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A Portable Impedance Meter for Monitoring Liquid Compartments of the Human Body under Space Flight Conditions

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Dynamics of liquid compartments of the human body under zero-gravity conditions is of theoretical and practical interest for assessing dosed and individual correction of hydration state of the human body of astronauts after space flight [2, 6]. Dynamics of liquid compartments of the human body have not yet been studied during long-term space flights because of the absence of noninvasive methods of measurement compatible with space flight conditions.

Volume of liquid compartments of the human body is usually measured using special *per os* or intravenous markers capable of distributing over the liquid volume. Organic dyes or radioactive substances are used as such markers. However, such methods are incompatible with space flight conditions because they are fairly awkward and have medical limitations [7].

The bioimpedance method is based on different conductance of biological tissues for alternating electric current of high and low frequency. At frequency 20 or 500 kHz alternating electric current predominantly propagates through blood vessels and intercellular space or intracellular space, respectively. The human body impedance at low and high frequency represents the amount of extracellular liquid and total amount of body liquid, respectively [1, 5, 9]. The advantages of the bioimpedance method are safety and noninvasive examination.

A portable two-frequency tetrapolar bioimpedance meter was developed to study the state of liquid compartments of the human body under conditions of long-term space flight (SPRUT-K).

Construction of Impedance Meter and Composition of Aboard Set

The AWS-01 Medass (Moscow) analyzer of water sectors of the human body was used as a prototype model of the hardware–software system of the impedance meter. The analyzer is designed to provide rapid evaluation and monitoring of water compartments of the human body, preclinical detection of edemas, and monitoring of hydration state of patients [3, 4].

The SPRUT-K impedance meter has metal housing (dimensions, 190 × 100 × 30 mm; weight, 620 g). There are three connectors for power source, computer, and patient. There is a pilot indicator of the power source. The impedance meter set includes: power cable; patient cable with 8 button jacks (4 colors) for cuffs; cuffs for arms and legs with two electrodes each; computer connection cable; patient-equivalent phantom; and computer disk with special software. A general view of portable onboard bioimpedance meter is shown in Fig. 1.

The cuffs are made of an elastic band and fixed with a fabric clasp. Each cuff contains two stainless electrodes, which can be connected to the patient cable. One-pole plugs of the patient cable are color-marked: red for right arm; yellow, left arm; green, left leg; black, right leg.

Specifications of SPRUT-K Impedance Meter

The tetrapolar (commutation of current and potential electrodes) impedance meter implements the method

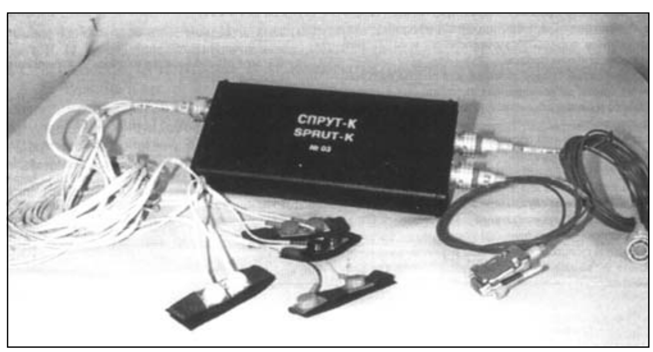

Fig. 1. General view of portable onboard bioimpedance meter for studying the volumes of liquid compartments of the human body under conditions of long-term space flight.

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of two-frequency impedancometry. Cyclic measurement includes 6 measurements per cycle. The number of electrodes is 8 (1 current and 1 potential electrode per each leg and arm). Examined areas of the human body and electrodes used are listed in Table 1.

A 4 MHz signal from the integral microprocessor quartz generator is applied to a frequency divider. Two signals are observed at the output of the frequency divider: low-frequency (19.2 kHz) and high-frequency (500 kHz). The two signals are applied to a current generator, which forms low-frequency and high-frequency components of measuring current. The output signal of the current generator is applied to the commutator of the current electrodes and analog-to-digital converter (ADC) to measure the amplitude of the measuring current. This signal is used for quality control of electrode installation.

Signals from potential electrodes are applied to the commutator of the potential electrodes. The commutator selects a pair of potential electrodes listed in Table 1. The commutator output signals is applied to low-frequency and high-frequency amplifiers and then to detectors. These signals are converted in an ADC into digital form and applied to the microprocessor. The microprocessor is connected to a computer using an optron. The computer selects pairs of current and potential electrodes and calculates impedance. The computer also monitors contact quality and overload.

The impedance meter determines total body water volume (10-100 liter), volume of extracellular liquid (5-60 liter), and intracellular liquid (3-40 liter). The information is renewed with frequency 0.2 Hz. The results of averaging of 24 cycles of measurement are shown on the computer monitor. Nominal probing low frequency and high frequency values are 19.2 and 500 kHz, respectively. The frequency error is ±1% at mean-square probing current 2 mA.

The impedance meter power voltage is 15 ± 0.5 V DC; consumed power, 5 W. The main specifications of the impedance measurement channel are given in Table 2.

The impedance measurement channel is tested using a patient-equivalent phantom containing a set of resistors. The software presents on the computer monitor the values of impedance of resistors simulating different areas of the human body. The measured values are accompanied with limits within which they can vary at nominal mode of impedance meter operation.

Because of special exploitation conditions, the SPRUT-K impedance meter should meet stringent requirements of stability and viability. The SPRUT-K impedance meter maintains working ability within temperature range 0-40°C; pressure range, 450-1000 mm Hg; and relative humidity, 20-80%. The SPRUT-K impedance meter should also withstand exposure to ionizing radiation with maximum dose 500 rad.

TABLE 1. Examined Areas of Human Body and Electrodes Used

Area of human body	Electrodes used	
	current	potential
Body	Left arm – right leg	Right arm – left leg
Body	Right arm – left leg	Leftt arm – right leg
Left arm + body	Left arm – right leg	Left arm – left leg
Right arm + body	Right arm – left leg	Right arm – right leg
Left leg + body	Left leg – right arm	Left leg – left arm
Right leg + body	Right leg – left arm	Right leg – right arm

TABLE 2. Main Specifications of Impedance Measurement Channel

Impedance measurement range, Ω	10-500
Measuring current frequency, kGz	f_1 = 19.2
	f_2 = 500
Impedance error, no more than	±6% at frequency f_1
	±16% at frequency f_2
Frequency setting error, no more than	±1%

Software

The impedance meter transmits data to a computer via serial interface. The information volume stored in the database during one 20-min examination session is 10 Kb. The results of averaging of 24 cycles of measurement are displayed on the computer monitor. The information is renewed with frequency 0.2 Hz.

The software is for Windows or DOS. The software provides examination data detection, control of measurement cycles, calculation of impedance of liquid media of the human body, and presentation of calculation results in graphical and/or numerical forms. The software also stores the results of measurement and calculation in a database. The impedance meter and computer provide real-time automatic measurement and calculation of the main liquid compartments of the human body.

Impedance Meter Work on Board the International Space Station

Russian astronauts took part in monitoring of the hydration state of the human body during a half-year-