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(54) **DEVICE AND METHOD FOR ASSESSING REGIONAL BLOOD CIRCULATION**

(57) The invention pertains to medicine, namely to medical technology, and can be used in various fields of medicine for non-invasive (percutaneous) and intraoperative (surgical) identification of the parameters indicating blood flow and oxygen saturation of blood.

The objective of the present invention is to create a method and device for real-time estimation of blood flow, tissue microcirculation and oxygen saturation of blood for control and correction of pharmacological, physiotherapeutic and surgical treatment.

In terms of method, the said objective is achieved by identifying the qualitative and quantitative parameters of blood flow from the microcirculation volume of tissue in the point of sensing with ultrasonic Doppler indicators of blood flow at a continuous radiation mode with a frequency of more than 20 MHz, by using the software electronic "Micro" unit functioning at a maximum amplification, with the simultaneous estimation of oxygen saturation of blood by using the pulse oximeter sensor which is affixed to the sensing area, and the tissue microcirculation and regional blood circulation are assessed on the basis of the obtained figures indicating the oxygen saturation of blood and the blood flow parameters in a single vessel and in a microcirculation volume of tissue for subsequent diagnosis, screening control and correction of the pharmacological, physiotherapeutic and surgical treatment, in real time mode.

The said objective in the device is achieved through

introduction of the pulse oximeter unit, software electronic "Micro" unit, control and visualization units, whereas the quantity, shape and frequency of acoustic heads is selected depending on the anatomic features of the subject under analysis: surgical, transcutaneous, laparoscopic, with a frequency of 10, 20, 25, 30 MHz, elongated, L-shaped; therewith the ultrasonic Doppler indicator is equipped with a titanium case to enable multiple sterilization.

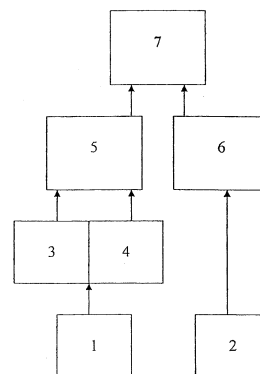


Fig. 1

## Description

### TECHNICAL FIELD

**[0001]** The invention belongs to the field of medicine, namely, to medical engineering and can be used for non-invasive (transcutaneous) and intraoperative (surgical) determination of parameters of blood flow and blood oxygen saturation in various fields of medicine: general medicine, beauty therapy, dermatology, traumatology, functional diagnostics, cardiology, neurosurgery, vascular surgery, urology, gynaecology, traumatic surgery, stomatology, maxillofacial surgery, plastic surgery, ophthalmology, rehabilitation, sports medicine, physiology, pathophysiology, pharmacology, oriental medicine.

### PRIOR ART

**[0002]** To study tissue microcirculation in clinical practice the following methods are most frequently used: intravital microscopy, laser doppler flowmetry, radionuclide clearance method, transcutaneous pO<sub>2</sub> and pCO<sub>2</sub> determination, thermography. Each of them has its advantages and disadvantages, but none of them fully satisfies clinicians. The usual objects under study are vessels of the skin, mucous membrane and retina microvasculature. These methods have certain limitations concerning assessment of tissue microvasculature of internal organs, including intraoperative assessment.

**[0003]** There are Acuson-128XP and HP-1500 devices for peripheral vessels blood flow study (Ultrasound comprehensive study of patients with aortic aneurysm // Angiology and Vascular Surgery. -1996.-No 5.-P. 46-58). Already existing devices are equipped with 7.5 MHz operating frequency ultrasonic sensors.

**[0004]** There is also VASCULAB SP25A hardware system (Comparison of data received by means of lower limbs subcutaneous veins ultrasonic dopplerography and clinical varicose vein disease // Imaging in Hospital.-1996. - December. No 9. - P. 30-35). Subcutaneous vessels hemodynamics in the above hardware system is investigated with the help of an ultrasonic sensor with an operating frequency of 8 MHz in the CW Doppler mode. The ultrasonic beam is kept at a 45-50° angle in order to reduce errors while performing quantitative assessment of blood flow velocity.

**[0005]** The operating frequency of the above devices sensors is significantly less than 20 MHz, which does not allow for a clear signal yielding information about blood flow of a single micro vessel in 8-mm depth. Furthermore, the existing devices make it possible to evaluate the velocity of blood flow only without determining its direction which is necessary for early non-invasive diagnosis of various diseases, such as pulpitis, stomatitis, etc.

**[0006]** Another disadvantage of these devices is inability to conduct examination on-site and in a mobile hospital as these devices are bulky stationary units and before examining patients one requires an additional long-

time preparation of devices in order to place them properly, connect cables of the electrodes and sensors.

**[0007]** The unit which possesses the most comparable technical characteristics and provides the most comparable results similar to the proposed device for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation is the unit for assessment of regional blood flow comprising the device for blood flow measurement which includes a Doppler ultrasound transducer with a sensor equipped with receiving and emitting piezoelectric elements (RU, patent number 2152173, class A61V8/06, 1998).

**[0008]** The most comparable technical characteristics and results of the proposed method of assessment of regional blood flow, tissue microcirculation and blood oxygen saturation is the method of regional blood flow assessment through tissue location by means of ultrasonic Doppler sensor set at the sounding point and determination of blood flow characteristics by means of the data processing unit (RU, patent number 2152173, class A61V8/06, 1998).

**[0009]** The most significant disadvantage of the given method and device of regional blood flow evaluation is that it is impossible to carry out a comprehensive study of blood flow system of macro- and micro-vessels simultaneously with pulse oximeter parameters and also impossible to provide a comprehensive evaluation of the reaction demonstrated by the entire circulatory system to various physiological and functional tests.

