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ESTIMATION OF CARDIAC FLOW IN CHILDREN BY MEANS OF IMAGING GATED PULSE DOPPLER

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Imaging pulse cardiac Doppler was used to investigate congenital heart conditions in children. Preliminary investigations were carried out in a group of 15 healthy children and in 23 children with congenital heart diseases. The recordings in normal children and in children with ventricular septal defect (VSD), atrial septal defect (ASD), patent ductus arteriosus (PDA) and with coarctation of aorta (CoA) will be shown.

1. Introduction

Encouraged by the excellent work and results of HATLE and ANGELSEN [1] we modified the previously described 4 MHz Imaging Gated Pulse Doppler (IGPD) [3] to investigate congenital heart conditions in childrens. Important modifications were made to increase the workable Doppler frequency range (maximum velocity). Double repetation frequency rate was introduced; 6.7 kHz for the whole penetration range of about 12 cm corresponds to $V_{max} = 63$ cm/s (0°) and 126 cm/s (60°), 13.4 kHz (6 cm) corresponds to $V_{max} = 126$ cm/s (0°) and 252 cm/s (60°).

A set of variable high-pass Doppler filters was used to prevent the output signals of the artifacts due to the movements of the heart walls and valves. The low cut off frequency was adjustable at 200 Hz, 600 Hz or 1200 Hz. The last one was in fact the most preferable in our investigation.

The upper range of the maximum velocity 2.5 m/s at 6 cm depth was often too low for estimation of the jet velocity in VSD and CoA. In order to minimize the aliasing problems due to the range — velocity ambiguity, in pulse

Doppler systems, a new type of alias tracking technique was implemented on the basis of the HARTLEY approach [2]. The tracking unit extends the workable range of Doppler frequencies from − 1/2 PRF to PRF. In terms of velocity it is equal to 1.2 m/s and 2.5 m/s (0°) for PRF, 6.7 kHz and 13.4 kHz respectively. With some additional limitation the frequency range can be extended even up to 1 1/2 PRF.

