ULTRASONIC LOCATION OF MOVEMENTS OF THE HEART VALVES AND MUSCLE BASED ON THE DOPPLER EFFECT

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A new bloodless method of selective investigation of movements of the heart valves and muscle using ultrasound is described. The method is based on the Doppler effect and can locate all the heart valves by a completely ultrasonic technique.

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None of the existing bloodless methods can give precise information on movements of each valve and each muscle wall of a given chamber of the human heart. These drawbacks of bloodless methods of recording movements of the valves and the muscles in various parts of the heart can be overcome by ultrasonic methods. However, the pulsed method of ultrasonic location of the heart [1-8, 12] gives information only on the kinetics of the left strium.

Fuller information can be obtained by the method of continuous ultrasonic location based on the Doppler effect and first described by Satomura [9-11] and Yoshida [13, 14]. The essential feature of the Doppler effect is that during location of a moving object (target) the signal reflected from it undergoes a change of frequency compared with that of the probing signal by an amount proportional to the velocity of movement of the studied target. If the target is stationary, the Doppler frequency is 0 and the recording

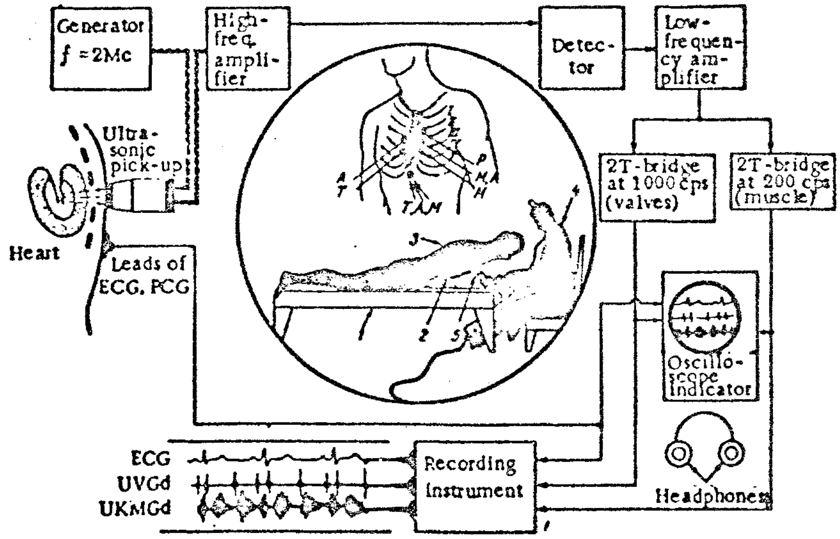

Fig. 1. Functional scheme of the ultrasonic Doppler-valvulocardiograph and method of selective location of heart valves and areas of heart muscle. Points of location: M) mitral valve and left heart; T) tricuspid valve and right heart; P) valve of pulmonary artery; A) aortic valve; 1) couch; 2) rest; 3) subject; 4) operator; 5) ultrasonic pick-up.

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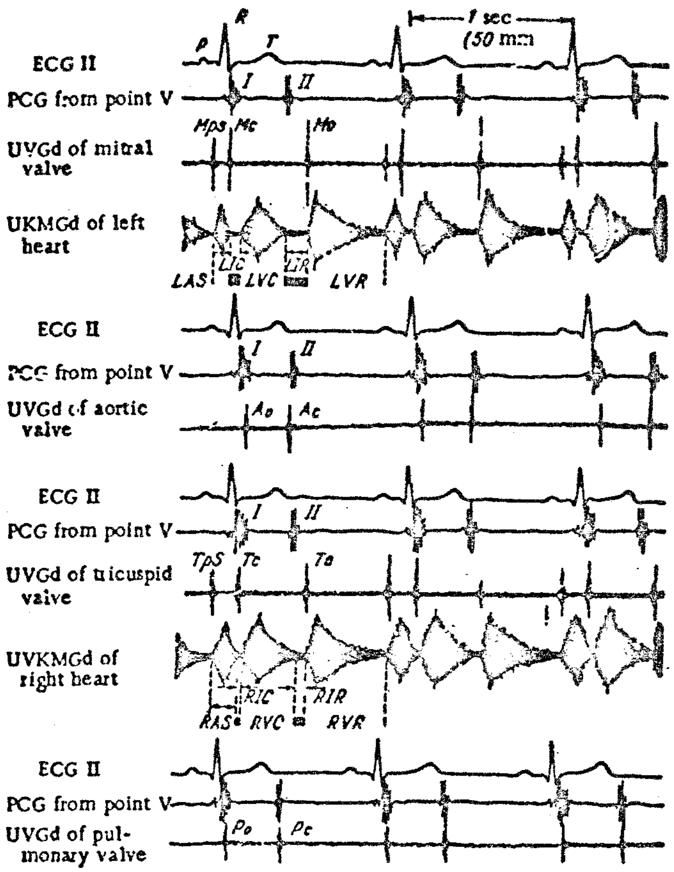

Fig. 2. Ultrasonic valvulograms and kinetomyocardiogram of a healthy person recorded synchronously with ECG and phonocardiogram. Mps represents movement of mitral valve during systole of left atrium; Mc) closure of mitral valve; Mo) opening; LAS) systole of left atrium; LIC) phase of isometric contraction; LVC) phase of emptying; LIR) phase of isometric relaxation; LVR) phase of filling of left ventricle; Ao) opening, and Ac) closing of aortic valve; Tps) movement of tricuspid valve during systole of right atrium; Tc) closure of tricuspid valve; To) opening; RAS) systole of right atrium; RIC) isometric contraction; RVC) phase of emptying; RIR) phase of isometric relaxation; RVR) phase of filling of right ventricle; Po) opening of pulmonary valve; Pc) closure.

