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Aortic blood flow patterns: a transcutaneous Doppler study

by

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In 35 normal children some variables of the aortic arch blood flow were studied by transcutaneous ultrasonic Doppler technique. Mean values for peak velocity (V), acceleration in early systole (Acc), duration of the acceleration phase, as well as the area under the early phase of flow systolic complex (S) were calculated. A significant difference in S value was found between girls and boys. Some significant correlation and regression coefficients were found between the mentioned indices of the aortic blood flow on the one hand, and the weight, height, age and heart rate on the other. The highest values for the correlation coefficients occurred in girls between V and Acc on the one hand, and the weight of the subjects on the other.

While physiologic studies have indicated that information about aortic blood flow dynamics may be of considerable usefulness in the assessment of heart performance, the lack of useful techniques has impaired clinical evaluation of this parameter [13, 21]. Most methods for measuring haemodynamic indices require that catheters or flow probes be inserted into arteries and measurements made under static and strictly controlled conditions. Thus, there remains an important need, especially in the paediatric field, of non-invasive methods of aortic flow or velocity determinations.

A new approach in the non-invasive evaluation of heart disease in infants and children was provided by ultrasound cardiography [7] and during the last years the number of echocardiographic studies has increased rapidly [17]. The Doppler technique has been found useful for cardiovascular diagnosis in adults, infants and children, as well as in the experimental field [7, 9, 10, 15, 20, 26, 27].

Recently, there is an intriguing possibility of determining aortic blood flow velocities and accelerations transcutaneously by ultrasonic Doppler techniques [4, 5, 13, 15, 21]. These two variables of aortic blood flow are considered to be the most sensitive indicators of overall left-ventricular function [20]. So far, these indices have not been evaluated in normal children by means of the mentioned technique.

* I dedicate this paper to my son, Łukasz. M.B.

Approach

Ultrasound waves emanating from a transmitting piezo-electric crystal are partially reflected by the moving blood corpuscles and possibly some proteins [19, 25, 26]. The reflected wave is detected by a receiving crystal and the resulting signal processed electronically to obtain a Doppler frequency shift, F_D, which is determined by the equation:

$$F_D = \frac{2 \times f \times V \times \cos\alpha}{c} \qquad (a)$$

where

f = frequency of transmitted wave;
c = velocity of sound in blood (= approximately 1.57×10^5 cm/sec);
α = angle between the transducer axis and the blood flow velocity vector;
V = velocity of the blood (in cm/sec).

Thus, the velocity of blood is determined by the formula:

$$V = \frac{F_D \times c}{2 \times f \times \cos\alpha} \qquad (b)$$

To obtain V, the angle α must be known, except for the special case when it is close to zero. In that case, provided it is less than 25°, cos α can be taken as 0.95 with a maximum error of $\pm$ 5%, thus allowing the actual velocity, V, to be calculated within that margin of error.

Material and Methods

A total of 35 normal children (21 boys and 14 girls) free from cardiovascular disease, ranging in age from 8 to 14 years were studied. The boys and girls were divided into two age subgroups, from 8 to 10 and from 11 to 14 years. Two other subgroups included the younger and older children without respect to sex. Mean values ($\pm$ SD) for age, weight and height of the subjects were 11 $\pm$ 1.5 years, 34.8 $\pm$ 8.1 kg and 144.2 $\pm$ 10.8 cm, respectively. All subjects had normal haemoglobin values and blood counts and other laboratory findings.

A portable Siemens Doppler ultrasound blood flow detector operated at 20 mW, transmitting a continuous beam of 5 MHz, was used. At this sound frequency, assuming an angle of incidence close to zero, each 1 KHz of Doppler signal frequency corresponds to 15.7 cm per second velocity of the erythrocytes. A Doppler probe, containing both transmitting and receiving transducers, was applied to the suprasternal notch and pointed towards the aortic arch, using an ultrasonic contactant. The purest and loudest possible sound audible in the loudspeaker, corresponding to the systolic flow complexes of clearest outline and greatest amplitude on the recording, was obtained by gently moving the probe or changing the angle of insonation. The Doppler sound produced was registered on a three-channel recorder synchronously with ECG and PCG curves (Figure 1). The PCG microphone was placed on the precordium in a position that allowed best visualization of the initial high frequency vibrations of the first and second heart sounds.