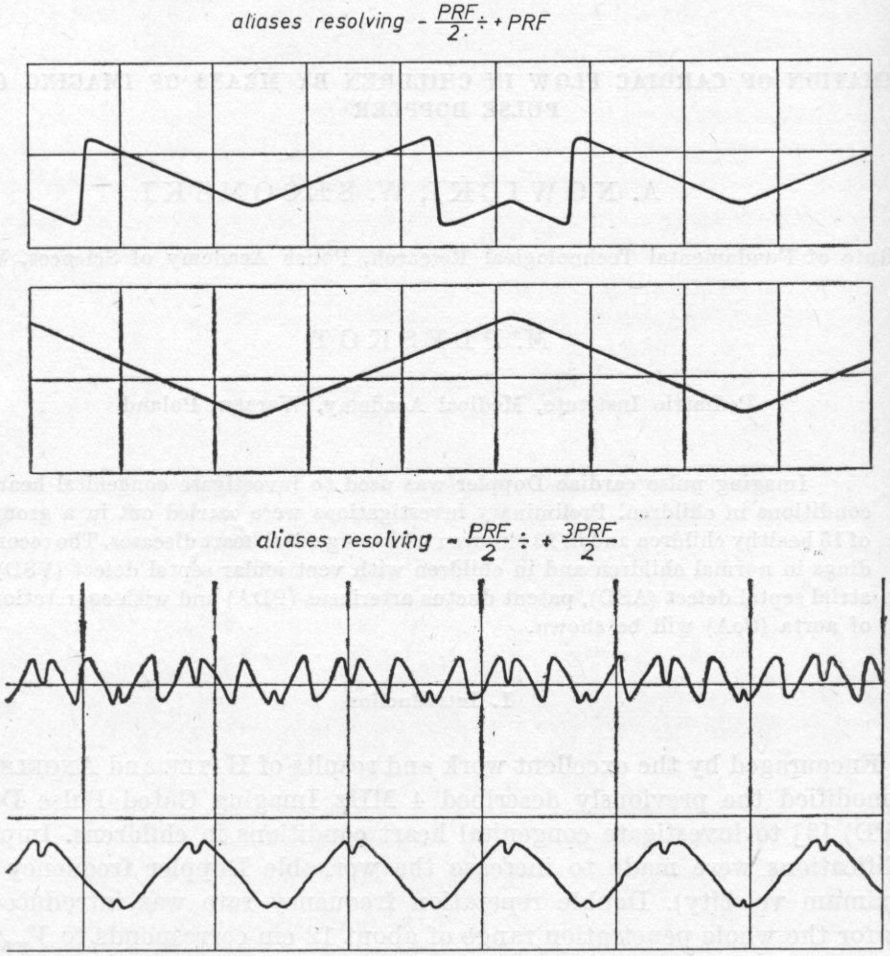

Fig. 1. Alias resolving trucker simulation for PRF (*a*) and 1 1/2 PRF (*b*)

The sample volume was 3×5 mm − transmision duration of 4 μs corresponds to ~ 3 mm in the tissue and the diameter of the ultrasonic beam in the zone of weak focusing does not exceed 5 mm.

The advantage of IGPD with its *A* scan Doppler in examination for congenital heart conditions results from the ability to visualize landmark signals in front or behind the region of interest and thus facilitate the localization of diagnostic signals.

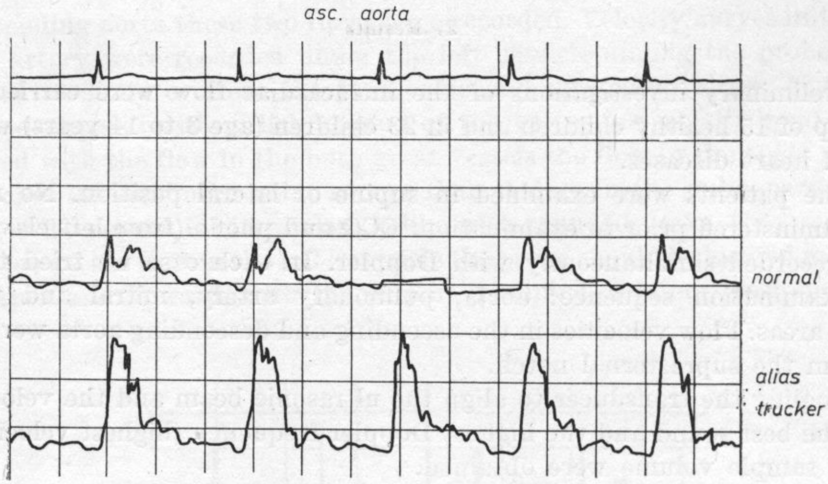

Fig. 2. Resolving of aliasing in the ascending aorta

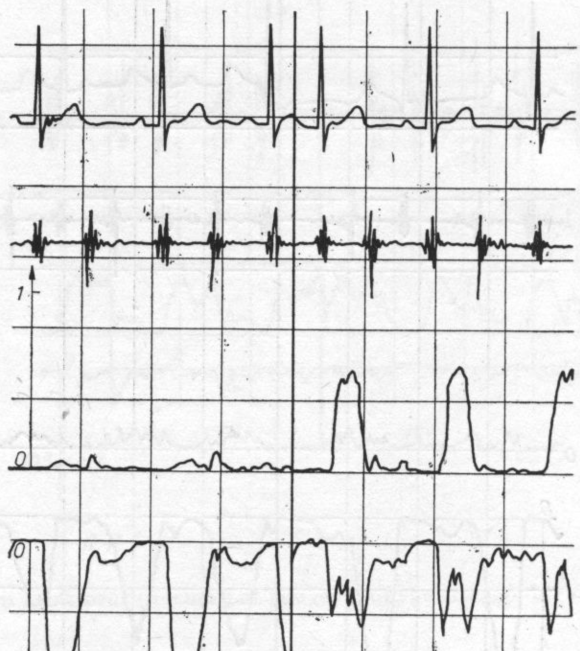

Fig. 3. Velocity recording in the descending aorta with low (6.5 kHz) and high (13 kHz) PRF. Obvious aliasing seen for low PRF