**[0010]** Moreover, the given method and device have following shortcomings:

1. They cannot be used to determine velocity characteristics - linear and volumetric blood flow velocity in the tissues of a living organism during surgery as the design of the sensors the given device is equipped with does not provide for this function, and the sensors were used only transcutaneously (transdermally), it was impossible to use them intraoperatively because of their shape.
2. No option of desired signal detection amid self-noise during surgical interventions.
3. It is impossible to measure linear and volumetric blood flow velocity, oxygen saturation, heart rate (HR) simultaneously.
4. It is impossible to differentiate the signal, namely arteriolar, venular, capillary, shunt or lymph signal which otherwise ensures a higher level of general diagnostics.
5. It is impossible to determine oxygen saturation and pulse rate simultaneously with data on blood flow.
6. It is impossible to determine blood flow characteristics in a single slice and tissue section.

### DISCLOSURE OF INVENTION

**[0011]** The technical result the present invention is

aimed at is to develop a method and a mobile device for assessment of blood flow, tissue microcirculation and blood oxygen saturation, allowing precise control of linear and volumetric blood flow velocity, resistivity and pulse index, dopplerogram, plethysmogram and heart rate (HR).

**[0012]** The stated technical result is achieved due to the fact that design of the device for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, comprising a device for blood flow measurement which includes Doppler ultrasound transducer with a sensor comprising receiving and emitting piezoelectric elements, according to the claim, is enhanced with a device for pulse oximetry equipped with a sensor as well as the unit to determine the oximeter characteristics, the pulse oximeter sensor has two LEDs, one of which emits visible light in the red spectrum (600 nm), the other in the infrared spectrum (940 nm); moreover, the device for blood flow measurement includes two electronic software units to determine quantitative characteristics in a single vessel and in tissue section: macro-and micro-measurement modes; it should be noted that data from all the units are transmitted to the data display unit and the shape and design of the acoustic heads used in the sensors of blood flow measurement device correspond to the anatomic features of the region of interest: surgical, transcutaneous, laparoscopic, with the frequency of 10, 20, 25, 30 MHz, elongated, L-shaped; the sensors are enclosed in a titanium case for repeated sterilization conditions. Furthermore, the stated technical result is achieved due to the fact that the device for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, according to the claim, can have laparoscopic sensors used with 5- and 10-mm diameter trocars. Furthermore, the length of the acoustic heads of sensors installed in blood flow measurement device may be  $0.1 \div 250\text{mm}$ , the sensor diameter is  $1.5 \div 30\text{mm}$  and the L-shaped sensor angle is  $135^\circ$  with a radius of 10mm.

**[0013]** The stated technical result is achieved due to the fact that the method for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, through tissue location by means of the ultrasonic Doppler sensor set at the sounding point and through determination of blood flow characteristics by means of the data processing unit, according to the claim, the Doppler ultrasound transducer is set either into the projection of a single vessel or into the projection of or directly on the microcirculation volume of tissue; when working with a single vessel, Macro software and electronic unit is used which, while calculating, utilizes a special filter singling out the signal from a single vessel; and, when working with a microcirculation volume of tissue, Micro software and electronic unit is used which runs at maximum gain, while the pulse oximeter sensor is additionally set on the patient's ear or finger; from two LEDs of the pulse oximeter sensor, one of which emits visible light in the red spectrum (600 nm) and the other in the infrared spec-

trum (940 nm), the light passes through the tissue to a light detector with some portion of radiation absorbed by the blood and soft tissues, depending on the concentration of hemoglobin, the amount of the absorbed light at each of the wavelengths depends on the degree of hemoglobin oxygenation in the tissue; at the same time the pulse oximeter data processing unit singles out the blood pulse component from the absorption spectrum, i.e. it separates the arterial blood component from the venous or capillary blood permanent component, while the Doppler signal processing unit and the pulse oximeter data processing unit display data on the screen via the connected visualisation unit. Furthermore, the stated technical result is achieved due to the fact that the method for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, according to the claim, presupposes that 25 MHz transcutaneous elongated sensor (cylindrical, the head length of  $30 \pm 2\text{ mm}$ , the effective diameter of  $1.5 \pm 0.2\text{ mm}$ ) can be used in abdominal surgery, and the 10 MHz surgical sensor (cylindrical, the head length of at least  $100 \pm 5\text{ mm}$ , the effective diameter of  $1.5 \pm 0.2\text{ mm}$ ), 20 MHz surgical curved sensor (cylindrical, the head length of  $100 \pm 5\text{ mm}$ , the effective diameter of  $1.5 \pm 0.2\text{ mm}$ ), 25 MHz surgical sensor (cylindrical, the head length of  $100 \pm 5\text{ mm}$ , the effective diameter of  $1.5 \pm 0.2\text{ mm}$ ) can be used in neurosurgery. 20 MHz laparoscopic sensor (cylindrical, the head length of  $250 \pm 5\text{ mm}$ , the effective diameter of  $1.5 \pm 0.2\text{ mm}$ ) is used in laparoscopic surgeries. In addition, 25 MHz L-shaped sensor (canted - the rounded working part of the head) is used to assess the irritating effects of substances on the vessels of chicken embryo chorio-allantoic membrane (CAM).

**[0014]** The device for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation is a universal diagnostic tool and can be used both in permanent hospital facilities and on-site, when examining astronauts immediately after landing, in sealed closed objects and in case of elevated pressure in decompression systems.

**[0015]** The method and device for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation are of great scientific and clinical importance and help to detect pathological changes in tissue microcirculation in the early stages of development, they are also relevant for dynamic monitoring of recovery processes in the course of treatment. The method and device are in demand in research activities when studying the mechanisms of the cardiovascular system affected by various adverse factors.

**[0016]** This integrated approach allows one to evaluate changes in the blood circulatory system as early as at the stage of functional dysfunction.

#### **BRIEF DESCRIPTION OF THE VIEWS OF THE DRAWINGS**

**[0017]** Figure 1 shows the device for assessment re-

gional blood flow, tissue microcirculation and blood oxygen saturation.

