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APPLICATION OF THE STATIONARY ECHO CANCELLATION TECHNIQUE (SEC) IN ULTRASONIC DOPPLER MEASUREMENTS OF BLOOD FLOW IN CHILDREN'S HEARTS

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The authors used an ultrasonic Doppler system based on the technique of the cancellation of stationary echoes (SEC) with an built-in conventional single-gate Doppler pulse flowmeter for recording blood flow rates in large vessels and cavities in children's hearts. The SEC technique facilitates considerably noninvasive investigation and identification of blood flow, as it permits the visualization of the blood velocity distribution over the whole depth of structures penetrated by an ultrasonic beam. The present system also permits records of blood velocities at chosen depths to be obtained. Examples of the visualization and records of blood velocities in large vessels and cavities of the heart are given.

The technique of the cancellation of stationary echoes (SEC), which was first developed in the radar, has recently been introduced into ultrasonic Doppler measurements of blood flow in peripheral vessels [1]. This technique is based on the subtraction of two successive pulses received, one of which is delayed with respect to the other by a time interval equal exactly to the repetition period of pulses transmitted. Stationary signals from the stationary boundaries of tissues can thus be eliminated, leaving only signals from moving structures, e.g. blood particles, which undergo further electronic processing and are represented on the oscilloscope screen. The spatial and temporal blood velocity distribution is thus given on the oscilloscope screen. A detailed description of the apparatus was given in paper [3] of Nowicki and Reid.

Fig. 1 shows the principle of the application of the SEC technique in the ultrasonic Doppler method. The UDP-30-SEC system, based on this technique, has an working frequency of 4.37 MHz, a repetition frequency of 15.6 kHz, a maximum range of 5 cm, while the maximum measured velocity is 260 m/s at a 60° angle of the inclination of the probe with respect to the flowing blood [2].

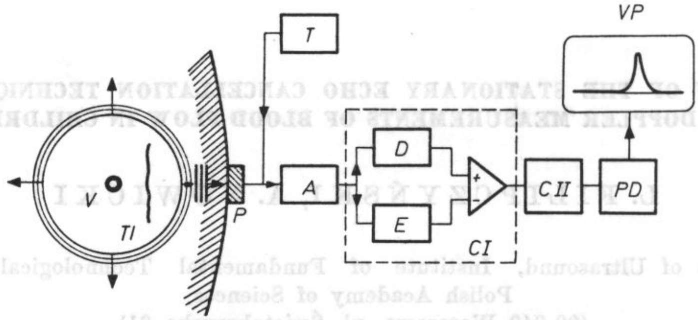

Fig. 1. The principle of the technique of the cancellation of stationary echoes (SEC)
T – transmitter, *P* – piezoelectric transducer, *TI* – the boundary of tissues at which stationary echoes occur, *V* – blood vessel, *CI* and *CII* – first and second canceller of stationary echoes, *D* – delay line, *E* – equilizer, *PD* – phase detector, *VP* – blood velocity in the vessel *V* represented on the oscilloscope screen, *A* – amplifier

Fig. 2 shows the results of an investigation by the SEC technique of two vessels in the area of the right collar-bone. At a depth of 8 to 12 mm it is possible

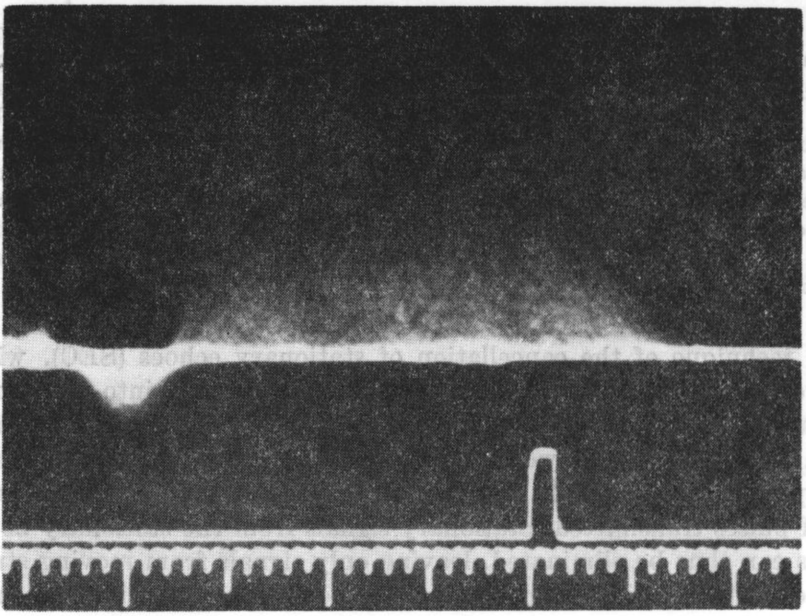

Fig. 2. The visualization by the SEC technique of blood velocities in two vessels; negative displacement – blood velocity in a jugular vein, positive displacement – blood velocity in the aorta