2. Results

Preliminary investigations of the intracardiac flow were carried out in a group of 15 healthy children and in 23 children (age 3 to 14 years) with congenital heart diseases.

The patients were examined in supine or lateral position. No medicine was adminstered prior to examination. ECG and phono (from left clavicle site) were recorded simultaneously with Doppler. In each case we tried to follow the examination sequence: aorta, pulmonary artery, mitral and tricuspid valves areas. Flow velocities in the ascending and descending aorta were recorded from the suprasternal notch.

Angling the transducer to align the ultrasonic beam and the velocity vectors, the best sound and the highest Doppler frequency (highest velocity peak) in the sample volume were obtained.

Aiming the probe forward and little to the right for the flow in the ascending aorta and backward to the left for the reverse (slightly smaller) flow in

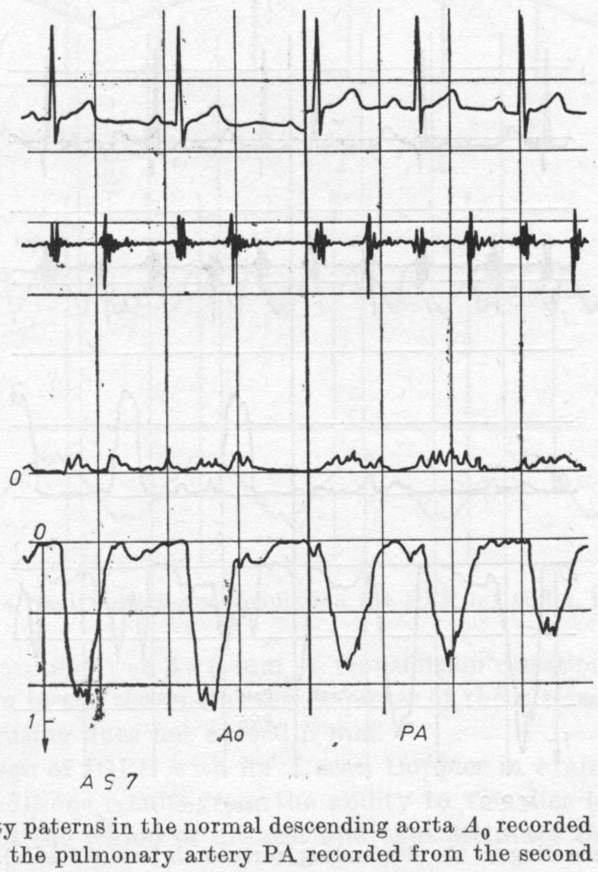

Fig. 4. Flow velocity paterns in the normal descending aorta A_0 recorded from the suprasternal notch and in the pulmonary artery PA recorded from the second intercostal space

the descending aorta these two flows were recorded. Velocity curves in the pulmonary artery were recorded under the left clavicle aiming the probe downward and medially or from the first or second intercostal space. The curve shape and characteristic "click" sound of the valves are usually good guides. Compared with the flow in the both great vessels the flow in the aorta is faster and reaches its maximum value sooner than it does in the pulmonary artery, where the flow curve is often triangle-like with rounded peaks.

To record the flow in the left ventricle the probe should be located medically to the apex and upward, with the patient in supine or lateral position.

