Toward Computer Assistance of Excimer Laser Coronary Atherectomy Procedures

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The introduction of minimally invasive surgery (MIS) was accompanied with great improvements both to the patient and surgeon. Despite these advantages, there was one obvious challenge: reduced visibility. Optical sensing modalities became paramount to sustain the viability of MIS and has become a mainstay in the operating room. Recent research suggests that these optical sensors may provide more than merely vision to the surgeon, but rather a competent computational agent to work alongside the surgeon. We propose algorithms and control integration for optical sensing modalities to make this possible.

Among the numerous surgical procedures which utilize optical sensing, an intriguing candidate to enhance through computational assistance is excimer laser coronary atherectomy (ELCA). This procedure utilizes picosecond cold laser pulses (308nm) to photoablate 30-50micron atherosclerotic plaque layers at 40-80Hz until the plaque is sufficiently removed. This procedure is currently preformed with basic interventional cardiology sensing—flashed fluoroscopy—which provides intermittent images of the laser probe positioned in the anatomy. This visual limitation can result in insufficient plaque removal and artery damage through unintentional lasing. Since the procedure only expends less than 1% of the optical fiber bandwidth during lasing, the remaining 99% could be utilized for optical sensing to enable feedback control of lasing (computational assistance). An algorithm which could detect regions of plaque and fire the laser, and conversely detect regions of artery and inhibit the laser could provide great enhancements to the procedure. This automated approach would require advancements in two key aspects: accurate sensing of arterial plaque and integrated control of an excimer laser. We present initial research into both of these areas and highlight the remaining challenges we have discovered while working towards augmenting the ECLA procedure.

The first research area concerns automated detection of arterial plaque. We propose this be accomplished via contact diffuse reflectance spectroscopy (CDRS), also referred to as elastic scattering spectroscopy. CDRS could be accomplished with only minor modifications to existing excimer laser probes. To test the efficacy of CDRS on arterial tissue, we have performed a study of ex-vivo coronary arteries to determine classification accuracy between plaque and artery regions, as labeled by pathology results. Initial results indicate that plaque and artery wall are very distinguishable using a linear discriminant analysis (LDA) classifier. Additionally, the classifier performance modestly improves by increasing the contact force at which the CDRS data is taken (Fig. 1). Patient to patient tissue variability adds complexity to the classification problem, but preliminary tests show encouraging separability despite these differences.

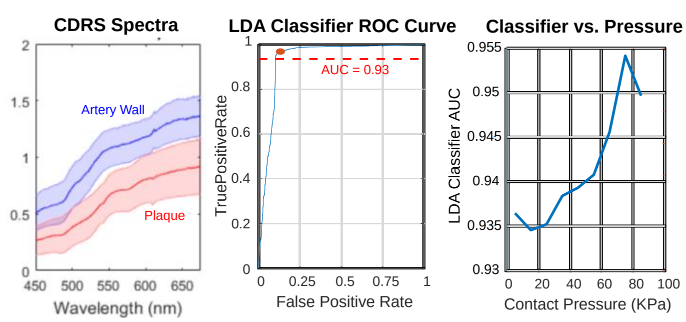

Figure 1-Normalized spectra intensity of CDRS depicting separability (left), LDA ROC curve (middle), LDA classifier vs. contact pressure (right)

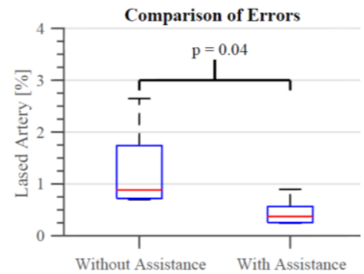

Figure 2-Error rates with and without assistance

The next related area of research aims to establish evidence that integrating computer assistance into ELCA improves procedure performance outcomes such as ablation accuracy. We conduct a user study (N=5 subjects) of a mock ELCA procedure and hypothesize that computer assistance can significantly reduce the number of errors as shown by a paired t-test ($p<0.05$). We further hypothesize that this inclusion of computer assistance does not significantly impair other performance outcomes of time and effectiveness. The mock procedure was done with a clinical ELCA laser, but was performed on 3D printed tissue phantoms of intentionally obvious regions of plaque and artery. The task was intended to be obvious to the users to show that computer assistance could even help in scenarios where experts performed. This study showed that errors were effectively decreased with statistical significance (Fig. 2), and task time was not shown to significantly change. Lasing results of a representive user trial are shown in Figure 3, with mistakes marked in red and correct lasing marked in green. A video of the experimentation can be found at http://www.me.umn.edu/labs/mrd/media.shtml.

These early results demonstrate that even existing FDA-approved clinical fiber optics can provide improved performance with minimal modification or added complexity. Optical sensing may play an expanded role in the future. Additional work in determining complementary approaches to improve plaque identification across patients would be beneficial, as well as clinical opinions to smoothly integrate this technology into surgical settings.

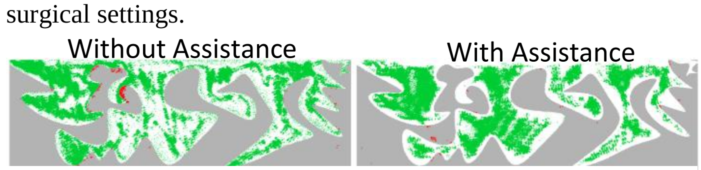

Figure 3-Representative data from user study with red pixels indicating errors and green pixels indicating correctly lased locations