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Diagnosis of Functional Disorders in Hollow Organs by Infrared Radiation Optoelectronic System

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Abstract

The paper proposes a method to study functional disorders of hollow tubular organs using an infrared optoelectronic system that functions on the principle of optical location. The paper provides a general design of the developed optical probes used in gastroenterology, proctology, pulmonology and urology. The diagnostic results of the study of functional esophageal disorders are demonstrated through the example of the trachea and bronchi. The results are visualized on the monitor as an amplitude diagram that depends on the speed and frequency of changes in the lumen of the examined organ. The analysis of the diagrams provides information on functioning and mobility of the walls of the examined organ. The study results are recorded and stored for subsequent analytical processing of information.

1 Introduction

Timely identification of functional disorders of hollow tubular organs reduces complications of therapeutic and surgical type in patients with various pathologies. Early diagnosis is necessary for timely treatment of functional diseases. This provides the conditions for creation of an optoelectronic method and its further implementation into clinical practice.

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Functional diseases in gastroenterology, proctology, urology and pulmonology are related to peristaltic dysfunctions of hollow organs. Peristalsis evaluation is very important for diagnosis of functional diseases in clinical practice.

Among currently used modern medical technologies, a number of diagnostic methods that record the peristaltic function can be used to record disorders of hollow organs. Radiological, endoscopic and ultrasound methods and esophagogastrectomy are popular methods that are currently used. However, these methods do not always provide precise and complete information on the dynamic work of the examined organ.

The commonly used methods do not give reliable conclusions and lack information on the dynamics of the hollow organ functioning. To improve the efficiency of the diagnostic research, we propose an optoelectronic method that employs emission of infrared (IR) radiation.

This method can be used to detect microvibrations of any segment of the examined organ, to graphically illustrate the dynamic function along the length of the organ with subsequent comparative analysis of the diagrams with respect to time and duration of the diagnostic procedure.

2 Experimental

The basic idea of the infrared optoelectronic method is recording the reflectivity of the biological tissue during its interaction with IR radiation (Fig. 1, a). Complicated processes like reflection, absorption and transmission can be observed in the biological tissue under IR exposure. Therefore, the coefficients were mathematically calculated to find the radiation range with the maximum prevalence of the reflection coefficient over the absorption and transmission coefficients of the biological tissue.

While choosing the IR source, a number of factors should be considered among which the main factor is the wavelength of the light emitting diode (LED) radiation. To find the LED wavelength, the predominant level of the reflection coefficient should be determined over the absorption and transmission coefficients since the optoelectronic probe uses a specific value of the reflection parameter (Fig. 1, b). Thus, the research results show that an appropriate type of LED was chosen for the optoelectronic probe. This enables us to obtain the maximum sensitive level of the probe.

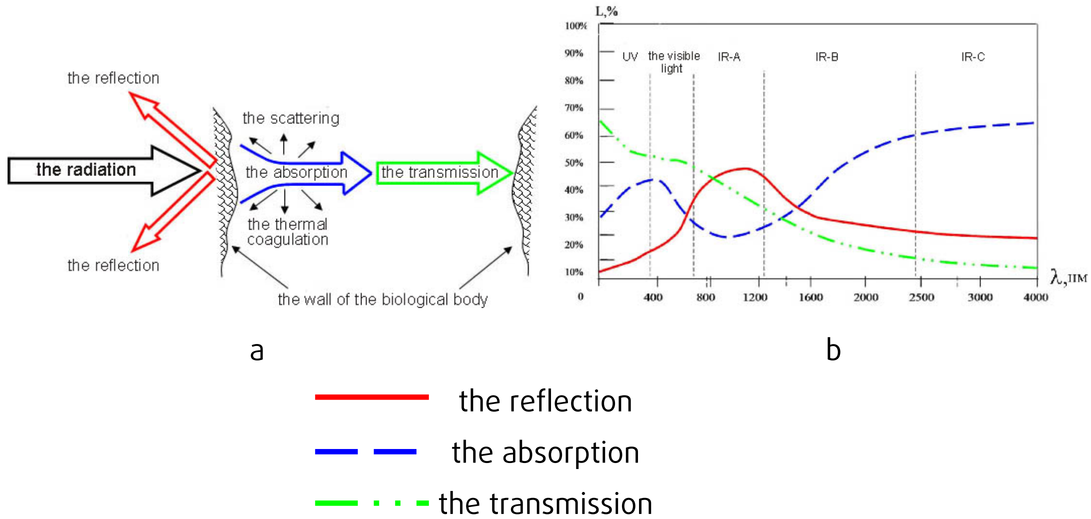

Fig. 1. The effect of a IR radiation with biological tissues: a – a schematic presentation; b – the schedule of the dependences of a characteristic on a wavelength

IR LEDs of AL107B type with a wavelength of about 940–960 nm and characteristics required for our research were taken to design an optical converter.

