Variable-Contact Diffuse Reflectance Spectroscopy in Intravascular Conditions Assessment

Darrin Beekman
Department of Mechanical Engineering, University of Minnesota, Minneapolis, MN 55455

Timothy Kowalewski
Department of Mechanical Engineering, University of Minnesota, Minneapolis, MN 55455

1 Background

Coronary artery disease (CAD) is the number one cause of death in the U.S. [1]. 720,000 Americans are projected to undergo coronary attacks in 2014, 215,000 of these attacks are expected to be repeat episodes [2], which implies a deficiency in the current CAD percutaneous coronary interventions. Angioplasty and stenting are the most common treatment options, but these methods can trigger an injury response, swelling, and restenosis. Currently, the outcomes of alternative plaque removing treatments like excimer atherectomy or mechanical atherectomy are similar to stenting, so their use has been limited to procedures not well suited for balloon angioplasty and stenting [3].

The creation of an accurate and reliable tissue-identification sensor may enable the control of atherectomy procedures by verifying that the tissue in the ablation zone is the correct tissue to remove in between each laser pulse. A sensor with this capability would increase the safety and effectiveness of minimally invasive interventions. An optics-based sensor may be the most suited for direct application as it could utilize the optical fibers already present in the laser atherectomy catheters. Additionally, evidence suggests that fiber-optic diffuse reflectance spectroscopy (DRS) provides an accurate means of classifying tissue. The sensitivities and specificities for Stelzle et al. are generally around 90% and 90% respectively [4]. Rocha et al. provided and reviewed some of the strongest evidence that this can be used to distinguish atherosclerotic plaque and healthy tissue [5]. Accounting for contact force, however, still remains a challenge, as it can significantly alter DRS spectra [6].

Building on the prior art mentioned above and our previous investigations [7], this work aims to explore the ability of contact DRS to discriminate tissue-specific spectra under typical intravascular conditions such as variable-contact force, the inclusion of ablation effects, and immersion in blood or saline.

2 Methods

The experimental setup shown in Fig. 1 was used to initially investigate whether variable-force DRS is able to distinguish between tissue types. The main components of this setup include a high resolution spectrometer (USB2000+, 3.5 nm FWHM, OceanOptics, Inc., Dunedin, FL), a halogen light source (Leica KL1500 electronic), a fiber-optic probe (QR200-7-VIS-NIR, OceanOptics, Inc.), a pocket scale (AWS SC-2 kg) delivering force measurements, (2) a Leica KL 1500 electronic halogen light source, (3) an Ocean Optics USB2000+ spectrometer configured for 3.5 nm resolution when using 200 μm optical fibers, (2) a Leica KL 1500 electronic halogen light source, (3) an Ocean Optics USB2000+ spectrometer configured for 3.5 nm resolution when using 200 μm optical fibers, (4) a Leica KL 1500 electronic halogen light source, (5) an Ocean Optics USB2000+ spectrometer configured for 3.5 nm resolution when using 200 μm optical fibers, (6) a laptop running a custom C++ console program to control data acquisition while synchronizing the data in time. Additionally, to investigate the DRS effects of photo-ablation, a Spectranetics CVX-300 Excimer Laser (308 nm pulsed) System with a Spectranetics ELCA coronary laser atherectomy catheter was used to ablate the tissue samples in specific regions.

Porcine aorta and fat tissue samples were used as coronary artery and atherosclerotic plaque tissue phantoms, respectively. The samples (one aorta sample, one fat sample, and a pint of blood) were acquired from the Visible Heart Lab at the University of Minnesota, Minneapolis, MN. Shortly after the animal’s time of death, the samples were collected and stored in a refrigerated environment for no more than 18 hrs.

Before the data were collected, the tissue samples were allowed to warm to room temperature. Each sample was then manually lased in three specific spots repeated with the Spectranetics CVX-300 system until visible signs of the ablation were detected. The laser was set at a fluence of 50 mJ/mm² and a repetition rate of 35 Hz.

Then, each sample was placed in a plastic box on the scale. The probe was used to illuminate the sample and deliver any diffusely reflected light back to the spectrometer. The DRS data were collected as the probe’s contact force was manually adjusted from 0 g to 200 g via the z-axis translational stage. In an air environment, DRS data were collected from each lased region four times (12 total lased data collections from each tissue type). DRS data were also taken from 12 nonlased locations on each sample in the air environment. After the air measurements were complete, the well-stirred porcine blood was added to the container. The DRS measurements were repeated on each lased region one time and the nonlased regions a total of three times due to the difficulty of accurately relocating the lased locations while the probe was submerged in the blood environment. The data were then processed using a custom MATLAB script.

3 Results

The spectra plots in Fig. 2 were created by averaging all 12 DRS runs for a specific tissue type (aorta, lased aorta, fat, or lased fat) within a specific force range (200–250 gf). These plots not only compare the spectra of the aorta sample with the spectra of the fat sample, but there is also a comparison of the lased and nonlased tissue in both an air and blood environment.

The curves plotted in Fig. 3 illustrate how the DRS data for the fat sample change as the contact pressure increases when immersed in a blood environment. Each contour is the average...
The effects of the photo-ablation with the excimer laser are also important to note. If DRS is to be used in a tissue sensing capacity within the coronaries to control a laser atherectomy, the photo-ablation process cannot remove the optical distinctiveness of the tissues. The results of this preliminary test shown in Fig. 2 demonstrate that the lasing slightly changes the DRS spectra but not enough to diminish the DRS tissue discrimination power.

Finally, a functional tissue sensor will have to perform when the tissue is experiencing a variety of stresses and strains caused by the surgical tool. This test was able to show that the variable-contact force has an impact on the DRS data. The plot in Fig. 3 is a contour map that tracks the DRS spectra within different force ranges. It can be seen that the DRS spectra seem to increase as the force increases, but the spectra change between the 150 gf range and the 200 gf range is a lot smaller than the other steps. This may indicate that there is a minimum contact force value at which any increased force will insignificantly affect the DRS data.

This study was a preliminary investigation exploring whether previous and promising DRS tissue sensing research could be shifted into a more clinically realistic environment by including variable-force contact, ablation effects, and blood immersion. The positive results of this test strongly motivate more complete DRS tissue sensing research.

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References
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