to see a negative velocity in the jugular vein, corresponding to the outflow of blood towards the right atrium of the heart. At a depth of 12 to 36 mm, in turn, it is possible to see a broad positive velocity corresponding to the inflow of blood in the aorta towards the probe. The depth at which the blood flow occurs can be evaluated easily using the millimetre and centimetre depth scale shown in the figure.

The flow in the aorta is strongly pulsating, which can be seen on the oscilloscope screen but which it is more difficult to show on photography in view of the exposure time of 1s.

The SEC technique seems to be very promising for applications in cardiology where the spatial and temporal blood velocity distributions are very complex. In view of this, the present authors have decided to use this technique in the children's cardiology where the penetration range is of the order of several cm. The present paper reports on the results of preliminary investigations in this field.

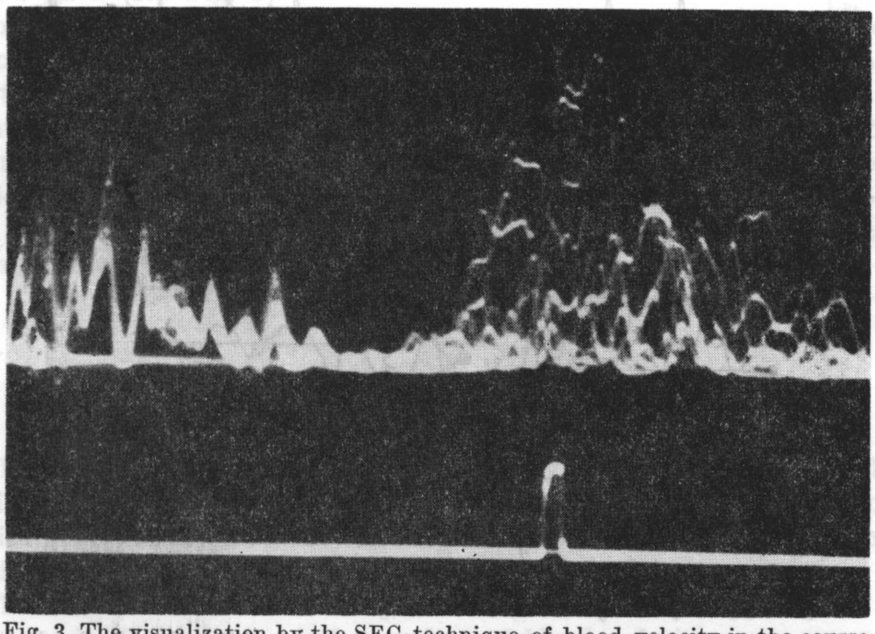

Fig. 3. The visualization by the SEC technique of blood velocity in the course of the outflow tract from the left ventricle

left the echoes from the moving structures of the heart, right – the instantaneous blood velocity distributions

Fig. 3 shows an example of the use of the SEC technique, giving the result of measurement in the course of the outflow of blood from the left ventricle of the heart. The photograph was taken with an exposure time of 0.5 ms. The slowly variable displacements farthest to the left correspond to the motion of the front wall of the left ventricle, while the displacements farthest to the right of the oscillogram represent the instantaneous blood velocity distributions. The displacements on the left and the right of Fig. 3 differ completely in character. In the blood flow displacements it is possible to distinguish a number of successive blood velocity distribution profiles where the time interval between them is equal to a repetition period of pulses of 0.064 ms (about 8 profiles).

In view of the frequency response of the period filter and the properties of the phase detection used, the output signal depends not only on the blood velocity but also on the amplitude of the signal scattered on blood particles (see [3], formulae (8) and (12)).