**[0018]** The device for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation includes a device for blood flow measurement (not shown in the drawing). The device includes a Doppler ultrasound transducer 1 with a sensor which comprises receiving and emitting piezoelectric elements (not shown in the drawing); a device for pulse oximetry with a sensor 2. The device for blood flow assessment includes two electronic and software units 3 and 4 to determine quantitative characteristics in a single vessel and tissue section: macro- and micro-measurement modes. Data from blocks 3 and 4 are transmitted to the display unit 5 (a Doppler signal data processing unit).

**[0019]** The shape and design of the acoustic heads used in the sensors of blood flow measurement device correspond to the anatomic features of the region of interest: surgical, transcutaneous, laparoscopic, with the frequency of 10, 20, 25, 30 MHz, elongated, L-shaped; the sensors are enclosed in a titanium case for repeated sterilization conditions.

**[0020]** The device for pulse oximetry includes unit 6 to determine pulse oximeter characteristics (pulse oximeter data processing unit).

**[0021]** The pulse oximeter sensor 2 has two LEDs (not shown in the drawing), one of which emits visible light in the red spectrum (600 nm), the other in the infrared spectrum (940 nm). All data is displayed on the visualisation unit 7.

**[0022]** The method for assessment of regional blood flow, tissue microcirculation and oxygen saturation implemented by the proposed device for assessment of regional blood flow, tissue microcirculation and oxygen saturation, is as follows:

The Doppler ultrasound transducer 1, with some gel applied thereto in advance, is set either into the projection of a single vessel or into the projection of or directly on the microcirculation volume of tissue. When working with a single vessel, Macro software and electronic unit 3 is used which, while calculating, utilizes a special filter singling out the signal from a single vessel. When working with a microcirculation volume of tissue, Micro software and electronic unit 4 is used which runs at maximum gain. During examination the pulse oximeter sensor 2 is additionally set on the patient's ear or finger, from two LEDs of the pulse oximeter sensor, one of which emits visible light in the red spectrum (600 nm) and the other in the infrared spectrum (940 nm), the light passes through the tissue to the light detector. Some portion of radiation is absorbed by the blood and soft tissues, depending on the concentration of haemoglobin, while the amount of the absorbed light at each of the wavelengths depends on the degree of haemoglobin oxygenation in the tissue. The pulse oximeter data processing unit 6 singles out the blood pulse com-

ponent from the absorption spectrum, i.e. it separates the arterial blood component from the venous or capillary blood permanent component. At the same time the Doppler signal processing unit 5 and the pulse oximeter data processing unit 6 are connected with the visualisation unit 7 in order to display data on screen.

**[0023]** The Doppler ultrasound transducer 1 and the pulse oximeter sensor 2 are connected to the device in parallel. Data reading and processing are performed simultaneously.

**[0024]** During abdominal surgeries 25 MHz transcutaneous elongated sensor (cylindrical, the head length of  $30 \pm 2$  mm, the working diameter of  $1.5 \pm 0.2$  mm) is mostly used.

10 MHz surgical sensor (cylindrical, the head length of min.  $100 \pm 5$  mm, the effective diameter of  $1.5 \pm 0.2$  mm), 20 MHz surgical curved sensor (cylindrical, the head length of  $100 \pm 5$  mm, the effective diameter of  $1.5 \pm 0.2$  mm), 25 MHz surgical sensor (cylindrical, the head length of  $100 \pm 5$  mm, the effective diameter of  $1.5 \pm 0.2$  mm) can be used in neurosurgery.

20 MHz laparoscopic sensor (cylindrical, the head length of  $250 \pm 5$  mm, the effective diameter of  $1.5 \pm 0.2$  mm) is used in laparoscopic surgery. Furthermore, 25 MHz L-shaped sensor (canted - the rounded working part of the head) is used to assess the irritating effects of substances on the vessels of chicken embryo chorioallantoic membrane (CAM).

## EXAMPLES OF METHOD IMPLEMENTATION

### Neurosurgery:

**[0025]** The possibility to adequately assess various links of the cerebral blood flow and the blood oxygen saturation during neurosurgical interventions is crucial for successful surgical treatment in general. With the help of this device with an integrated oximeter one can adjust the plan and extent of surgeries, change the duration of certain procedures and regulate the degree of traction effects on the brain, thus reducing the risk of intra- and postoperative complications, as well as explore the possibility of assessment of blood flow in arteries and veins of different calibre in the cortex, brainstem, sinuses and cranial nerves arteries by means of surgical sensors with the frequency of 10, 20, 25 MHz.

Example 1.

**[0026]** Intraoperative studies using the proposed device and method involved 70 patients with tumours and cerebrovascular pathology and were conducted by means of special sterilized sensors with the frequency of 10, 20 and 25 MHz. We investigated the possibility of assessing blood flow in the arteries and veins of different calibre in the cortex, brainstem, sinuses and cranial

nerves arteries.

**[0027]** When studying large brain vessels such as medial cerebral artery branches, the adequate result was achieved by using a 20 MHz sensor, and made it possible to estimate the radical clipping of aneurysm, as well as the risk of a postoperative spasm.

**[0028]** During interventions in the region of the cranial sinuses, the use of a contact sensor enables one to evaluate the existing blood flow in the region of the sinus affected by a tumour tissue. The study of the arteries and veins of the cerebral cortex can be carried out with the help of 20-25 MHz sensor that can adequately assess velocity parameters of blood flow in vessels with the outer diameter of up to 0.25 mm.

**[0029]** We studied blood flow in small-diameter vessels of the cerebral cortex in patients with neuroectodermal tumours of different histological structure by means of functional loading tests. Preliminary evidence of a certain connection between the type of blood flow response to hyperventilation and the histological structure of the tumour has been obtained.

**[0030]** During the surgeries of tumours in the chiasmosellar region blood flow in the optic nerve was assessed and the criteria for prediction of possible impaired blood circulation in it were tried and tested.

**[0031]** It was found that the method and device for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation enables assessment of blood flow in vessels of the brainstem and cranial nerves, including in the area of their immediate outlet from the brainstem (facial and vagus nerves). Thus, it is possible to conclude that the present method and device may be used in neurosurgery and provide some opportunities to control blood flow in different vessels of the brain and cranial nerves.