As a result, the optoelectronic probes were designed using IR LEDs (Fig. 2). The parameters of each of the probes were determined based on anatomical features of the examined organ. The probe has a polished monolithic tip of the NiTi-based alloy. It provides not only free sliding of the probe inside the esophagus, but does not produce "noise" effect on the electronic system due to high level of vibration damping. In addition, the NiTi alloy does not irritate the bio-system because it is a biocompatible material.

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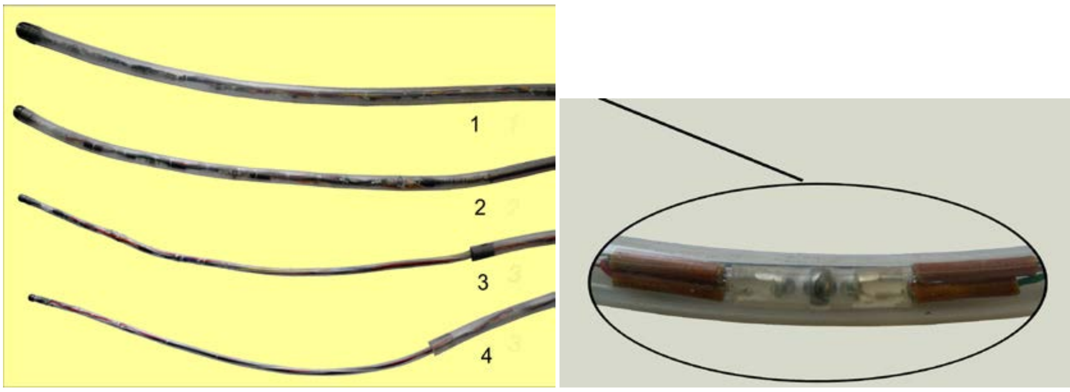


Fig. 2. The types of the optoelectronics probes

Table 1. The sizes of a probes and the number of an optical converter according on their application

The type of the probe	d of the probe [mm]	L of the probe [mm]	The number of the sensors [pcs]
1. proctology	9	300	5
2. gastroenterology	6.4	300	5
3. pulmonary	3.6	300	3
4. urological	2.8	200	1

The optoelectronic probe is inserted into the examined organ to study the peristaltic function. The signal (luminous flux) is reflected from the organ walls. The contraction of the walls causes changes in the intensity of the reflected luminous flux (Fig. 3), which is recorded by the IR receivers and transmitted to the electronic unit of the diagnostic equipment. Then the analog signal is processed and transmitted to the electronic device where it is converted from an optical waveform into an electrical one. The signal is amplified, filtered and transferred to the computer. The changed amplitude, frequency and waveform of the recorded signal indicate functional disorders of the organ.

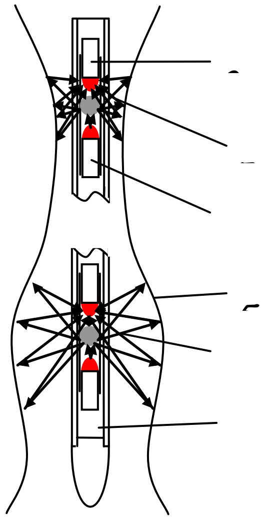


Fig. 3. The principle of the operation of an IR probe: 1 – the source of an IR radiation; 2 – the reception of an IR radiation; 3 – the direction of the radiation flux; 4 – a probe of the case; 5 – the wall of a biological body

The optical IR method requires an electronic unit to amplify and filter a useful signal from the optoelectronic probe. The device includes five identical channels to process the data arriving from the optical isolators (Fig. 4). Then the signal undergoes processing that is essential for further software implementation.

Fig. 4. The electronic device to use for a diagnosis by IR method

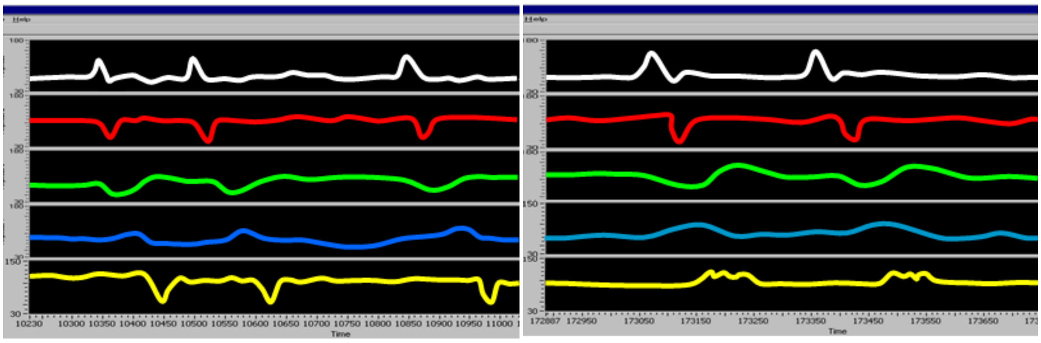
This method enables recording microvibrations of the small separate segments of the investigated organ. At the same time, a high level of interference protection was implemented since the source is not electrically connected to the receiver of the optical device. The connection between the source and the receiver is performed via light radiation [2, 4].

