ULTRASONIC METHOD OF INVESTIGATING THE REGIONAL CIRCULATION

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The paper describes a bloodless, noise free method of depth-zonal ultrasonic sphygmography based on the principles of acoustic bioecholocation, by means of which information regarding the parameters of the circulation can be obtained separately but simultaneously from virtually all parts of the vascular system in different regions of the body and at different depths.

For some reason or other many of the physico-technical and electronic instrumental methods of investigation of the circulation cannot be used to study the regional circulation, especially in the brain [1, 4].

Methods of ultrasonic pulsed bioecholocation have recently been used to study the blood vessels (aorta, carotid, temporal, vertebral, and other arteries) either to detect thrombosis [2] or aneurysms of the arteries [5, 8], or for clinical investigation of the dynamics of the circulation under normal and pathological conditions [7, 10, 11]. In these methods the amplitude and the time shift of the echo signal reflected from the blood vessel were recorded.

However, these methods did not take into account the important fact that values of amplitude–time characteristics of the echo signal reflected from the blood vessel are determined not only by changes in

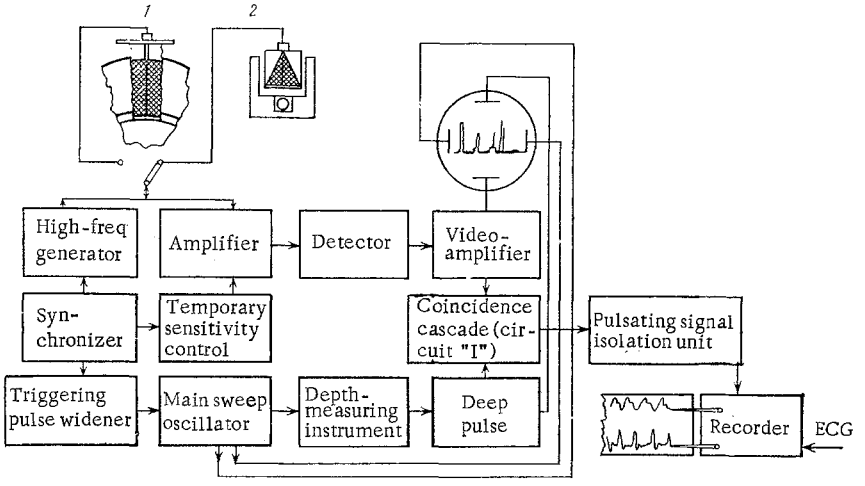

Fig. 1. Functional diagram of apparatus: 1) detector for investigating deep vessels; 2) detector for investigating isolated vessels. Remainder of explanation in text.

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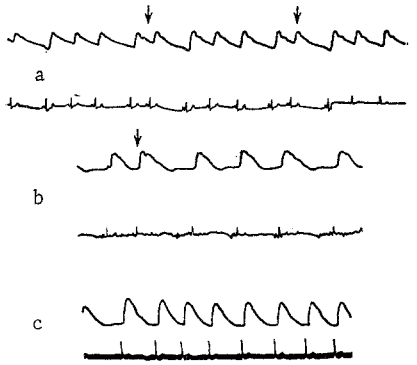

Fig. 2. Ultrasonosphygmograms of isolated carotid artery (a), isolated femoral artery (b), and blood vessels of the circle of Willis (c) of an intact dog.

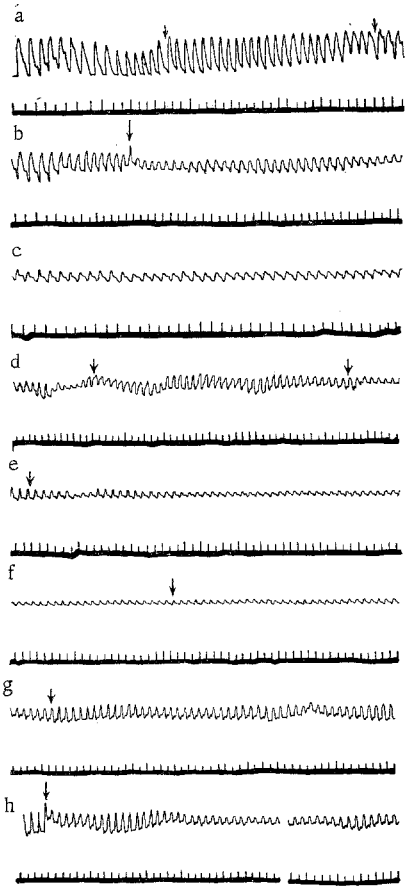

Fig. 3. Ultrasonosphygmograms of blood vessels of the circle of Willis of an intact dog before and after administration of nembutal and listhenon in apnotic doses: a) original background, injection of Nembutal; b, c) anesthesia, absence of corneal reflex; d) respiratory wave, injection of listhenon; e, f) absence of spontaneous respiration; g, h) restoration of spontaneous respiration, appearance of corneal reflex.

the hemodynamics, but also by other biological and physicochemical factors (CSF pressure, temperature, hydration of the tissues, etc.), which influence the absorption of ultrasound in the tissue structures in the path of its spread to the blood vessel to be located [6, 9].

