OPTICAL FIBER CHARACTERIZED WITH A LOW REFRACTIVE INDEX CAN DETECT BLOOD

Blood Increased Light Loss through an Air–cladding Optical Fiber

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Abstract: Large amounts of undetected blood loss during hemodialysis are caused by venous needle dislodgement. A special air-cladding plastic optical fiber with a low refractive index, fluoropolymer, PFA fiber, JUNFLON®, was developed to monitor oil and lipid leakage in industrial fields, and to monitor the dust in the air in clean rooms. To apply the air-cladding plastic optical fiber as a bleed sensor, we studied the optical effects of soaking the fiber with various liquids and porcine blood on light-loss experimental settings. Light intensity through the fiber was studied with a light emitting diode and a photodiode under various conditions of soaked fiber with reverse osmosis water, physiological saline, glucose, and porcine blood. The more the soaked length increased with all mediums, the more the light intensity decreased. Although the slopes of the decreased curves varied according to the mediums, the light scattering phenomena caused by the mediums can be applied to a bleed sensor for clinical use.

1 INTRODUCTION

Although hemodialysis has evolved into a safe and less stressful procedure for both patients and caregivers (Sarkar, Kaitwatcharachai and Levin, 2005; Hawley, Jefferies, Nearhos and Van Eps, 2008), intradialytic complications still cause considerable patient morbidity and rarely, mortality (Sarkar et al., 2005). Venous needle dislodgment (VND) is one of the most serious accidents that can occur during hemodialysis (Hawley et al., 2008; Van Waeleghem, Chamney, Lindley and Pancírová, 2008). The European Dialysis and Transplant Nurses Association/ European Renal Care Association has produced 12 practice recommendations to help reduce the risk of VND and detect blood leakage as soon as possible (Van Waeleghem et al., 2008). A safety device from Redsense Medical, Halmstad, Sweden for use during hemodialysis that uses fiber optic technology to detect blood has been approved as a Class I medical device with the intended purpose of detecting VND (Van Waeleghem et al., 2008; Ahlmén, Gydell, Hadimeri, Hernandez, Rogland and Strömbom, 2008).

On the other hand, optical fibers are widely and directly used in fiber optic communications, medical endoscopes, and sensors (Goodyer, Fothergill, Jones and Hanning, 1996; Zubia and Arrue, 2001; Sugita, 2001; Lee, 2003). An optical fiber generally consists of a core and a surrounding layer called “cladding” with a low refractive index. Based on the difference in refractive indices, light is reflected at the core-cladding interface. An air-cladding plastic optical fiber characterized with a low refractive index of 1.328 nD was developed by the Junkosha Co., Ltd. (Yamanashi, Japan), that can monitor contaminates or impurities in a clean room or environs (Suzuki, 2004). When the air-cladding optical fiber is contaminated with a liquid, the light

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signal may partially be lost from the contaminated site and may decrease when the area contaminated with the liquid increases. Hence, it would be possible to detect bleeding by monitoring the light loss from the air-cladding plastic optical fiber attached to the skin around the needle site of a patient's arm or leg. To our knowledge, any relationship between lengths of the segment soaked with a liquid and light loss has not yet been reported in either PubMed or Optics InfoBase literature, nor has utilizing this particular relationship to detect VND been reported. The present study presents the optical characteristics of air-cladding optical fiber to detect blood or fluid leakages.

2 MATERIALS AND METHODS

2.1 Experiment Overview

Figure 1 shows an experimental work desk on which an optical fiber was placed with a straight segment to test the effect the mediums have on the optical fiber. The working area was strictly cleaned to prevent any contamination from other mediums, e.g., dust, hand oils, or any liquids.

The examined air-cladding optical fiber is a fluoropolymer, PFA core fiber, JUNFLON® (Junkosha), with a 1-mm diameter, and a refractive index of 1.328 nD. The fiber used in this experiment was 2 m in length and weighed 2 g. It was resistive to acids and alkalines, and to ethanol, ethylene oxide gas, and heating for sterilization.

The sensor module, LEAKLEARN OPT® (Junkosha), consisted of a light emitting diode (LED), a detector photodiode (PD), and electrical circuits for monitoring and alarming. The sensor module monitors voltage as light intensity. Thus, the voltage decreases as the light transmitted to the PD becomes darker.

2.2 Mediums used to Soak the Optical Fiber

The applied liquids were: reverse osmosis (RO) water, physiological saline, and glucose in water at 5%, 10% and 20%. All of which except the RO water were pharmaceutical products. Porcine plasma and blood (Hct 40% and 20%) were also applied and tested in the same manner. The hematocrits were prepared by adding porcine plasma but not saline.