The children were placed in the supine position at room temperature of 20—25°C

Fig. 1. Aortic blood flow velocity curve (lower tracing) registered synchronously with ECG and PCG curves

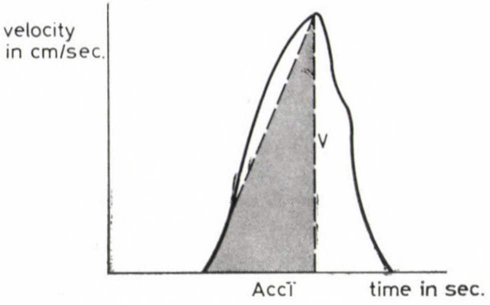

FIG. 2. Signals obtained from aortic blood flow velocity curve. V = peak velocity; AccT = = acceleration time; $\frac{V}{AccT}$ = acceleration; $\frac{V \times AccT}{2}$ = area under early phase systolic flow complex

The examination was begun after a 5—10 minute rest in order to achieve a steady state.

In each subject four systolic flow complexes of clearest outline and greatest amplitude, were analysed. Peak blood flow velocity (= V in cm/sec.), acceleration in early systole (= Acc in cm/sec^2.) and duration of the acceleration phase (acceleration time = AccT in sec.), as well as the area under the early phase of the flow systolic complex (= S in cm), were measured.

V was obtained from equation (b), assuming that α equals zero. Acc was determined by dividing V by AccT; the latter was measured from the beginning up slope to the point of crossing the baseline with the projection of V. S was calculated (with triangular approximation) from the formula: $\frac{V \times AccT}{2}$ (Figure 2). Heart rate (= HR in beats/min) was determined by dividing paper speed by the interval (both in mm) between the beat used to calculate the mentioned parameters and the previous beat.

The mean values of V, Acc, S and AccT for all children, boys, girls and age subgroups, were calculated and the significance of differences between these values was determined by means of Student's t test.

The correlation and regression coefficients were estimated to determine the relationships between V, Acc, S, AccT on the one hand, and the age, weight, height and HR of all children, boys and girls, on the other. In the assessment of the significance of the difference between means, as well as of the correlation coefficients, Snedecor's tables were utilized. For assessing the significance of regression coefficients, the t-test was used.

The results were analysed by computer.

RESULTS

Results are shown in Table I as means with their standard deviations. A significant ($p < 0.05$) difference in S was found between girls and boys.

In Table II the correlation and regression coefficients between the mentioned variables of aortic blood flow and the presented parameters concerning all children, boys and girls, are demonstrated.

DISCUSSION

The results of Huntsman et al [13] as well as Sequeira et al [21] and others indicate that it is possible to measure aortic blood flow velocities and accel-

Table I

Mean values for some variables of aortic blood flow with standard deviations in normal children

Subjects \ Variables	Peak velocity, cm/sec.	Acceleration, cm/sec.^{2}	Area, cm	Acceleration, sec.
All children	40.692	286.093	3.082	0.151
n = 35	±6.332	±81.948	±0.943	±0.038
Younger group	39.332	279.498	2.955	0.149
n = 19	±6.893	±82.732	±0.994	±0.040
Older group	42.307	293.924	3.233	0.152
n = 16	±5.197	±80.954	±0.862	±0.036
Boys	39.687	297.445	2.798	0.140
n = 21	±6.723	±84.522	±0.811	±0.032
Girls	42.200	269.065	3.508	0.166
n = 14	±5.409	±75.491	±0.974	±0.041
Younger boys	39.196	293.953	2.753	0.140
n = 13	±7.667	±86.079	±0.859	±0.033
Younger Girls	39.626	248.178	3.392	0.170
n = 6	±4.947	±66.284	±1.138	±0.048
Older boys	40.483	303.119	2.871	0.141
n = 8	±4.822	±82.969	±0.732	±0.033
Older girls	44.130	284.730	3.596	0.163
n = 8	±4.978	±79.121	±0.839	±0.037

erations in man by the transcutaneous ultrasonic Doppler method. This technique has been compared to other techniques in order to evaluate its potential usefulness [13], and it was found suitable for quantitating blood velocity in both the ascending aorta and the aortic arch. Moreover, the technique has been found safe (power level less than 1 W/cm^2) and convenient.

The continuous wave (CW) device with its broader beam and lack of range-gating, as compared to pulsed ultrasonic Doppler techniques, was used in this study. A comparison of these two Doppler techniques [13] revealed a close similarity between the pulsed and the CW data and the differences appeared to be within the range of normally occurring short-term variations and experimental error.