Example 2.

**[0032]** The study involved 12 patients with pituitary adenomas and meningiomas of the tubercle of sella turcica - three men and nine women. The patients were aged 42- 69. 4 patients were diagnosed with meningioma of the tubercle of sella turcica and 8 patients were diagnosed with pituitary adenoma. The clinical presentation is predominantly visual malfunctions and (in case of adenomas) hormonal disorders of varying intensity.

**[0033]** All patients underwent a surgery - bifrontal trepanation, removal of the tumor. Various parts of the sagittal sinus were located before and after opening the dura mater and also under the conditions of hyperventilation by means of 20 MHz ultrasonic sensor. Blood flow through the optic nerves arteries was monitored while accessing the tumor immediately after the optic nerves were detected by means of the same device with the help of 25 MHz micro-Doppler sensor.

**[0034]** Findings: parameters of the linear velocity of blood flow in the initial sections of the anterior third of the superior sagittal sinus are  $6 \pm 2.1$  cm/sec maximum and

$4 \pm 1.8$  cm/sec minimum. Velocity characteristics increase toward the sinus distal parts and on the border of the anterior and middle thirds are as high as  $18 \pm 6.6$  cm/sec maximum and  $9 \pm 4.4$  cm/sec minimum. When opening the dura mater (up to the moment the beginning of the sinus is separated from the cockscomb), it was noted that velocity values decrease by 70-90% in the initial areas of the sinus and by 20- 50% on the border of the anterior and middle thirds.

**[0035]** Blood flow through the optic nerves arteries was monitored at the exact moment when accessing the tumor under direct vision. The average speed through the optic nerves arteries was  $24.5 \pm 4.8$  cm/sec, PI -  $0.67 \pm 0.11$ , RI -  $0.49 \pm 0.07$ .

**[0036]** The operated patients showed different dynamics of visual functions: three patients manifested improved vision (acuity, field) after the surgery, three patients did not manifest any dynamics and two patients had impairment of vision.

**[0037]** Both patients with consequent impairment of vision showed dramatically increased pulse index (1.1 and 1.3, respectively), as well as, to a lesser extent, increased resistive index (0.6 and 0.8, respectively), with medium-velocity characteristics (1 and 24 cm/sec) preserved.

**[0038]** Thus, we can assume the possibility of intraoperative prediction of the state of blood flow in the optic nerve, with further correction of the scope of manipulations in the optic nerve.

### Use in cavity and laparoscopic surgery

**[0039]** Ultrasonic dopplerography together with a pulse oximeter can be used in various fields of surgery to determine microcirculatory blood flow and hemodynamics in major vessels of various diameters. Possible areas of application:

- studies conducted in the intestine during surgery for acute intestinal failure: it is possible to determine indicators of blood flow and blood oxygen saturation after reduction of incarcerated intestine in case of strangulation, in the borders of the resected intestine before application of anastomosis, assessment of intestinal viability in case of strangulated and incarcerated hernia;
- in vascular surgery: intraoperative assessment of blood flow and assessment of blood oxygen saturation in blood vessels immediately after revascularization;
- assessment of blood flow in flaps and transplants, including those used in the esophagus plastic procedures, determination of blood flow and blood oxygen saturation in the large intestine (descendent colon) in case of abdominal-anal resection.

Example 3.

**[0040]** At present myocardial revascularization (coro-

nary artery bypass grafting - CABG) in patients with ischemic heart disease has become a conventional method of treatment of this disease. The effectiveness of surgical treatment of ischemic heart disease (IHD) is determined by many factors - the patient's age, concomitant diseases (old myocardial infarction, left ventricular aneurysm, hypertension, etc.) and, primarily, the extent of coronary arteries and myocardial microvasculature damage. Considering the above, the key issue in improving the results of surgical treatment of patients with ischemic heart disease (IHD) remains an objective assessment of the coronary and myocardial blood flow prior to the main stage of intervention and after revascularization surgery.

**[0041]** Modern methods dealing with recording of blood flow in the coronary arteries and assessment of total blood flow in the myocardial microvasculature which are introduced in cardiac surgery practice enable one to find new ways of tackling this problem.

**[0042]** Objective: to evaluate the possibility of use of high-frequency ultrasound Doppler flowmetry device for intraoperative monitoring and assessment of blood flow in the coronary arteries and total blood flow in the microvasculature section of myocardium.

**[0043]** Parameters measured by the device:

Indexes:

Ri - total peripheral resistance index (Purcell factor).  $RI = (Vs - Vd)/Vs$

Vs - maximum systolic velocity.

Vd - end-diastolic velocity.

ISD - systolic and diastolic index (Stewart index) reflects the elastic properties of blood vessels.  $ISD = Vs/Vd$

Pi - pulsatility index (Gosling index) reflects the elastic properties of the arteries.  $Pi = (Vs - Vd)/Vm$ .

Blood flow linear characteristics:

Vas - maximum systolic velocity on medium velocity curve.

Vam - average velocity on the medium velocity curve.

Vd - maximum diastolic velocity on medium velocity curve.

Blood flow volumetric characteristics:

Qas - maximum systolic velocity on medium velocity curve.

Stages of the study:

The study was performed intraoperatively with all of the above blood flow characteristics being recorded. Myocardial blood flow was investigated

ed in the apex of heart area on the myocardium of the left and right ventricles.

**[0044]** The study was performed in accordance with the stages of the surgery. Stage 1 - measurement of blood flow characteristics prior to cardiopulmonary bypass, i.e. after pericardiotomy the surgeon placed a sterile ultrasound transducer with a frequency of 20 MHz ultrasonic vibrations at the angle of 60° into the projection of the coronary artery. The sensor with a frequency of 25 MHz ultrasonic vibrations was placed directly on the myocardium in the apex of heart area. Stage 2 - during cardioplegia the sensor with an operating frequency of 25 MHz was placed directly into the myocardium. Stage 3 - after anastomoses were performed and blood flow was re-established, there was assessment of linear and volumetric characteristics of blood flow in the myocardium, through the graft, in the area of the distal anastomoses and in the coronary arteries distal of the graft.

