the development of such a catheter that is able to complete the aforementioned tasks.

3. Long period grating technology

In general the problem may be summarized as: it is necessary to create a flexible, thin, up to 10-cm long, light source; it should provide constant intensity along the source and be focused onto the tissue with up to 1 W/cm linear-light power density. All tasks were successfully resolved:

- A 10-cm long diffuser was fabricated in a multimode fiber, using a fiber LPG technology;
- The fiber catheter body was cast from high-temperature rubber silicone, and was then gold coated to form a reflector;
- The fiber catheter end had a cooler–reflector that dissipated excess heat, kept the fiber mechanically sound, and improved the optical homogeneity of radiation near the fiber end.

Fig. 1 shows an outline of the catheter design, and Fig. 2 shows a 3D image of the catheter. A photograph of the first prototype is shown in Fig. 3. As the development of the catheter proceeds, the most challenging part, the

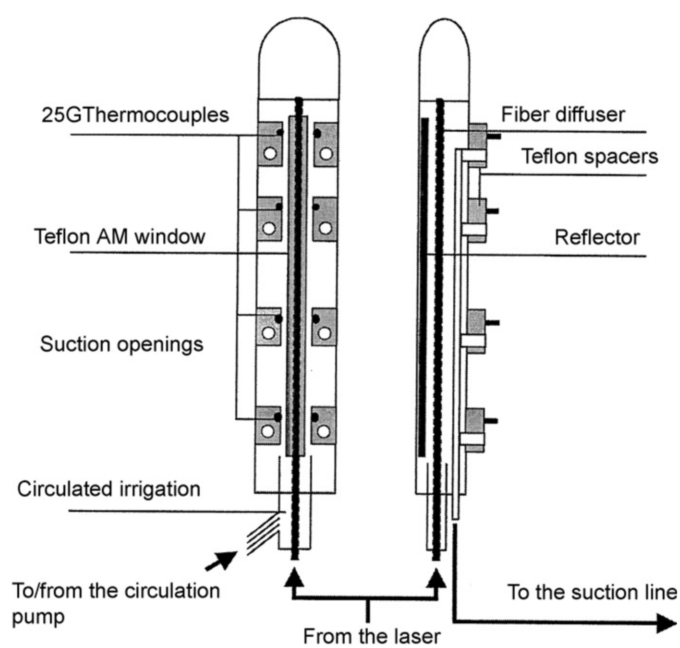

Fig. 1. Top and side view of tentative design.