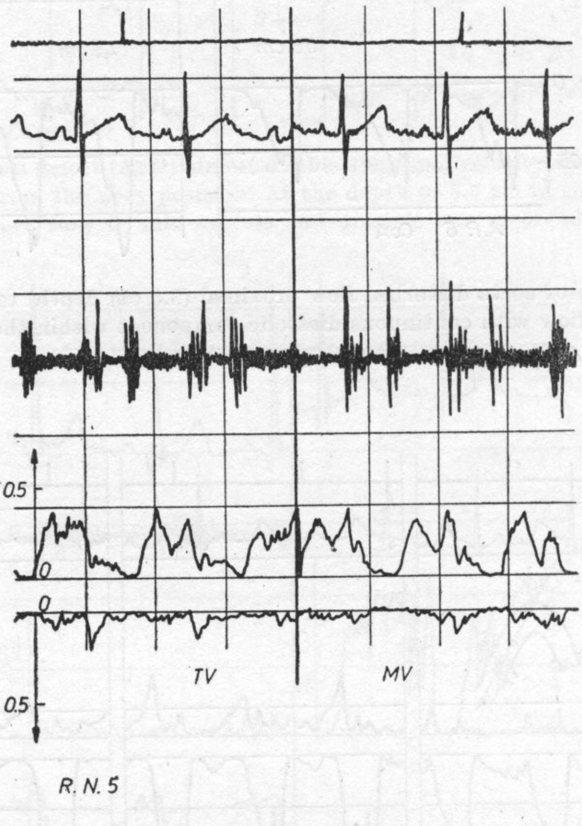

Fig. 5. Flow velocity patterns (normal) at the level of the tricuspid TV and mitral MV valves

Again, the characteristic sounds of the mitral value opening and closure clicks are primary in proper location. Flow curves are then recorded in the left ventricle at various depths toward the mitral valve and in the left atrium. Mitral flow usually shows two peaks (*M* shape) with the second peak slightly smaller — the first one in the early diastolic filling and the second in the atrial contraction.

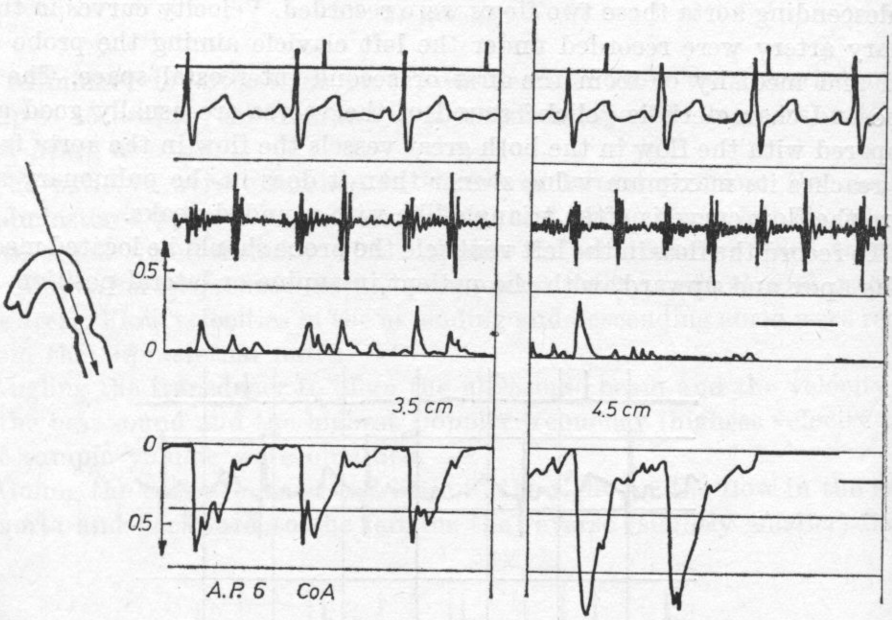

Fig. 6. Coarctation of aorta disturbed flow proximal (3.5 cm depth) to the coarctation and increased systolic flow with continuous diastolic component within the coarctation (4.5 cm depth) were recorded