3 Results and discussion

The obtained diagrams illustrate the signal recorded, processed and visualized on a computer. The functional activity of the examined organ is estimated at the required time based on the changed amplitude, frequency and waveform of the signal. Consider the diagrams illustrating peristaltic activity of the esophagus and bronchial trachea. Figure 5 presents the diagrams illustrating esophageal peristalsis in Patient 1 with no function disorders (Fig. 5, a) and in Patient 2 with achalasia of cardia (Fig. 5, b). The optoelectronic probe is inserted into the oral cavity and then fixed for 15 seconds.

Patient 1. The signal from the first optical isolator (sensor) illustrates the process of swallowing. The amplitude peak on the diagram indicates contraction of the esophageal walls. The esophageal walls are relaxed and dilate at the level of the second sensor. Inactive esophageal contractions that correspond to the proper esophageal functioning in this area can be observed at the level of the third and fourth sensors. The fifth sensor is located at the level of the lower sphincter in patients whose esophageal walls contract properly during the peristaltic activity.

Patient 2. The results of the esophagus diagnostics presented in the diagram show proper peristaltic activity of the four upper esophageal segments. However, the lower sphincter does not open properly and closes spasmodically that indicates achalasia of cardia.



a) b)

Fig 5. The diagrams of the peristaltic esophagus along the length from the lower sphincter (yellow color) to the top sphincter (white color), the diagnosis of the patients: a) the normal; b) the pathology (echolalia cardio)

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Consider the diagrams showing the results of the trachea-bronchial dyskinesia diagnostics. The recording is performed along the main bronchi and trachea. The recording time should be no less than 10 seconds in each segment.

The intact trachea lumen was recorded at the first stage of the experiment. The signals with the time shift along the X-axis and the changed lumen of the intact trachea along the Y-axis were compared (Fig. 6, a).

The respiratory excursion of the examined tracheal wall is presented in the diagram in the form of relaxations of the signal amplitude synchronous to inhalation and exhalation. A small amplitude corresponds to inhalation and a large one indicates exhalation, namely the tracheal lumen reduction. The source of the signal amplitude modulation is microvibrations of the membranous part of the trachea occurring during the gas passage along the elastic wall.

The second diagram shows the recorded lumen of the trachea after strengthening the wall with the implant of the porous NiTi alloy. The elastic-flexible properties of the wall restore after strengthening. The analysis of the diagram shows stabilization of the amplitude in the exhalation phase (Fig. 6, b) [5, 6].

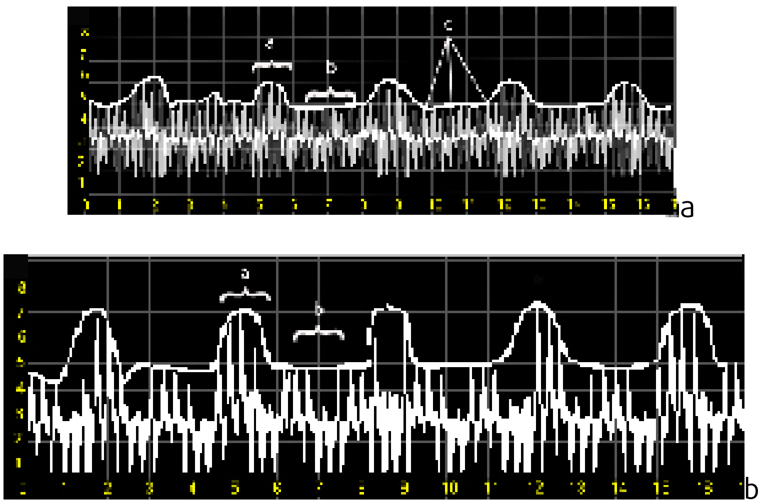

Fig. 6. The registration inner space of the trachea: diagrams inner space of the trachea before surgery (a – the inhalation, b – the exhalation, c – the microvibrations of the trachea); after - diagrams inner space of the trachea after surgery

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4 Summary

The optoelectronic method enables accurate detection of peristaltic disorders of hollow organs. This method is an additional effective tool to record the pathologies occurring in gastroenterology, proctology, pulmonology and urology.

The research ensures early detection of functional disorders. The optoelectronic method is used to evaluate the microvibrations of individual segments of the examined organ.

In addition to diagnostic testing, the proposed method is currently employed to graphically save the research data and to observe changes after some time.

Positive results of the research allow further investigation aimed to improve the proposed method.

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