Hybrid Optical Coherence Tomography and Photoacoustic capsule endoscopy for esophageal imaging

Qian Li[1], Zakiullah Ali[2], Christian Zakian[2], Vasilis Ntziachristos[2], Wolfgang Drexler[1]

[1] Center for Medical Physics and Biomedical Engineering, Medical University of Vienna, Vienna, Austria
[2] Institute of Biological and Medical Imaging, Helmholtz Zentrum München, Neuherberg, Germany

Objective

Esophageal cancer remains the sixth deadliest form of cancer. Presently the white light endoscopy (WLE) is employed to survey the esophagus for dysplasia. However, WLE provides only a poor contrast of the tissue surface without insights of the structure and the microvasculature within the lumen wall. To overcome the limitations of WLE, a novel multimodal esophageal endoscopic capsule combining optical coherence tomography (OCT) and photoacoustic imaging (PAI) is designed and evaluated. While the OCT part provides the anatomical information of the esophagus and performs a so-called 'optical biopsy' of the tissue, PAI provides vascular information from the surface to deeper tissue.

Methods

A distal scanning tethered endoscopic capsule (Fig. 1) is designed for 360° side-view imaging of the esophagus. With a diameter of 12.5 mm, the esophageal surface would be tightly attached to the capsule surface for imaging. Within the capsule, the OCT and PAI excitation light paths are intrinsically aligned and integrated through a double clad fiber coupler. A double-clad-fiber-based GRIN lens then delivers the dual-modal excitation light on the tissue. A motor inside the capsule rotates the excitation beams to realize a 360° circumferential imaging at 30 Hz. Manual or motorized pull-back of the capsule produces a three-dimensional imaging of the tissue. The whole OCT/PA endoscopy system is mounted inside a mobile cart (Fig. 1(c)).

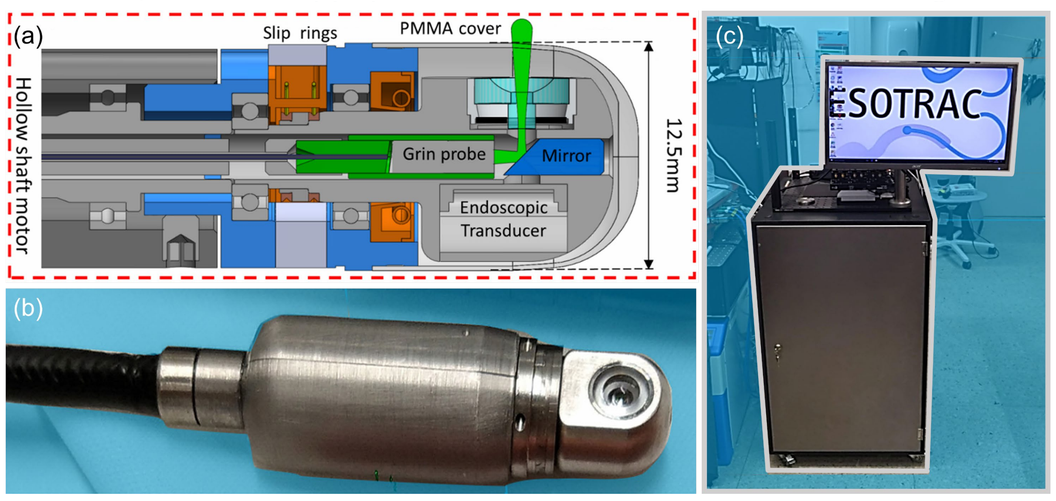

Figure 1. A schematic diagram (a) and photos of the OCT/PA capsule (b) and the complete OCT/PA endoscopy system mounted inside a mobile cart (c).

In vivo results

We demonstrate *in vivo* imaging of the human mouth cavity using the designed OCT/PA endoscopy (Fig. 2).