It has been suggested that the anatomy and physiology of blood flow in the thorax may be suitable for a simpli-

TABLE II

Correlation and regression coefficients between some variables of aortic blood flow and chosen parameters of normal children

Subjects and number of measurements		Variables: peak velocity and age	peak velocity and weight	peak velocity and height	peak velocity and heart rate	acceleration and age	acceleration and weight	acceleration and height	acceleration and heart rate
All children	140	$r=0.276$ $b=1.013$ $P<0.01$	$r=0.453$ $b=0.352$ $P<0.01$	$r=0.343$ $b=0.189$ $P<0.01$	NS NS	NS NS	NS	NS	NS
Boys	84	NS	NS	NS	NS	NS	NS	NS	NS
Girls	56	$r=0.466$ $b=1.180$ $P<0.01$	$r=0.729$ $b=0.416$ $P<0.01$	$r=0.575$ $b=0.246$ $P<0.01$	NS	NS	$r=0.453$ $b=3.604$ $P<0.01$	$r=0.340$ $b=2.034$ $P<0.05$	NS

Subjects and number of measurements		Variables: area and age	area and weight	area and height	area and heart rate	acceleration time and age	acceleration time and weight	acceleration time and height	acceleration time and heart rate
All children	140	$r=0.183$ $b=0.100$ $P<0.05$	$r=0.330$ $b=0.038$ $P<0.01$	$r=0.270$ $b=0.022$ $P<0.01$	NS	NS	NS	NS	NS
Boys	84	NS	$r=0.238$ $b=0.033$ $P<0.05$	NS	NS	NS	NS	NS	NS
Girls	56	NS	NS	NS	NS	NS	NS	NS	NS

fied approach using continuous wave ultrasound. Access to the aortic arch from the suprasternal notch proved adequate in more than 90% of normal subjects resting in the supine position [13, 15, 18] (Figure 3).

The geometric relationship between a sound originating in the suprasternal notch and the aortic arch was investigated in 7 subjects with apparently normal anatomy and cardiovascular function [13]. It was found that even with the tendency of the technique to overestimate the minimum angle, the angle between the ultasonic beam and the aortic axis was quite small and the assumption that cosinus of this angle equals unity, introduced an error of less than 2%. On the other hand, some investigators concluded that

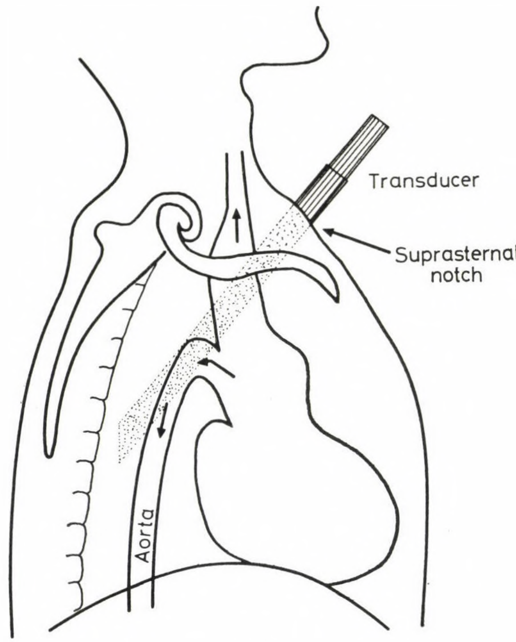

Fig. 3. Path of the ultrasound beam from the transducer positioned in the suprasternal of notch. After Nichol et al. [18]

absolute flow values could not reliably be determined by transcutaneous aortovelography [16]. Thus, it is possible to utilize the mentioned formula to calculate from the recordings only the approximate aortic peak flow velocity and its derivatives, Acc and S. On the other hand, the technique applied allows a precise determination of the time parameter, AccT.

The most sensitive indicators of cardiac performance are the rates of change, including the rates of ejection (outflow velocity) and that of the change of velocity (acceleration) [20].

Mean V of the blood in the aortic arch for all examined children in this study was 40.7 ± 6.3 cm/sec (Table I). This value agreed well with the results of most other authors examining mean aortic blood velocity in resting adult subjects with normal haemodynamics and cardiac outputs [2, 4, 13]. Highly significant correlation and regression coefficients were found for V on the one hand, and weight, height and age of all the children, and of the girls on the other hand, with the value of the first correlation coefficient (V and weight) being the highest (Table II). No correlation was found between V and HR, and this finding disagreed only directly with the results obtained by Rushmer [20] who observed lower flow rates with increasing heart rates.

Maximum aortic acceleration is considered a valuable indicator of heart performance [20, 22, 24] while the normal value for peak aortic