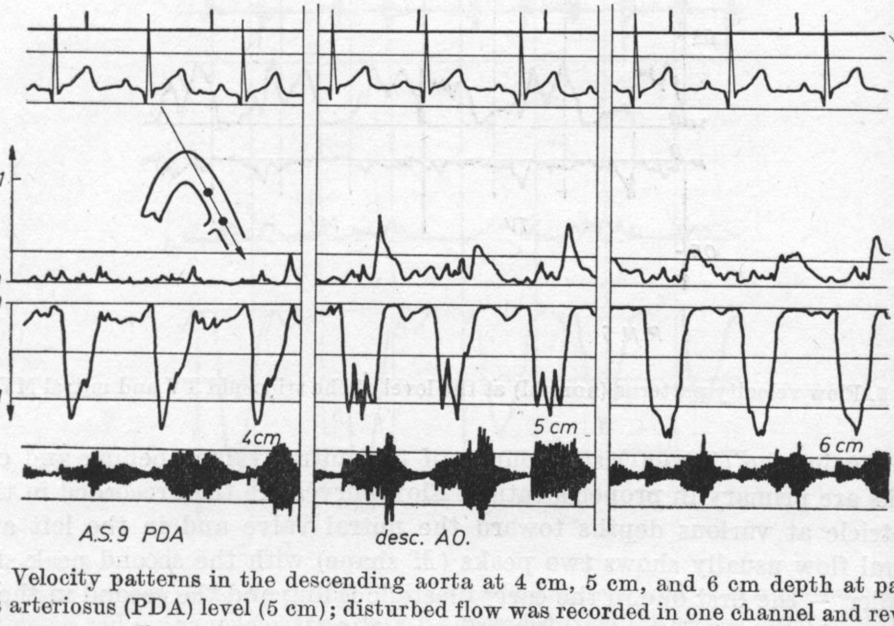

Fig. 7. Velocity patterns in the descending aorta at 4 cm, 5 cm, and 6 cm depth at patent ductus arteriosus (PDA) level (5 cm); disturbed flow was recorded in one channel and reverse flow in diastole in the second channel was recorded

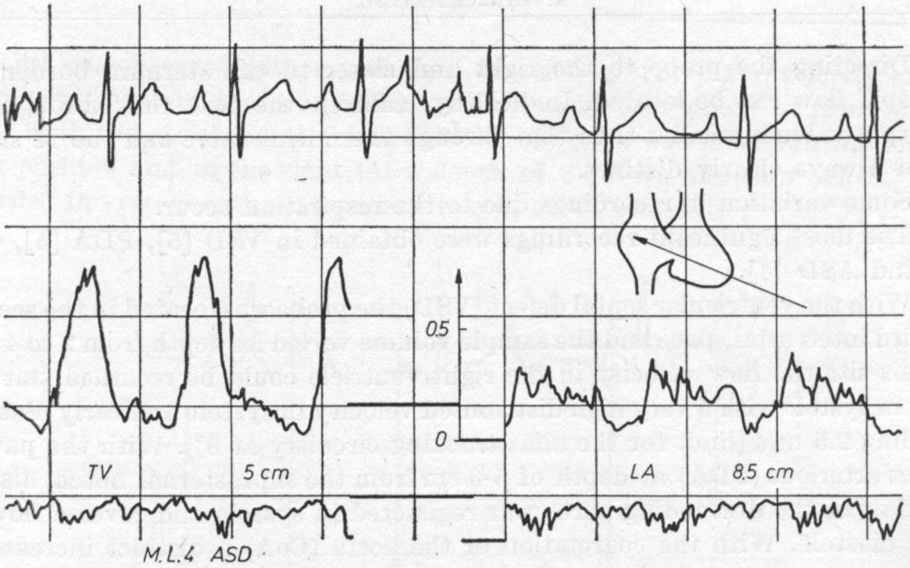

Fig. 8. For atrial septal defect (ASD) almost double abnormal velocity was recorded through the tricuspid valve from the apex position. At the depth of 8.5 cm in the right atrium forward flow in mid systole and diastole was recorded

