OCT-guided laser therapy shows promise

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Advances in optical-coherence tomography may lead to a new class of endoscopic, image-guided therapies that target disease with microscopic precision.

Nearly 15 years of technical innovation, robust engineering, and cross-disciplinary collaboration have advanced endoscopic optical-coherence tomography (OCT) from a promising laboratory tool to clinically deployed instrumentation. The latest OCT technologies are being studied at research hospitals throughout the world for applications such as heart disease and cancer. One of the applications we have pursued in our laboratory is the use of OCT to identify cancer in the gastrointestinal (GI) tract. It is hoped that OCT’s high-resolution, cross-sectional imaging will allow for earlier detection of cancerous and precancerous lesions and offer new opportunities for early intervention.

It is important to remember, however, that the benefit of early detection depends on the efficacy of available therapies. For a number of GI tract cancers, early therapeutic options remain limited. The development of powerful diagnostic imaging tools such as OCT may be the first step, and the development of advanced therapeutic instrumentation the second step, in the effort to improve cancer management through optical technologies.

Multiple approaches for destroying early cancers in the GI tract have been studied with highly variable results. A lack of sufficiently powerful in situ guiding and monitoring capabilities is a major reason for this variability. Therefore, there is an opportunity for the same imaging technologies originally developed to diagnose disease to play a role in treatment. We have focused recently on combining optical frequency-domain imaging (OFDI)—a second-generation OCT with dramatically faster imaging speeds and increased depth ranging—with controllable laser thermal therapy. Our near-term aim is to provide image-guided therapy of Barrett’s esophagus, a precancerous lesion affecting the esophageal lining.

Multiple technical innovations are required to adapt OCT to therapy guidance. The first challenge is to ensure that the imaging field matches the diseased tissue area. In the case of Barrett’s esophagus, this can be many centimeters of the distal esophagus. An OFDI preclinical instrument was built that provides comprehensive microscopic imaging greater than 5 cm of the distal esophagus using a balloon catheter. Imaging was performed by helically scanning a focused imaging beam to survey the entire field. The resolution and contrast of the system revealed the microanatomical and pathological boundaries needed to guide intervention. Figure 1 shows a volumetric rendering of the acquired data sets in the swine esophagus. This technology is now being studied in patients for diagnostic applications.

To treat disease, therapy is provided in a separate optical channel. The therapy light is incident on the esophageal surface with a relatively large beam diameter (several millimeters) providing localized thermal coagulation of targeted tissue. This therapy beam co-scans the esophagus with the imaging beam, effectively

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“painting” the esophagus with the therapy laser where needed. Methods for controlling the induced injury depth through modification of both laser wavelength and power have been developed to get the necessary fidelity and range in injury depth control. To provide in situ monitoring of the induced injury as feedback, we developed techniques for determining injury boundaries from the detection of coagulation-associated microdeformations and modulations. In both ex vivo and in vivo settings, these deformations and modulations were detectable using OFDI and could serve as markers of the coagulative injury depth. Figure 2 illustrates images derived from Doppler-based measurements of deformation showing a clear delineation of viable and coagulated tissue.⁸

We are currently at the early stages of technical development of an OCT-guided laser therapy instrument. While the approaches developed to date have shown tremendous promise, it is likely that they will evolve as we continue to test instrumentation in preclinical settings. The application of Barrett’s esophagus is compelling on its own merit. It also is a powerful proving ground for this image-guided surgical platform that has applicability to many diseases.

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