**[0045]** During all stages of the surgery peculiarities of blood flow were determined in the ramus interventricularis anterior (RIVA), right coronary artery (RCA) and circumflex branch (RCX). The criteria for selection of patients for the study was manifested lesion of the arteries.

**[0046]** For each artery sensors with a certain operating frequency were selected: RIVA, RCX, RCA - 10 MHz; in the distal end of RIVA - 20 MHz; directly on the myocardium - 25 MHz.

**[0047]** All measurements were performed in the supine position at a constant temperature and humidity. All patients had their arteriolar pressure and heart rate measured on-line.

Details of clinical impressions:

**[0048]** The study included 21 patients of both sexes. All patients were diagnosed with ischemic heart disease (IHD) and cardiac angina functional class 3-4. To evaluate the effectiveness of the method the patients were divided into 3 groups: group I - normothermic cardiopulmonary bypass with normothermic blood cardioplegia; group II - hypothermic cardiopulmonary bypass with Custodiol cardioplegia; group III - surgeries without cardiopulmonary bypass. With the purpose of monitoring all the patients had echocardiography done in the pre- and post-operative periods. All studies were carried out during coronary artery bypass surgery.

Results of the study:

**[0049]** Peculiarities of coronary blood flow when operating on the patients of group I.

**[0050]** When analysing the patients of group I at the beginning of the surgery, the total BFLV (blood flow linear velocity) value in RIVA, DB, RCA, PIV (posterior interventricular artery) and in the myocardium decreased from  $46 \pm 5$  cm/s to  $39 \pm 2$  cm/s before cardiopulmonary bypass was started ( $p > 0.05$ ). At the stage of distal anas-

tomoses no significant decrease in BFLV values was recorded as compared to the beginning of normothermic cardiopulmonary bypass ( $p > 0.05$ ). After the clamp was removed from the aorta there was a rapid increase in BFLV in LCA and RCA circulation up to  $62 \pm 4$  cm/s as compared with the stage of distal anastomoses ( $p < 0.05$ ). BFLV remained at this level until the end of the surgery, which is related to adequate coronary blood flow restoration.

**[0051]** A similar pattern was observed when analyzing tissue myocardial microcirculation in the projection of RIVA and RCA at the beginning and at the end of the surgery with physiological decline in average blood flow velocity. Thus, at the beginning of the surgery the total values of velocity were decreasing from  $43 \pm 3$  cm/s to  $36 \pm 4$  cm/s before cardiopulmonary bypass was started ( $p > 0.005$ ). At the stage of distal anastomoses there was no record of significant decrease in velocity as compared with the beginning of normothermic cardiopulmonary bypass ( $p > 0.05$ ). After the clamp was removed from the aorta, velocity was rapidly increased in RIVA and RCA circulation up to  $50 \pm 6$  cm/s as compared with the stage of distal anastomoses ( $p < 0.05$ ) which remained at this level until the end of the surgery.

**[0052]** The study of BFLV and tissue microcirculation in LV (left ventricle) and RV (right ventricle) in group I revealed the fact of steady blood supply in RIVA, RCA, the myocardium of LV and RV during the whole surgery. This is related to perfusion of the coronary bed with normothermic oxygenated blood cardioplegic mixture at the stage of aortic clamping with minimal demand in oxygen and energy substrate because of asystole.

**[0053]** Peculiarities of coronary blood flow when operating on the patients of group II.

**[0054]** When analyzing the patients of group II, BFLV values were decreased from  $45 \pm 5$  cm/sec to 0 at the stage of aortic clamping which corresponds to the period of myocardial ischemia ( $p < 0.05$ ). Removal of the clamp from the aorta led to restored BFLV in LCA and RCA circulation up to  $59 \pm 7$  cm/s, which remained at this level until the end of the surgery.

**[0055]** When analyzing tissue microcirculation, one could observed decrease in average blood flow velocity in the myocardium from  $41 \pm 4$  cm/sec to 0 prior to the stage of distal anastomoses ( $p < 0.05$ ), followed by a rapid increase to  $47 \pm 6$  cm/sec after the clamp was removed from the aorta.

**[0056]** Complete termination of coronary blood flow at the stage of aortic clamping in group III, a rapid increase in linear and volumetric characteristics of coronary blood flow, as well as increased perfusion of myocardial microcirculation after bypass surgery and blood flow restoration caused reperfusion injuries during the transition from anaerobic to aerobic metabolism and from hypo- to normothermic blood circulation.

**[0057]** Peculiarities of coronary blood flow when operating on the patients of group III.

**[0058]** When analysing the patients of group III at the

beginning of the surgery, the total BFLV value in RIVA, DB, RCA, PIV and in the decreased from  $48 \pm 4$  cm/s to  $41 \pm 2$  cm/s prior to the stage of distal anastomoses due to myocardial stabilization devices ( $p > 0.05$ ). At the stage of distal anastomoses no significant decrease in BFLV values was recorded as compared to the beginning of the surgery. After adequate coronary blood flow was restored, as compared to the stage of distal anastomoses, there was a rapid increase in BFLV in LCA and RCA circulation up to  $63 \pm 5$  cm/s ( $p < 0.05$ ) which remained at this level until the end of the surgery.

