LAPAROSCOPIC LASER SPECKLE CONTRAST IMAGING FOR REAL-TIME MINI-INVASIVE SURGERY: ANIMAL STUDIES

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Abstract. The work describes the methodology and technical implementation ofoptical imaging approach for intraoperative diagnostics of microcirculatory violations occurring in acute destructive pancreatitis during percutaneous interventional and laparoscopic treatment. The laser speckle contrast imaging technique is one of the most widespread imaging methods specially designed for monitoring of blood flow in tissues. As the process of tissue ischemia characterizes pancreatitis, the solution of merging laser speckle contrast imaging equipment and a standard laparoscope is proposed and tested in an animal model.

Introduction. The search for new diagnostic methods and criteria for the visualization and analysis of pathological tissues in minimally invasive surgery is a dynamically developing field of research. Information about microcirculation in abdominal organs tissue is important for determining the margins of normal, inflamed or necrotic tissues during surgery. One of the most commonly used methods of surgical treatment of pancreatitis is a laparoscopy. It helps diagnose or perform therapeutic interventions through several small incisions in the abdomen. The key element is the use of a laparoscope, which includes a system of long fiber optic cables, which allows the surgeon to control the affected area. However, the problem of more accurate evaluation of tissue state by visual control during the surgery remains relevant.

One of the most often pathologies treated by percutaneous interventional radiology and laparoscopic interventions is acute destructive pancreatitis. Acute destructive pancreatitis is a severe pathology with a high probability of complications and mortality, which make it one of the urgent problems of modern abdominal surgery. The main factors influencing the development and morbidities of acute pancreatitis are microcirculation violations and reperfusion ischemia. Microhemodynamic disorders are the leading trigger of inflammation and further necrosis in pancreatic tissue.

The possible solution is the implementation of optical diagnostic methods together with standard laparoscopic instruments. Optical techniques provide additional diagnostic information in real time, which can help to increase the frequency and effectiveness of minimally invasive abdominal interventions in clinical practice. The information about blood microcirculation in organs tissue can be collected and visualized by the method of laser speckle contrast imaging (LSCI). The LSCI method is based on the properties of laser radiation. When laser radiation illuminates a non-uniform surface, random interference of the coherent light occurs, which creates a random intensity pattern called speckle. The temporal and spatial statistics of speckle patterns provide information on the movement of scattering particles inside the tissue.

Therefore, the aim of the work is the development of an experimental laparoscopic setup and testing of the methodology in model animals.

Experimental equipment. Experimental studies were carried out using a setup, consisting of laparoscope Richard Wolf GA-S001 and LSCI optical measuring system. LSCI system includes 10 mW 635 nm laser source (Edmund Optics Inc., USA) to illuminate the object, as well as CMOS-camera DCC 3260M (Thorlabs, Inc., USA) with 1936×1216 pixels and 5.86 μm pixel size to record raw speckle images.

The data processing was performed using custom-developed software in MATLAB software in the offline mode. The standard spatio-temporal algorithm has been used for speckle contrast images obtaining. The calculation of the average speckle contrast of the image was performed using the Eq. 1:

$$K = \left\langle \frac{\sigma_N}{\langle I \rangle_N} \right\rangle_k \qquad (1)$$

where $\langle\ \rangle$ — the symbol of averaging; N — the window of averaging NxN (N=7); k — the number of consecutive frames (k=20); $\langle I \rangle_N$ — average intensity in the window NxN; σ_N — standard deviation in the window NxN.

Experimental studies were performed on clinically healthy male Balb/c mice obtained from the Scientific and Production Centre for Biomedical Technologies, Branch "Andreevka" (Moscow, Russia). The basic rules of maintenance and care corresponded to the standards of the sanitary rules for the arrangement, equipment and maintenance of experimental biological clinics and in the guide «Laboratory animals» and GLP principles.

Methodology. Before the experiment, a series of routine measurements on a specially designed speckle contrast phantom was made to check the normal operation of LSCI set up.

Mice were anesthetized with Zoletil 100 (Vibrac, France) at standard dose. Each animal was fixed on a special platform in the position on the back. A transverse laparotomy procedure was performed; the operative access was made to the upper part on the back wall of the abdominal cavity in the retroperitoneal space. After that, the complex of abdominal organs was carried out. Before recording, the main supply vessels of the pancreas were prepared for clamping.

The laparoscope was fixed on a tripod in a vertical position perpendicular to the area of interest. For speckle images acquisition, the animal was placed under the optical system to visualize the area and record the frame sequences. The registration of images was made before ligating and every 3 minutes after ligating to monitor dynamical changes in pancreas blood flow. At the initial stage, there was an increase in contrast after clamping as the smallest visible vessels contribute to the overall speckle contrast. The next stage of reperfusion is characterized by a significant drop incontrast below the initial level. After a certain period, the original values of the contrast are restored.

Conclusion. The obtained results confirm the possibility of using additional imaging approach to assess the microcirculation rate during laparoscopic and percutaneous interventional surgical operations. Speckle contrast values demonstrate the close dependence of changes in the image contrast on the parameters of tissue microcirculation. LSCI method shows high sensitivity to the presence, absence or increased blood flow. However, initial studies show the need for methodology and diagnostic criteria development for future prospects in clinical practice. Additional research is needed to analyze the influence of the movement and fluctuations caused by both the biological object and the operator as well.

In general, the results of this study will be used to adjust the LSCI methodology for use during routine percutaneous interventions and laparoscopic surgical operations. While the main emphasis of further research will be made on determining the microcirculation state in acute destructive pancreatitis, the implementation of imaging methods also seems promising for other abdominal pathologies complicated by ischemia process (for example, strangulated intestinal obstruction).

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