For this reason, however, the SEC technique is not suitable directly for blood velocity measurements, although it may serve for the observation of the flow. Accordingly, apart from the SEC technique, a system of signals which is typical of the pulse Doppler flowmeter with one analyzing gate was used in

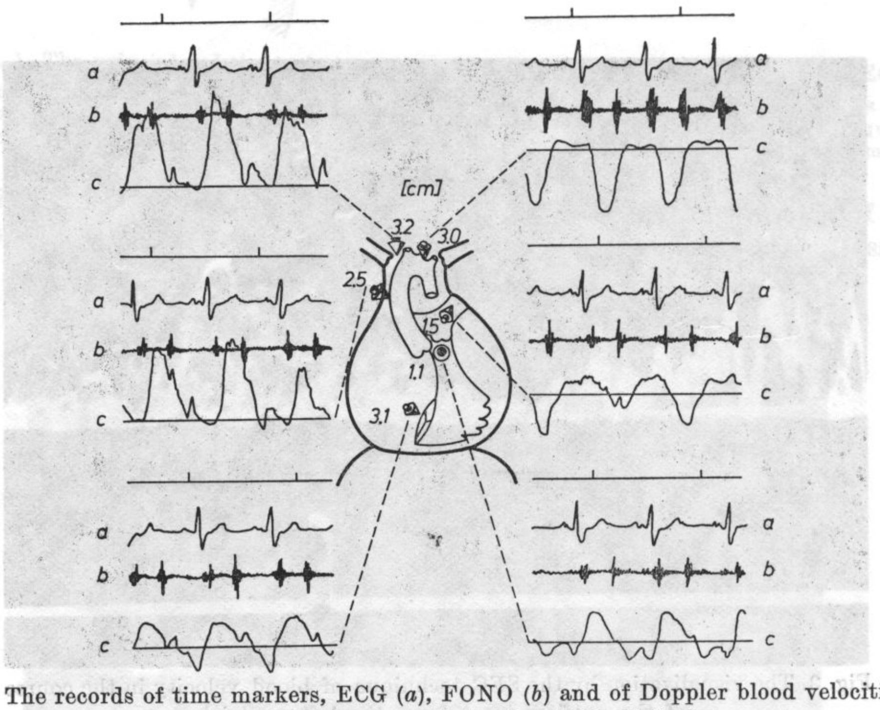

Fig. 4. The records of time markers, ECG (*a*), FONO (*b*) and of Doppler blood velocities (*c*) made at 6 points at different depth by the UDP-30-SEC apparatus

threedimensional arrows mark the place and direction of the application of the ultrasonic probe; numbers, in cm, alongside give the depth at which blood velocities have been recorded

the UDP-30-SEC apparatus in the investigations. This system uses the procedure of signal processing of the zero-crossing counter and of the determination of the direction of blood flow. This permits the measurement of the recording of the blood velocity at chosen depth by means of an analyzing gate shown in Figs. 2 and 3.

Fig. 4 shows as an example the application of the present technique on a 4-year-old child with cardiomyopathy. The recording was made noninvasively at 6 different points. Threedimensional arrows mark the place and direction of the application of the ultrasonic probe; numbers alongside give the depth at which the recording was made. Apart from a schematic diagram of the structures of the heart, the records obtained are given. The topmost line in all the 6 records is time markers of 1 s, the second line is an ECG record, the third line a phonocardiographic record from the area of the pulmonary artery, the fourth line a Doppler record of blood velocity.

In the range of venous and arterial vessels the UDP-30-SEC measuring apparatus permits the visualization and determination of the velocity and direction of blood flow and the determination of the diameter of a vessel and the depth at which it occurs. This facilitates considerably the identification of individual flows and the elimination of the motion of the anatomical structures of the heart which disturb the measurement of blood flow, giving an image different from the flow itself (see Fig. 3).

In the area of the Erb point where the anatomical relationships and the motion of the heart are very complex, velocities in the course of Doppler measurements are often obtained in a direction different from the expected one. The present authors think that this may be caused by transverse motion of flowing blood resulting from the rhythmical displacement of the heart which echocardiographic investigations show. At this stage it is also difficult to exclude the possibility of an inaccurate angular position of the ultrasonic probe with respect to the stream of flowing blood.

Conclusions

The SEC technique facilitates considerably the investigations of blood flows in the heart, permitting the identification of blood flows as a result of the visualization of the blood velocity distribution over the whole depth of structures investigated.

The combination of this technique with a conventional Doppler pulse flowmeter permitted the taking and recording of blood velocity measurements at chosen depths in large vessels and in the cavities of the hearts.

The first records of the blood flow rate obtained in children's hearts agree with previous observations made using other methods, but standards based on more examined patients must still be made.

The visualization of blood flows in blood vessels and in the heart by means of the SEC technique permits rapid and direct control of hemodynamic disorders. This may have great practical value, irrespective of the subsequent registration of blood velocity.

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