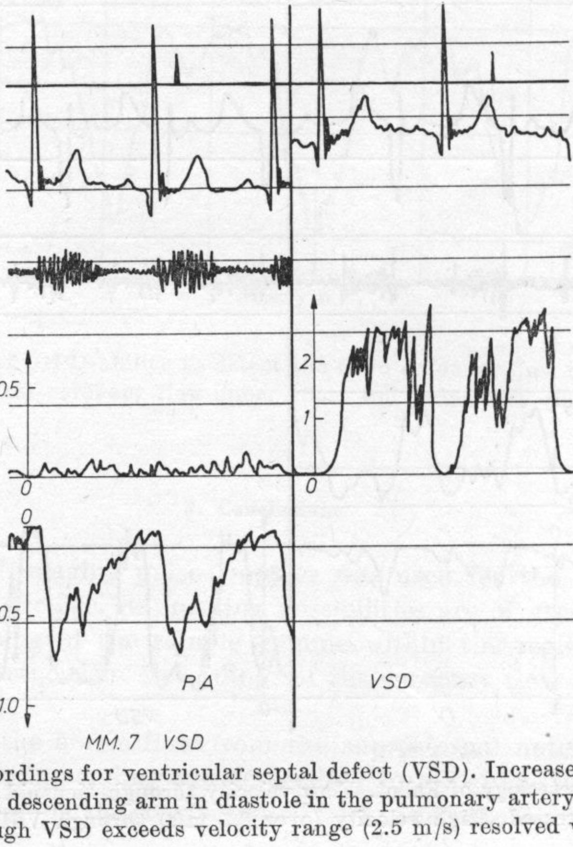

Fig. 9. Velocity recordings for ventricular septal defect (VSD). Increased velocity with irregular and prolonged descending arm in diastole in the pulmonary artery PA is noticed. High velocity (jets) through VSD exceeds velocity range (2.5 m/s) resolved with aliasing trucker

Directing the probe to the right and closer to the sternum border the tricuspid flow can be located. In healthy children the peak flow through the tricuspid valve is smaller than that through the mitral valve and the *M* shape is not always clearly distinct.

Some variation in recordings due to the respiration occur.

The most significant recordings were obtained in VSD [5], PDA [5], CoA [4] and ASD [4].

With the ventricular septal defect (VSD) the probe was located in the second or third intercostal space and the sample volume varied its depth from 2 to 4 cm. At this site the flow velocity in the right ventricle could be recorded starting early in systole with a very high distributed velocity in systole and early diastole exceding 2.5 m/s (limit for the alias tracking circuitry at 0°). With the patent ductus arterious (PDA) at depth of 5-6 cm from the suprasternal notch, disturbed flow in the descending aorta was registered in systole and reverse flow in early diastole. With the coarctation of the aorta (CoA) a distinct increase in