instrument traces a zero line. The Doppler deviation of frequency on account of beats between frequencies of the applied and reflected signals may be expressed by the following formula:

$$f_d = f_g \frac{2V}{c-V} \approx f_g \frac{2V}{C} \approx \frac{2V}{\lambda_{ac}}.$$

where f_d represents the Doppler frequency of the oscillations, f_g the frequency of applied generator signals, C the velocity of spread of ultrasound in the given medium (in this case along the path from the anterior chest wall to the heart), V the velocity of movement of the studied target (the heart valve, for example), and λ_{ac} the wavelength of the incident ultrasonic signal.

The Doppler signals are recorded graphically as spikes reproducing the time and velocity of movement of the studied target.

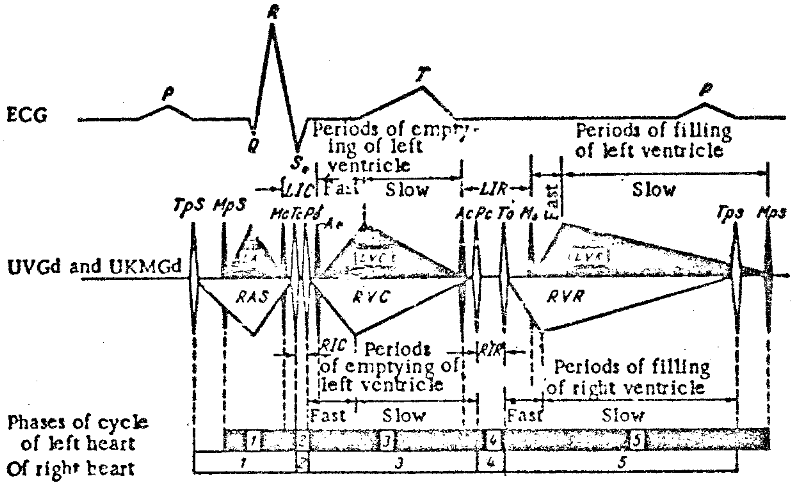

Fig. 3. Scheme of kinetics of valves and muscle and contraction-relaxation activity of the heart in healthy subjects. Elements of movement and phases of the cycle of the left heart are shown in black, and of the right heart in white; 1) atrial systole; 2) phase of isometric contraction of ventricles; 3) phase of emptying of ventricles; 4) phase of isometric relaxation; 5) phase of filling ventricles. Identification of periods of movements as in Fig. 2.

The present authors have developed an original technique enabling reliable location of any heart valve and selection of any part of the heart muscle, so that all phases of the cycle of the right and left heart can be determined differentially. The functional scheme of the apparatus and of the method of investigation are given in Fig. 1.

To ensure reliability of the location of the heart valves we advise that the subject be investigated lying in the prone position with the upper part of the trunk raised to an angle of 25-30° (Fig. 1). This increases the area of contact between the heart and anterior chest wall and the number of points of application of the ultrasonic signal avoiding lung tissue containing air which extinguishes the signal. In this way all the valves can be reliably located from 6 points in the 2nd, 3rd, and 4th intercostal spaces to the left and right sides of the edge of the sternum, and also by applying acoustic signals through the anterior abdominal wall below the xiphisternum.

With frequencies of incident ultrasonic signals of between 2 and 3.5 Mc, the Doppler frequencies of the signals reflected from the more rapidly moving cusps of the valves occupy a band from 500 to 1000 cps, while the frequency of signals reflected from the less rapidly moving muscular walls of the heart lies between 100 and 200 cps. These bands are separated by two T-shaped bridge filters, enabling the kinetics of the valve and of a particular portion of the heart muscle to be recorded separately and simultaneously through 2 channels. The tracings are made with a "Kardiorex-6" monograph, the phonocardiographic channels of which transmit frequencies of up to 1000-1200 cps. Movements of the left heart (atrium and ventricle) are recorded from the point of location of the mitral valve, and those of the right heart from the point of location of the tricuspid valve. The valve can be reliably located by observing the bursts of waves, reflected during movement of the valves, on the oscilloscope screen and audibly with the headphones.

We have called the traces of the movements of the heart valves obtained in this way the ultrasonic valvulogram (UVGd), and the trace of the movements of the heart muscle the ultrasonic kinetomyocardiogram (UKMGd). The index d denotes a trace made on the basis of the Doppler effect.

Traces of movements of the valves and parts of the heart muscle of the left and right sides of the heart of a healthy man aged 27 years are given in Fig. 2.

The moments of movements of the different elements of the heart are denoted by abbreviations in the English transcription used by the Japanese workers. These recordings show that the mitral (M) and tricuspid (T) valves under normal conditions move 3 times: during closure (Mc, Tc), opening (Mo, To), and atrial systole (Mps, Tps). Only one movement of the valves is shown on the phonocardiogram (Mc and Tc).

All phases of the cardiac cycle can be determined separately for the left and right heart bloodlessly by ultrasonic Doppler-valvulocardiography (Fig. 3). Ultrasonic valvulocardiography also reveals the kinetic sequence of the valves and heart muscle and enables the contraction-relaxation activity of the healthy human heart to be contrasted with the typical disturbances found in diseases, especially lesions of the heart valve. Such information has been obtained from the investigation of 60 healthy persons and 123 patients.

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