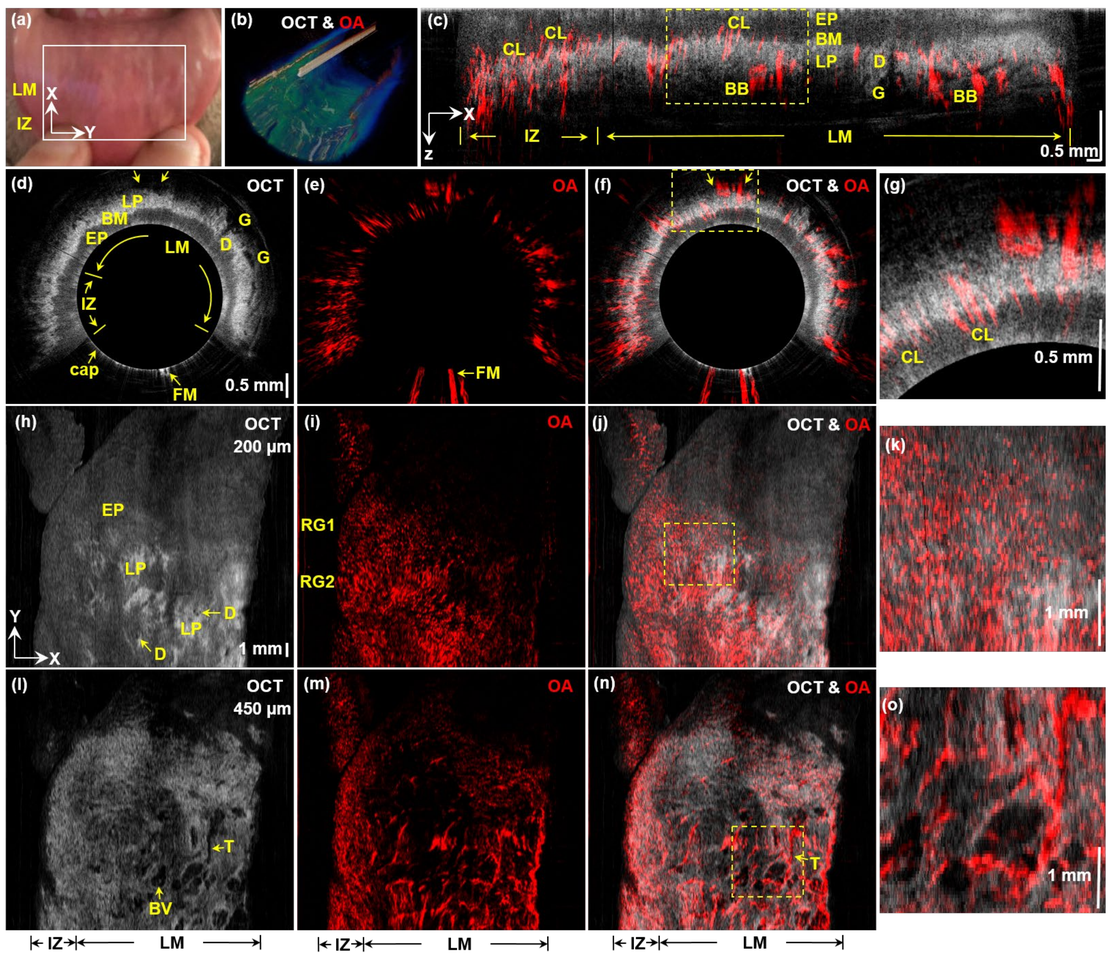

Figure 2. In vivo hybrid imaging of human mouth mucosa. (a) Mucosa photo. The imaged area includes the intermediate zone (IZ) and the labial mucosa (LM) of the lip. (b) 3D volumetric render of OCT-PA data. (c) A frame shown in Cartesian coordinates. The frame corresponded to the yellow line in (b). EP, epithelium. BM, basement membrane. LP, lamina propria. G, salivary gland. D, gland duct. CL, capillary loops. BB, branching blood vessels. (d-f) OCT, PA and hybrid frames of the same location as (c) in polar coordinates, respectively. FM, fiduciary marker. (g) Magnified view of the dashed box in (f). (h-j) OCT, PA and hybrid en face (XY) projection images at the depth of 200 µm, respectively. RG1, region 1. RG2, region 2. (k) Magnified view of the dashed box in (j). (l-n) OCT, PA and hybrid en face (XY) projection images at the depth of 450 µm, respectively. T, a tubular structure. (o) Magnified view of the dashed box in (n).

Clinical results

We explore the clinical potential of OCT/PA endoscopy through imaging endoscopic mucosa resection (EMR) esophageal specimens. The sample was mounted to mimic the setup of endoscopic esophageal imaging (Fig. 3(a)).

