JOHNS HOPKINS MEDICINE | JOHNS HOPKINS BIOMEDICAL ENGINEERING

Novel Capsule Imaging for Gastrointestinal Surveillance: Multifunctional Ablative Gastrointestinal Imaging Capsule (MAGIC)

Hyeon-Cheol Park [1], Dawei Li [1], Theethawat Thanawiboonchai [2], Rongguang Liang [3], Ivan George [2], Gina Adrales [2,4], and Xingde Li [1]

1. Department of Biomedical Engineering, Johns Hopkins University
2. School of Medicine, Johns Hopkins University
3. College of Optical Sciences, University of Arizona
4. Malone Center for Engineering in Healthcare, Johns Hopkins University

OBJECTIVE:

Esophageal cancer is ranked as the seventh most common and the sixth deadliest cancer globally. Barrett's esophagus is usually identified through endoscopy and biopsy, which requires sedation and can overlook dysplasia. Optical Coherence Tomography (OCT) via tethered capsule endomicroscopy (TCE) presents a less invasive diagnostic alternative, eliminating the need for sedation and potentially reducing biopsy errors. However, the existing TCE technology, primarily operating at 1300 nm, faces challenges in detecting early lesions due to its limited resolution and contrast. In comparison, OCT imaging at 800 nm can differentiate fine histopathological alterations in the mucosal layers with superior resolution and enhanced contrast. To overcome the limitations of the existing OCT-TCE, we developed a Multifunctional Ablative Gastrointestinal Imaging Capsule (MAGIC) OCT system operating at both 800 nm and 1300 nm. The MAGIC not only aims to improve gastrointestinal surveillance but also offers the ability to perform laser ablation. Additionally, it provides a traditional camera-based endoscopy view, further enhancing its diagnostic capabilities.

TECHNOLOGY AND METHODS:

The MAGIC device can perform dual-wavelength OCT imaging (800 nm and 1300 nm), endoscopy imaging, and laser ablation/marking, all integrated within a compact capsule. Two single-mode fibers were used for delivering (1)800 nm light for ultrahigh-resolution OCT imaging, (2)1300 nm light for standard resolution OCT imaging, and (3)1470 nm light for laser ablation. Circumferential OCT imaging was achieved by scanning the OCT beam using an aberration-corrected reflector driven by a miniature motor. The device includes an ultracompact camera for endoscopy. The imaging optics and beam scanner are encased within the compact capsule (11 mm diameter x 26 mm length) (figure 1(A)). The device features a watertight, biocompatible glass enclosure and a flexible torque coil attached to the capsule's proximal end for in vivo use (figure 1(B-C)).

PRELIMINARY RESULTS:

In vivo swine esophagus imaging demonstrated MAGIC's effectiveness in clinical diagnostics and treatment. During capsule insertion, random locations were selected for laser ablation to simulate dysplastic mucosa, showcasing the device's practical application in identifying and marking target regions. The integrated system allowed precise navigation and real-time feedback. Laser ablation created distinct fiducial marks, visible in both endoscopic and OCT imaging, facilitating accurate correlation and assessment. Histological analysis confirmed its ability to detect microarchitectural changes and assess invasion depth (figure 2(A-E)).

CONCLUSION AND FUTURE DIRECTION:

The dual-wavelength OCT imaging of the MAGIC device demonstrates outstanding resolution and contrast capabilities, crucial for revealing detailed structures in both surface and deeper layers of tissue. Specifically, the 800 nm OCT imaging shows significant potential in detecting minute microstructures and possible dysplastic alterations, making a notable improvement over traditional imaging methods. This novel integration of multiple imaging techniques in the MAGIC device paves the way for increased diagnostic precision and therapeutic accuracy in the medical field. By combining essential diagnostic and treatment functions into a single unit, this technology presents a practical and efficient approach for conducting endoscopic examinations, diagnostics, and potential ablation therapies for the upper gastrointestinal tract in a clinical setting.

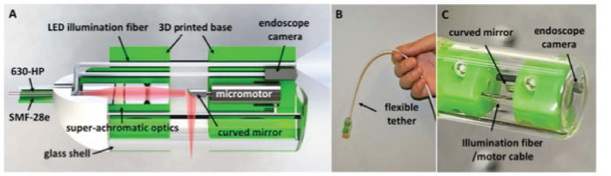


Figure 1. (A) Schematic illustration of the MAGIC. Two single mode fiber for the dual wavelength OCT imaging and laser ablation, and the endoscope camera with a LED illumination fiber. (B)-(C) photographs of the assembled MAGIC with a flexible tether.

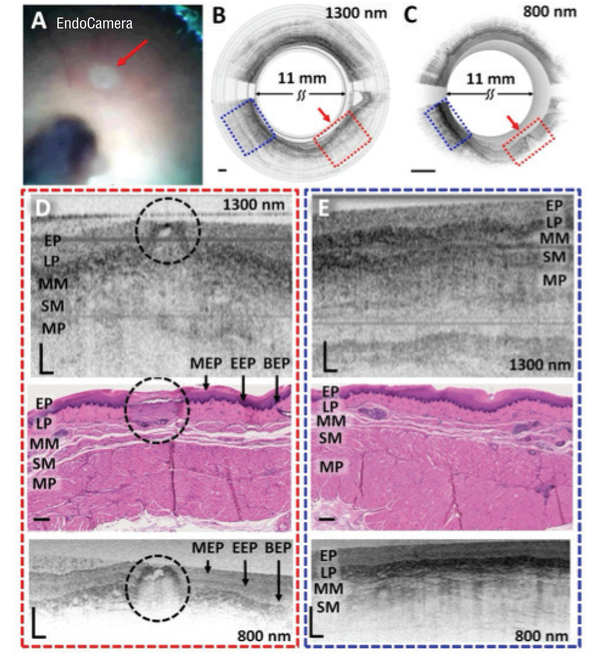


Figure 2. *In vivo* swine esophagus imaging results (A) Endoscope video camera view of the esophagus. (B)-(C) Real-time circumferential OCT images around and ablated spot captured at 1300 nm (B) and 800 nm (C). (D)-(E) Zooomed-in OCT images and corresponding histology micrographs of the area indicated with dotted boxes in (B) and (C). Red arrow: laser spot, Dot circles: ablated spot, EP: stratified squamous epithelium MEP: mature epithelium, EEP: embrynoic epithelium, BEP: basal epithelium. LP: lamina propria, MM: muscularis mucosae, SM: submucosa, MP: muscularis proria. Scale bars 250 μm.