**[0059]** A similar pattern was observed when analyzing tissue myocardial microcirculation at the beginning and at the end of the surgery with physiological decline in average blood flow velocity. Thus, at the beginning of the surgery the total value of velocity was decreasing from  $44 \pm 3$  cm/s to  $39 \pm 2$  cm/s prior to the stage of distal anastomoses ( $p > 0.005$ ). As compared to the stage of distal anastomoses, after it was completed, velocity was rapidly increased in LCA and RCA circulation up to  $53 \pm 4$  cm/s and remained at this level until the end of the surgery. The parameters of tissue microcirculation in group III were favourable for bypass surgery on RCA and RIVA circulation. When performing bypass surgery on the posterolateral artery (PLA) and obtuse marginal artery there was a significant decrease in linear and volumetric blood flow characteristics, leading to impaired tissue microcirculation associated with increased demand in oxygen and energy substrates. It is caused by significant impairment of intracardiac hemodynamics when dislocating the heart and providing access to the coronary arteries on its posterolateral surface.

**[0060]** The conducted high-frequency ultrasound Doppler flowmetry monitoring of coronary blood flow during cardiac surgeries showed that an important stage of the surgery is insersion of an aortic cannula. In the course of uncomplicated cannulation of the ascending aorta there was no microembolia recorded. Increased duration of manipulations with the aorta resulted in microembolia in LCA and RCA circulation. The beginning of cardiopulmonary bypass was always accompanied by changes in blood flow velocities and decreased myocardial microvasculature perfusion. However, in all cases the average linear flow velocity exceeded its critical value (20 cm/s). Preserved autoregulation of coronary blood flow is likely to compensate for short-term episodes of decrease in arteriolar pressure.

**[0061]** Complete cardiopulmonary bypass significantly changed the shape of the dopplerogram-blood flow acquired a "non-pulsating" sinusoidal character. At the stage of aortic clamping there was no coronary blood flow in group II. After cardiac function is restored and blood flow is released, BFLV values and myocardial microcirculation are restored to their original values. However, group I manifested a greater decrease in myocardial tissue microcirculation in the affected artery circulation.

**[0062]** Significantly high linear and volumetric charac-

teristics of coronary blood flow and blood flow through the graft, as well as a significant increase in myocardial microcirculation perfusion during performance of distal anastomoses were recorded in groups I and III as compared to group II. At the same time, there were no considerable differences between groups I and III. Cardioplegic mixture in group I and blood in group III were evenly supplied to both LV and RV through the system of RIVA, circumflex branch and PCA throughout the surgery, which excluded the period of myocardial ischemia.

**[0063]** The conducted high-frequency ultrasound Doppler flowmetry monitoring of coronary blood flow and myocardial perfusion during cardiac surgeries with cardiopulmonary bypass showed that during hypothermic cardiopulmonary bypass there was a steady tendency of decreased blood flow and perfusion in the microcirculation area, the pulsating character of perfusion changed into sinusoidal. It should be noted that these changes affected hypothermic perfusion to a greater extent, they were observed less often during normothermic cardiopulmonary bypass, and least often during surgeries without CPB cardiopulmonary bypass. The method allowed not only to evaluate the characteristics of coronary blood flow but also the adequacy of perfusion restoration in microcirculation area of the coronary bed after myocardial revascularization. The study showed that the impaired coronary bed causes the asymmetry of blood flow in LV and RV, reduced BFLV in the affected artery circulation and a compensatory increase of BFLC in the unaffected artery circulation. The same regularity is observed in the coronary bed microcirculation. This regularity was recorded in all investigated groups.

**[0064]** In order to illustrate the above, we took the ratio of the velocity of total microcirculatory blood flow in the myocardium of the ventricles (myocardium of the left ventricular/ myocardium of the right ventricular - LV/RV). So, it was observed that there is homogeneous distribution of blood-base normothermic cardioplegic solution between the myocardium of the left and right ventricles of the heart, as evidenced by the values registered during surgery-LV/RV = 1. In case of phar-maco-hypothermic cardioplegia these values were LV/RV = 1,25 (p < 0,02).

**[0065]** One of the consequences of prolonged perfusion of the heart is development of myocardial stunning manifested by the average blood flow linear velocity increased by more than two standard deviations from the baseline together with a reduced peripheral resistance. We did not record any case of myocardial stunning syndrome affecting the patients, which was confirmed by transesophageal echocardiography before the surgery and on the operating table after cardiac function and blood flow were restored. This shows the effectiveness of all analyzed methods despite the period of ischemia and reperfusion injuries in group II.

**[0066]** Thus, the given device is an explicit and highly informative method for intraoperative assessment of coronary and myocardial blood flow.

## Potential use in hygiene, toxicology and sanitary science

**[0067]** 25 MHz L-shaped sensor (canted - the rounded working part of the head) is used for toxicological research and testing of perfume and cosmetics (PC) products, oral care products, as well as raw materials for their production, including those obtained with the use of nanotechnology or containing nanomaterials.

**[0068]** With the help of this device one can perform quantitative assessment of blood flow velocity in case of irritation.

### Example 4.

**[0069]** The egg is placed on the fixing stand with its blunt end upwards and then the air cell is opened. Shell is removed from the whole air cell, then the surface of the outer shell membrane is moistened with normal saline solution and it is completely removed so as not to damage the chorioallantoic membrane (CAM). CAM is covered with layers of 400 mm<sup>3</sup> of normal saline solution (to prevent it from drying) The egg is placed in a temperature-controlled chamber for 20 min to eliminate the traumatic shock. (If there is some damage to CAM or bleeding occurs, the egg is rejected).

**[0070]** Having selected a blood vessel on the surface of CAM, the sensor is positioned at 60° to the examined vessel, while ensuring dopplerogram with low amplitude pulsations and no sharp peaks (the slowly varying wave) which are displayed on the screen of the device.

**[0071]** After blood flow velocity in the selected vessel is measured in minute 0, the extract of the tested sample is applied in layers in the amount of 400 mm<sup>3</sup>. Minute 0 corresponds to the intact condition of the embryo CAM vessels. After 80 seconds the change in blood flow velocity in CAM vessels under the influence of the tested sample is evaluated.