The writers have developed a method of obtaining information regarding the state of any part of the vascular system separately, regardless of its location (in bony canals, inside the skull, deep in the soft tissues, and so on) and regardless of the degree of absorption of ultrasound by the tissues surrounding the vessel.

The essence of the suggested method is as follows.

The ultrasonic detector, using the reverse and direct piezoeffect, emits short acoustic pulses toward the vessel for investigation and receives an echo signal reflected from it.

If the volume of blood entering the vessel is increased, the diameter of the vessel increases and, consequently, so also does the area of the lateral reflecting surface bounded by the diameter of the ultrasonic beam in the zone of location of the vessel. The amplitude of the reflected echo signal thus increases, and it is determined by the known expression [3]:

$$U_c = K \frac{S_a S_c}{\lambda^2 L^2} e^{-2\sigma L},$$

where S_a and S_c represent the areas of the piezovibrator and blood vessel; σ the damping of the ultrasound in the tissues; K a constant; L the distance to the vessel; and λ the wavelength.

With a decrease in the volume of blood flowing through the vessel its diameter decreases and, consequently, so also does the amplitude of the reflected echo signal. Consequently, the changes in amplitude of the echo signal are proportional to the degree of filling of the vessel with blood. These changes are recorded on an ink-writing instrument. The curves thus obtained resemble sphygmographic, plethysmographic, and rheographic curves in its shape, and the name ultrasonic sphygmogram or ultrasonosphygmogram (USG) is suggested for it. the USG is recorded simultaneously with the ECG.

An instrument (the USG-1) was designed to embody the principles outlined above, and its functional scheme is shown in Fig. 1.

The synchronizer emits short pulses which trigger the high-frequency generator and also (through a triggering pulse widener) the main sweep oscillator.

The high-frequency generator activates the detector (1 or 2), which emits ultrasonic waves inside the organ to be tested. When it reaches the artery or vessel, some of the ultrasonic energy is reflected from its wall, and is received by the same detector and transformed into an electrical signal, which is fed into the amplifier. The amplified and detected echo pulses are fed from the output of the videoamplifier to the vertical deflecting plates of an electron-beam tube (ELT) and coincidence cascade.

Simultaneously with the emitted pulse the main sweep is started in a forward direction, and its voltage is applied to the horizontally deviating plates of the ELT. A series of echo signals reflected from the boundaries of the tissue compartments and blood vessels located along the path of spread of the ultrasonic beam is then visible on the screen of the ELT.

A gate pulse generator and depth-measuring instrument are used to isolate (gate) the required pulsating signal from the blood vessel from the series of reflected echo signals and to determine the distance to it. The depth-measuring device consists of a coincidence circuit fed with a sawtooth potential from the main sweep oscillator and a steady reference voltage which serves to trigger the gate pulse generator. By changing the amplitude of the reference voltage, the time of appearance of the step at the output of the coincidence circuit relative to the beginning of scanning can be regulated. The amplitude control is brought out onto the front panel and has a scale of depth of reflection of the echo signal graduated in millimeters.

The gate pulse generator forms a square pulse (gate) 7 μsec in duration, and this is fed into the coincidence cascade and to the vertically deviating plates of the ELT.

Besides the reflections of the echo signals, a square pedestal (the gate pulse) is thus also visible on the ELT screen. If the leading edge of the gate pulse coincides with the leading edge of the reflected echo signal, the distance to the reflecting surface is shown on the scale of the depth-measuring device. Under these circumstances, only the echo signal coinciding with the gate pulse is isolated at the output of the coincidence cascade. It consists of a steady component, characterizing the damping of the ultrasonic waves along their path of spread to the vessel, and a variable component due only to filling of the vessel with blood.

To exclude the effect of damping of the ultrasonic waves and to isolate only the variable component, a pulsating signal isolation unit, consisting of an integrating circuit with capacitance output, is provided. So as to compare the USG curves recorded from different vessels in various pathological states, percentage changes in the lumen of the vessels are recorded.

In the writers' experiments a Soviet ÉLKAR-2 cardiograph was used to make the recordings, and the ECG was simultaneously recorded in standard lead II.

Type TsTS-19 piezoceramics were used as sensory elements of the transducers, and the measurements were made at frequencies of 1.8, 2.5, and 5 MHz. The type of transducer, the zones of location, and the points of entry of the ultrasonic waves and working frequency were chosen depending on the purpose of the investigation and the program of the physiological experiment.

USGs obtained with an intact dog using a transducer fixed directly to the isolated carotid artery (a), isolated femoral artery (b), and the surface of the skull (c) are shown in Fig. 2. In the last case, blood vessels of the circle of Willis were investigated.

The USGs of the vessels of the circle of Willis of an intact dog after injection of nembutal and listhenon in apnotic doses are shown in Fig. 3. The sharp changes in the hemodynamics in the blood vessels of the circle of Willis, observed on fragments b, c, e, f characterize the high sensitivity of the method, and the effect of the respiratory excursions of the chest wall and diaphragm on the character of the USG observed in fragments d, g, h are, in the writers' opinion, of interest to the investigator on their own account. Parameters of the USG can evidently be used also to verify the depth of anesthesia.

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