Monitoring oncological surgery using optical coherence tomography

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Detailed, real-time imaging allows for adjustment of surgical margins, thus sparing healthy tissue and increasing the likelihood of complete tumor removal.

Development of local recurrence is one of the main causes of unsatisfactory long-term recovery prospects following cancer surgery. Determining the adequate balance between radical tumor removal and maximum preservation of the surrounding tissue is therefore very important for cancer management and, subsequently, the patient’s quality of life. Rates of recurrence following surgical resection are appreciably high for a number of cancers. Following transurethral resection of bladder tumors (TURBT), they are reported to be as high as 40–80%, with a 2–45% risk of progression to invasive disease, depending on the grade and stage of the original tumor.\(^1\) Because of these high rates, partial cystectomy (removal of a major portion of the bladder) is advised for 6% of bladder-cancer patients.\(^2\) Following rectal-cancer surgery, the majority of recurrences are observed within the first two years postsurgery and arise in 21–36% of patients.\(^3\) After surgery for esophageal adenocarcinoma, the tumor-recurrence rate in the resected region is 18%.\(^4\) This indicates that existing diagnostic methods have limited potential for determining the true extent of tumors.

We have evaluated the use of optical coherence tomography (OCT) for pre- and intraoperative planning of tumor-resection margins for bladder, esophageal, and rectal carcinoma. OCT is an imaging method used to obtain cross-sectional images of living tissue in a noncontact and noninvasive manner by visualizing the distribution of backscattering intensities. The OCT device we employed uses probing radiation at a wavelength of 1300nm and a power of 3mW. Each OCT image has 200 \(\times\) 200 pixels across an area of \(2\times2\text{mm}^2\), a depth resolution in free space of 15\(\mu\)m, and a longitudinal resolution of 25\(\mu\)m registered for 2s.\(^5\)

We used OCT for intraoperative planning for 44 patients with bladder cancer undergoing TURBT.\(^6\) The OCT forward-looking probe (2.7mm in diameter) was introduced through the operating channel of the cystoscope and anchored during the procedure. Under visual control, the probe was pressed directly against the mucosa. We imaged two tumor sites and multiple sites along four directional paths (12, 3, 6, and 9 o’clock), up to 2cm around the visual tumor border. We then compared all OCT image readings with histological data from the same site. The OCT and histological borders coincided in 79% of cases. At the level of the traditional resection line (0.5cm from the visible tumor border along the perimeter), suspicious OCT images were observed in one third of cases (sensitivity was 93% and specificity 74%). If an abnormal or suspicious OCT image

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was revealed along the line, an additional resection was performed accordingly (see Figure 1). Based on the OCT data, 14 of the 44 patients having undergone intraoperative resection-line examination and one patient who had undergone a postoperative resection-line examination required additional resection.

When using OCT intraoperatively in the open bladder, we can determine the condition of the inferior bladder at the bladder neck for possible preservation. This significantly improves the odds of maintaining normal urinary function. This study included 25 patients who underwent partial cystectomy. Three of the 25 partial-cystectomy patients (12%) required intraoperative conversion to radical cystectomy, as OCT revealed tumor tissue near the bladder neck, while 17 patients (68%) underwent more limited resection than planned during presurgery. Combined, these studies suggest that OCT can help define bladder-tumor margins in real time and has the potential of improving bladder-resection adequacy, thus optimizing bladder sparing and reducing recurrence rates.

We also evaluated the use of OCT for pre- and intraoperative planning of tumor-resection margins for patients with esophageal and rectal carcinoma. Standard endoscopic OCT was used for 19 patients with rectal adenocarcinoma and 24 patients with distal esophageal cancer. Examinations were performed for those patients with esophageal cancer located no higher than 5cm from the Z line (the point at which the esophagus meets the stomach) and rectal tumors located in the upper and middle thirds. This inclusion criterion was applied because of the increased possibility of performing organ-preserving surgery in these patients. Taking into account that endoscopic biopsy involves only the superficial esophageal layers (mucosal and submucosal), determination of the OCT border and the histopathological examination of the specimens was done ex vivo. Based on this data we developed a technique of endoscopic tumor-border detection. Scanning was done during the presurgery endoscopic examination. The OCT border was detected and marked for further surgery. The endoscopic OCT probe investigated the visual border of the tumor (distal for rectal carcinoma and proximal for esophageal carcinoma) along four directional paths (12, 3, 6, and 9 o’clock: see Figure 2). We imaged the zones in 0.3-0.5cm steps until structural images corresponding to normal mucosa were obtained. We marked the OCT border using an electrocoagulator or methylene blue tattoo.

Where mucosal growth occurred, OCT correctly detected tumor borders in all four patients with esophageal cancer and all 16 patients with rectal cancer. For submucosal tumor growth, OCT worked very well for detection of tumor borders in all 16 cases of esophageal cancer and all nine cases of rectal cancer. However, OCT could not determine tumor borders in patients with cancer that had spread to the muscle in either the esophagus or the rectum.

OCT monitoring during oncology surgery allows adjustment of surgical margins, sparing neoplasia-negative areas, and increasing the amount of functional tissue. This procedure also permits modifying the margin to include neoplasia-positive areas that may otherwise have been left behind, decreasing the rates of recurrence and/or invasion. To further improve the diagnostic accuracy of OCT monitoring, we are exploring a number of developments, including use of polarization-sensitive OCT, high-speed scanning systems that would enlarge the area of the analyzed surface, and further minimization of the probe for better complementation with standard endoscopic equipment.

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Natalia Gladkova received the State Prize of the Russian Federation in Science and Technology for her research on OCT.

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