**[0072]** At least 10 embryos should be analysed in order to test one sample.

**[0073]** The software developed for the device analyzes the dopplerogram automatically by calculating blood flow linear velocity (Vs parameter, cm/sec). The software allows one to single out tissue microsections filled with arterial, venular, capillary and bypass blood flow. The following histogram is introduced: 4 columns display % of particles moving at an appropriate speed in ascending order. The calculation of K ratio was introduced. K ratio is % of capillary blood flow in the given tissue section. In order to perform calculations an additional filter was installed which cuts off all velocities exceeding 0.1 cm/s.

**[0074]** The four-channel feature of the device allows to register micro- and macro-signals simultaneously in real time at 4 points.

**[0075]** Due to electronic, software and hardware and mechanical design of the sensors combined, taking into account additional filtering, one can measure low velocity starting from 0.001 cm/s.

## INDUSTRIAL APPLICABILITY

[0076] Thus, the use of the proposed device for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation and the proposed method for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation allows precise control of linear and volumetric blood flow velocity, resistivity and pulse index, dopplerogram, plethysmogram and heart rate (HR).

## Claims

1. The device for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, comprising a device for blood flow measurement which includes Doppler ultrasound transducer with a sensor comprising receiving and emitting piezoelectric elements, **characterized in that** it is enhanced with a device for pulse oximetry equipped with a sensor and the unit to determine the oximeter characteristics, the pulse oximeter sensor has two LEDs, one of which emits visible light in the red spectrum (600 nm), the other in the infrared spectrum (940 nm); moreover, the device for blood flow measurement includes two electronic software units to determine quantitative characteristics in a single vessel and in tissue section: macro-and micro-measurement modes; it should be noted that data from all the units are transmitted to the data display unit and the shape and design of the acoustic heads used in the sensors of blood flow measurement device correspond to the anatomic features of the region of interest: surgical, transcutaneous, laparoscopic, with the frequency of 10, 20, 25, 30 MHz, elongated, L-shaped; the sensors are enclosed in a titanium case for repeated sterilization conditions.

1.1. The device for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, according to claim 1, **characterized in that** laparoscopic sensors are used with trocars 5mm and 10 mm in diameter.

1.2. The device for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, according to claim 1, **characterized in that** the length of the acoustic heads used in the sensors of blood flow measurement device is  $0.1 \div 250\text{mm}$ , the diameter of the sensor is  $1.5 \div 30\text{mm}$  and the angle of L-shaped sensor is  $135^\circ$  with the radius of 10mm.

2. The method for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, through tissue location by means of the ultrasonic Doppler sensor set at the sounding point and determination of blood flow characteristics by means of

the data processing unit, **characterized in that** the Doppler ultrasound transducer is set either into the projection of a single vessel or into the projection of or directly on the microcirculatory section; when working with a single vessel, Macro software and electronic unit is used which, while calculating, utilizes a special filter singling out the signal from a single vessel; and, when working with a microcirculation volume of tissue, Micro software and electronic unit is used which runs at maximum gain, while the pulse oximeter sensor is additionally set on the patient's ear or finger; from two LEDs of the pulse oximeter sensor, one of which emits visible light in the red spectrum (600 nm) and the other in the infrared spectrum (940 nm), the light passes through the tissue to a light detector with some portion of radiation absorbed by the blood and soft tissues, depending on the concentration of haemoglobin, the amount of the absorbed light at each of the wavelengths depends on the degree of haemoglobin oxygenation in the tissue; at the same time the pulse oximeter data processing unit singles out the blood pulse component from the absorption spectrum, i.e. it separates the arterial blood component from the venous or capillary blood permanent component, while the Doppler signal processing unit and the pulse oximeter data processing unit display data on the screen via the connected visualisation unit.

2.1. The method for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, according to claim 2, **characterized in that** 25 MHz transcutaneous elongated sensor (cylindrical, the head length of  $30 \pm 2\text{ mm}$ , the effective diameter of  $1.5 \pm 0.2\text{ mm}$ ) can be used in abdominal surgeries.

2.2. The method for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, according to claim 2, **characterized in that** 10 MHz surgical sensor (cylindrical, the head length of at least  $100 \pm 5\text{ mm}$ , the effective diameter of  $1.5 \pm 0.2\text{ mm}$ ), 20 MHz surgical curved sensor (cylindrical, the head length of  $100 \pm 5\text{ mm}$ , the effective diameter of  $1.5 \pm 0.2\text{ mm}$ ), 25 MHz surgical sensor (cylindrical, the head length of  $100 \pm 5\text{ mm}$ , the effective diameter of  $1.5 \pm 0.2\text{ mm}$ ) can be used in neurosurgery.

2.3. The method for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, according to claim 2, **characterized in that** 20 MHz laparoscopic sensor (cylindrical, the head length of  $250 \pm 5\text{ mm}$ , the effective diameter of  $1.5 \pm 0.2\text{ mm}$ ) is used in laparoscopic surgeries.

2.4. The method for assessment of regional blood flow, tissue microcirculation and blood oxygen saturation, according to claim 2, **characterized in that**

**terized in that** 25 MHz L-shaped sensor (canted - the rounded working part of the head) is used to assess the irritating effects of substances on the vessels of chicken embryo chorioallantoic membrane (CAM).

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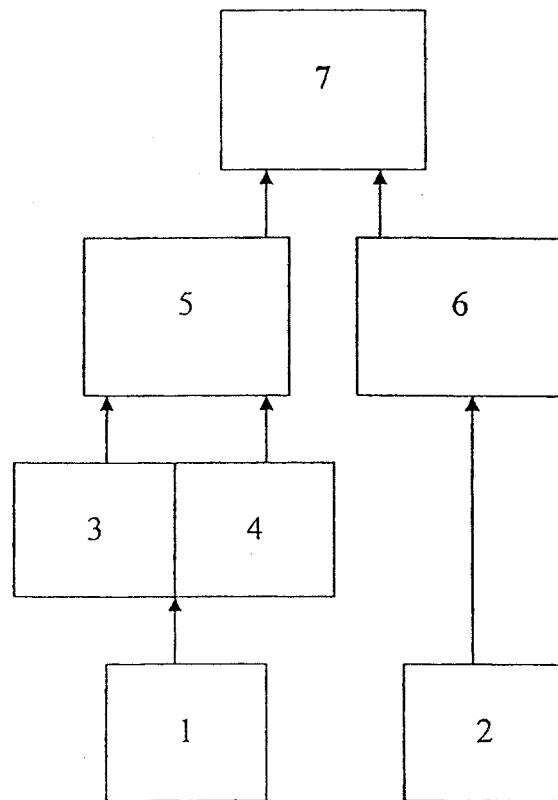