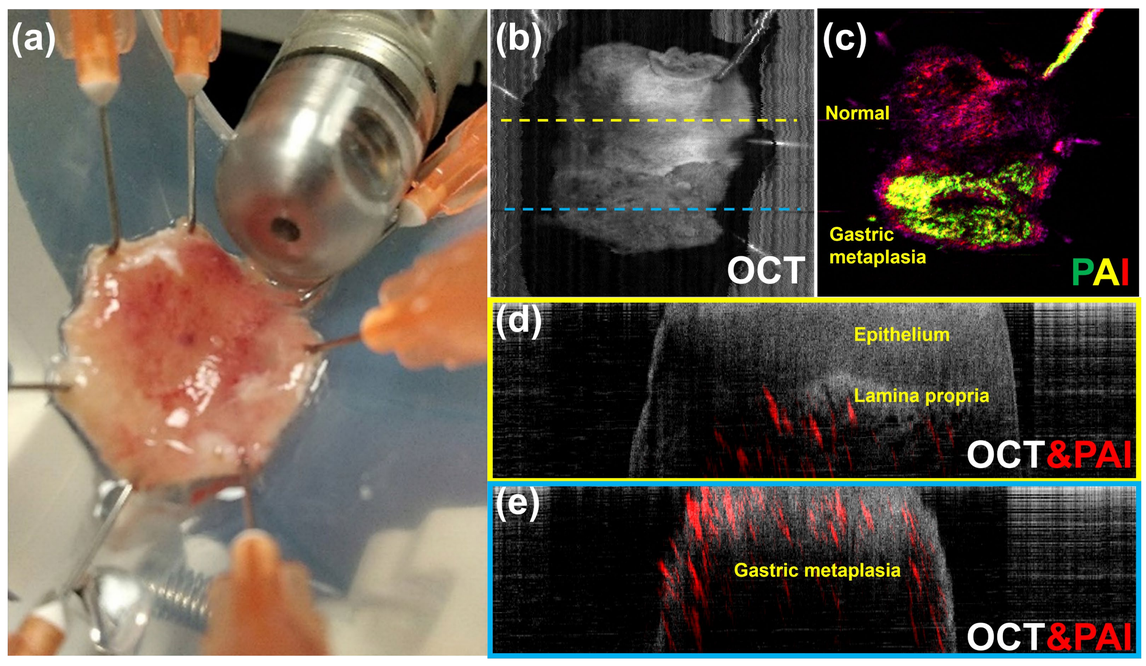

Figure 3. EMR sample imaging set-up (a) and representative results showing normal region and gastric metaplasia: (b) OCT *en face* image, (c) PAI *en face* image, (d&e) dual-modal cross-sectional images corresponding to the yellow and blue dashed lines in (b), respectively.

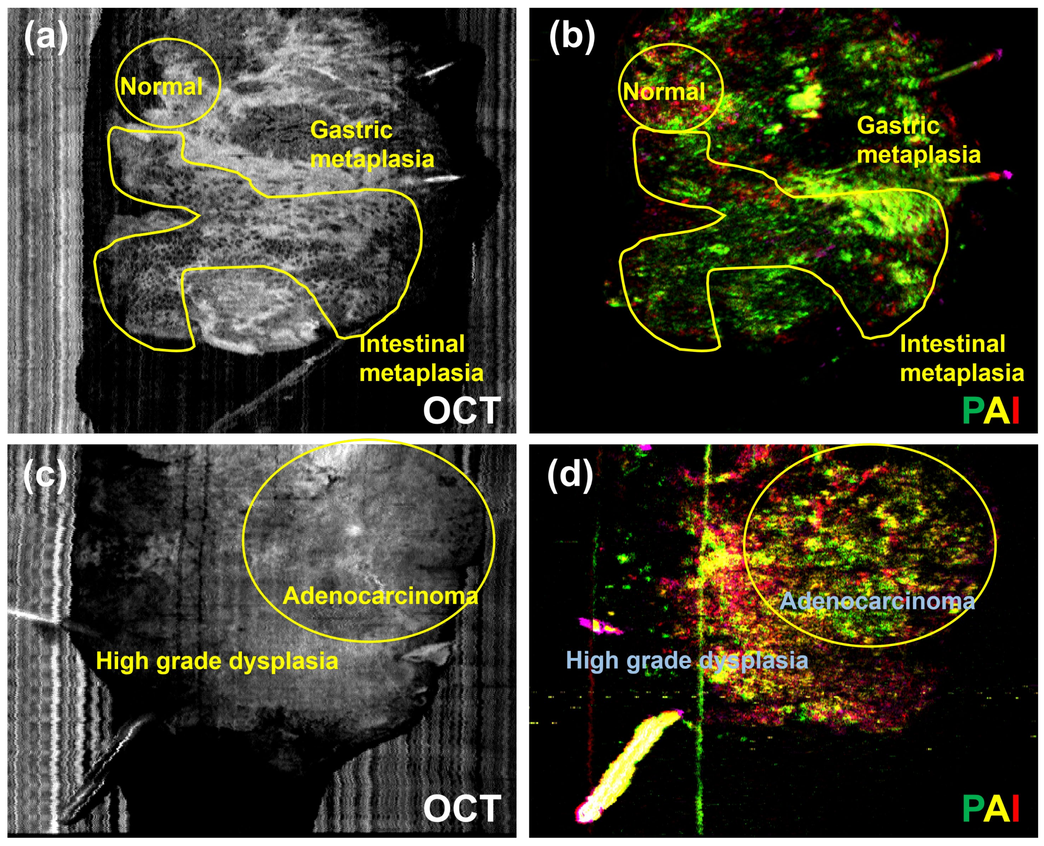

Figure 4. Representative EMR sample imaging results showing intestinal metaplasia in OCT *en face* image (a) and the corresponding PAI *en face* image (b), as well as the OCT (c) and PAI (d) *en face* images of a sample with the adenocarcinoma.

Conclusion

A dual-modal OCT/PA endoscopy for esophageal imaging is developed. Through OCT, the structural information of mucosa can be clearly visulised and the disruption of the normal mucosal structure is a biomarker for metaplasis. Through PAI, the 3D vascular structures are imaged. The vasculature locations and structural features provide a biomarker for identifying dysplasia and cancer.