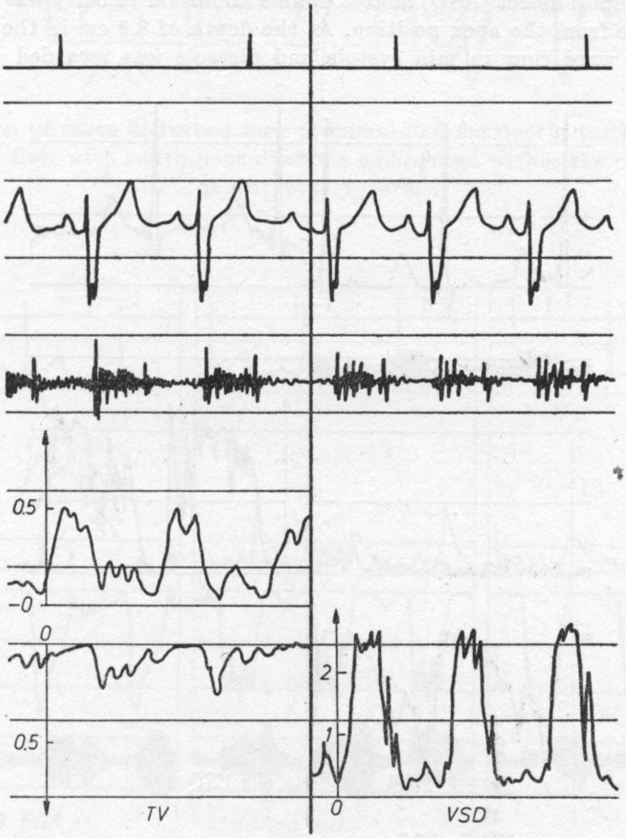

Fig. 10. Child with tetralogy of Fallot. Flow velocity through ticuspid valve is slightly increased. High velocity (over 2.5 m/s) through VSD

velocity was observed with a prolonged descending arm of the velocity curve. In general, next to the coarctation, a continuous component of flow can be seen. With the atrial septal defect (ASD), the probe was placed in the medial apex position and to the right. At a depth of 8.5-9 cm the flow velocity was recorded in systole with a secondary rise in atrial contraction.

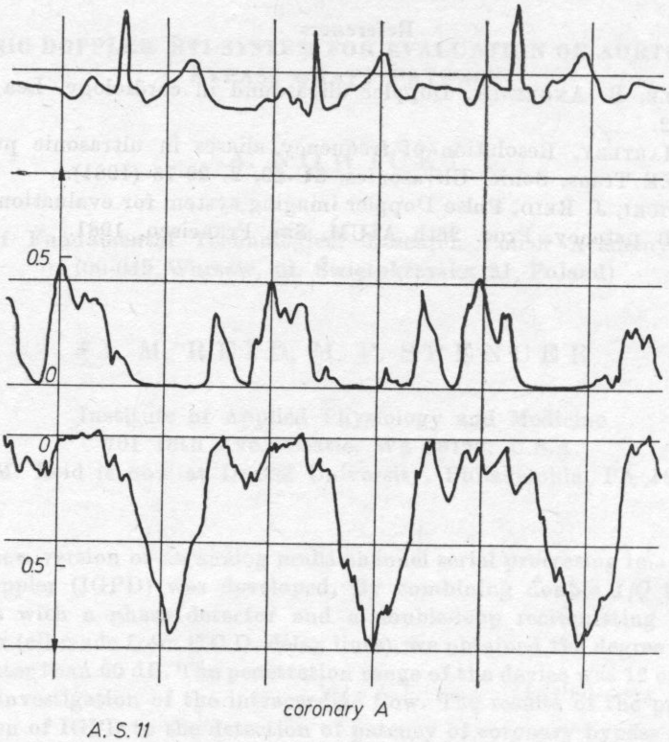

Fig. 11. An example of IGPD ability to detect the main coronary flow in a healthy child. Diastolic (two peaks: coronary flow-upper trace and pulmonary flow-lower trace)

3. Conclusions

A new type of imaging pulse Doppler was used for the examination of cardiac flow. In particular, its imaging possibilities are of great assistance in the proper positioning of the sample volume within the region of the heart chamber under investigation. Recordings of the coronary flow are good examples of this ability.

Recordings of the aortic flow from the suprasternal notch were easy to obtain in all cases (for ascending and descending aorta), giving us the important diagnostic information on the coarctation of aorta and patent ductus arteriosus.

The examination of the flow through the tricuspid and mitral valves require more experience, especially in the left and right atrium.

Location of VSD and its high jet velocities was easily performed after proper positioning of the sample volume, however, we could not estimate the peak velocity due to the maximum Doppler frequency limit of 2.5 m/s.

References

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