To control a length of fiber soaked with a medium without a longitudinal leak under the fiber, narrow gauze strips were crossed over the fiber or wrapped around the fiber. Then each medium was manually dripped on each gauze strip. The mediums, thus, soaked the gauze strips and circumferentially surrounded the fiber for the whole width of the strips. There was no expansion observed of the mediums along the fibers.

For physiological saline, light intensities were compared with two settings, the continuous and the separate modes, of the gauze strips on the fiber. The soaked lengths were the sum of the widths of the gauze strips in the separate mode. For other mediums, the light intensities were measured in the continuous mode on the fibers.

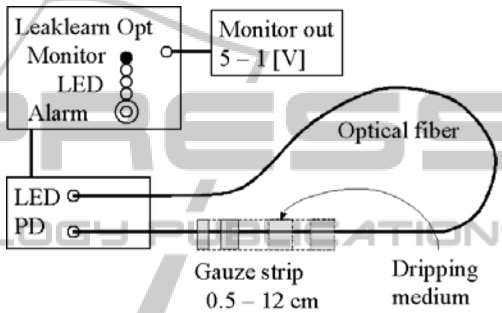

Figure 1: Experimental setting.

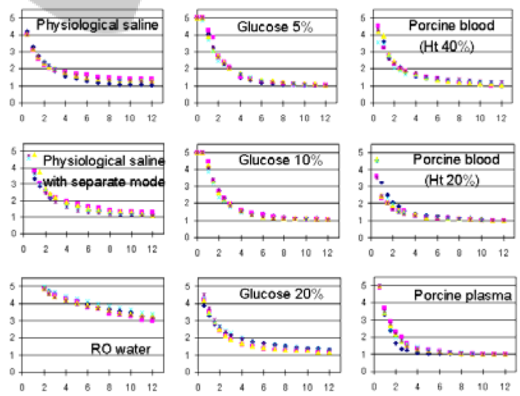

Figure 2: Light intensity to soaked length for each test medium. The horizontal axis indicates the soaked length in centimeters.

3 RESULTS

Figure 2 shows all of the raw data obtained for each medium tested. Data points for all experiments including duplicates are shown with 5 symbols for the 5 experiments. The light intensities clearly and exponentially decreased with the longer soaked length for all the mediums. For physiological saline, the raw data of the continuous mode were visually the same as those of the separate mode. Porcine plasma showed a slightly steeper curve than did the porcine blood. The raw data of RO water showed a milder decreasing curve than did those of the other mediums.

4 DISCUSSION

The light intensity decreased as the length soaked with the medium increased. Although Golnabi and Azimi (2007) proposed a plastic optical fiber leakage sensor by immersing liquids with the higher index of refraction, the quantitative relationship between soaked lengths and light loss was not reported in detail in their study.

The phenomenon of scattering back to the front end of a fiber is also utilized as a sensor, optical time domain reflectometry (OTDR) (Sugita, 2001). Although the OTDR is also widely used in medical and chemical analyses and molecular biotechnology (Lee, 2003; Barnoski and Jensen, 1976; Sensfelder, Bürck and Ache, 1998), it is difficult for commercially available OTDR to detect any clinical events in a region less than 1 m from the sensor module. The mechanism of our sensor is simpler than that of OTDR, and only based on light intensity without any chemical modifiers to sense bleeding or liquids. The phenomena that the decrease of light intensity depends on the length soaked can be applied to monitor VND.

Although it is well known that bending a fiber modifies its guiding properties and increases light loss, the optical fiber used in the present study showed no light loss even when bending it in a 1-cm-diameter loop. This flexibility would be useful for attaching the optical fiber to the skin around a needle site of a patient's arm or leg.

The optical fiber can be used as a non-invasive disposable sensor to detect bleeding or leakage during hemodialysis. The optical fiber was looped on the surface of the skin around the puncture site (Figure 3). Although the sensor can detect bleeding from the needle site, it can not sense a subcutaneous bleeding.

Although this sensor module may be made smaller while maintaining its sophisticated functions for clinical use, the air-cladding optical fiber offers certain advantages, such as the fiber's light weight, flexibility, and the ability to adjust the fiber length, loop size, and route, simple fixation with surgical tape, and continuous real-time sensing. These advantages allow the air-cladding optical fiber to be used as a disposable sensor to quickly detect bleeding and leakage during hemodialysis and continuous venous infusion.

Figure 3: Clinical setting during hemodialysis. The optical fiber was attached with 3M tape to the skin and partially passed through a white tube.

5 CONCLUSIONS

We confirmed the phenomenon that light intensity clearly decreased as the soaked length of a fiber increased. This phenomenon can be used to quickly detect bleeding and leakage and set off alarms for patients undergoing hemodialysis and for those receiving infusion therapy.

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