Fig. 1

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/RU 2012/000096

## A. CLASSIFICATION OF SUBJECT MATTER

A61B 5/02 (2006.01); A61B 8/02 (2006.01); A61B 8/06 (2006.01); A61B 5/1455 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

A61 B 5/00-5/04, 8/00-8/06, 5/1455

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatSearch (RUPTO internal), Esp@cenet, PAJ, USPTO

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                  | Relevant to claim No. |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | US 2010/0152591 A1 (ZENGPIN YU et al.) 17.06.2010, the abstract, fig. 2A, 28 A-C, 32, 35, 36                                        | 1-2.4                 |
| Y         | RU 2207052 C2 (GIRINA MARINA BORISOVNA et al.) 27.06.2003, p. 3-4                                                                   | 1-2.4                 |
| Y         | US 2005/0109351 A1 (ALEJANDRO HECTOR FARMACHE) 26.05.2005, [0024], [0028]                                                           | 1-2.4                 |
| Y         | RU 2383888 C1 (OTKRYTOE AKTSIONERNOE OBSHCHESTVO ZAVOD EKOLOGICHESKOI TEKHNIKI I EKOPITANIYA "DIOD") 10.03.2010, the abstract, p. 4 | 2.4                   |

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

23 October 2012 (23.10.2012)

Date of mailing of the international search report

01 November 2012 (01.11.2012)

Name and mailing address of the ISA/  
RU

Authorized officer

Facsimile No.

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**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- RU 2152173 [0007] [0008]

**Non-patent literature cited in the description**

- Ultrasound comprehensive study of patients with aortic aneurysm. *Angiology and Vascular Surgery*, 1996, 46-58 [0003]
- Comparison of data received by means of lower limbs subcutaneous veins ultrasonic dopplerography and clinical varicose vein disease. *Imaging in Hospital.*, December 1996, 30-35 [0004]

|                |                                                                                                                                                          |         |            |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|---------|------------|
| 专利名称(译)        | 用于评估区域血液循环的装置和方法                                                                                                                                         |         |            |
| 公开(公告)号        | <a href="#">EP2815697A1</a>                                                                                                                              | 公开(公告)日 | 2014-12-24 |
| 申请号            | EP2012868512                                                                                                                                             | 申请日     | 2012-02-13 |
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| 申请(专利权)人(译)    | GIRINA , MARINA BORISOVNA<br>GIRIN , 伊万诺维奇                                                                                                               |         |            |
| 当前申请(专利权)人(译)  | GIRINA , MARINA BORISOVNA<br>GIRIN , 伊万诺维奇                                                                                                               |         |            |
| [标]发明人         | GIRINA MARINA BORISOVNA<br>GIRIN IVAN IVANOVICH                                                                                                          |         |            |
| 发明人            | GIRINA, MARINA BORISOVNA<br>GIRIN, IVAN IVANOVICH                                                                                                        |         |            |
| IPC分类号         | A61B5/02 A61B8/02 A61B8/06 A61B5/1455 A61B5/00                                                                                                           |         |            |
| CPC分类号         | A61B5/0205 A61B5/02433 A61B5/0261 A61B5/0285 A61B5/14551 A61B8/06 A61B8/488 A61B5/024<br>A61B5/026 A61B5/1459 A61B8/12 A61B8/445 A61B8/5223 A61B17/00234 |         |            |
| 其他公开文献         | EP2815697B1<br>EP2815697A4                                                                                                                               |         |            |
| 外部链接           | <a href="#">Espacenet</a>                                                                                                                                |         |            |

#### 摘要(译)

本发明涉及医学，即医学技术，并且可以用于各种医学领域，用于非侵入性（经皮）和术中（外科）识别指示血液流动和血液氧饱和度的参数。本发明的目的是提供一种用于实时估计血流，组织微循环和血液氧饱和度的方法和装置，用于控制和校正药理学，理疗和手术治疗。在方法方面，所述目的通过在连续辐射模式下以超过20的频率的超声多普勒血流指示来识别来自组织的微循环体积的血流的定性和定量参数来实现。通过使用在最大放大率下起作用的软件电子“微”单元，同时估计氧饱和度通过使用固定在感应区域上的脉搏血氧计传感器进行血液分析，并根据获得的数字评估组织微循环和局部血液循环，这些数据表明血液的氧饱和度和单个血管中的血流参数。用于随后诊断，筛选控制和药理学，理疗和手术治疗的组织的微循环体积，以实时模式。通过引入脉冲血氧计单元，软件电子“微”单元，控制和可视化单元来实现设备中的所述目标，而根据所分析的受试者的解剖学特征来选择声学头的数量，形状和频率。：手术，经皮，腹腔镜，频率为10,20,25,30 MHz，细长，L形；因此，超声波多普勒指示器配备钛壳以实现多个消毒。

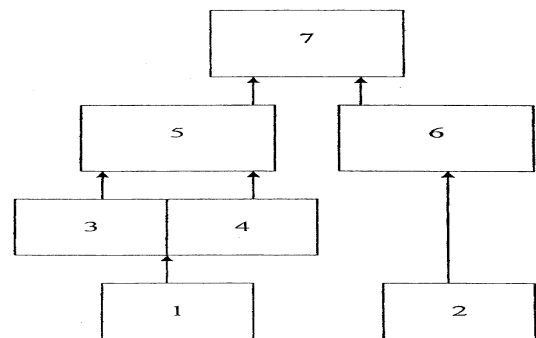


Fig. 1