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Doppler Aortic Flow Velocity Measurement in Healthy Children

To determine normal values for Doppler parameters of left ventricular function, ascending aortic blood flow velocity was measured by pulsed wave Doppler echocardiography in 63 healthy children with body surface area (BSA) <1 m^2 (age <10 yr). Peak velocity was independent of sex, but increased with body size. Mean acceleration was related to peak velocity (r=0.75, p<0.0001). Both stroke distance and ejection time had strong negative correlations with heart rate and positive correlations with BSA, suggesting that these parameters should be evaluated in relation to heart rate and body size. Mean intra- and inter-observer variability for peak velocity, ejection time, stroke and minute distance ranged from 3 to 7%, whereas variability for acceleration time was 9 to 13%. These data may be used as reference values for the assessment of hemodynamic states in young children with cardiac disease.

Key Words : *Blood Flow Velocity; Child; Echocardiography, Doppler*

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INTRODUCTION

Doppler measurement of aortic blood flow has been used as a noninvasive index of left ventricular (LV) performance, with a close correlation with conventional invasive indexes (1-5). Many Doppler variables can be used, such as aortic peak velocity and peak or mean acceleration. Measurement of these variables may provide clinically useful information in the evaluation of patients with heart disease (6-8) and in the assessment of hemodynamic response to cardioactive medications (2, 9-12). By serial evaluation of Doppler velocity waveform, it can be possible to detect hemodynamic changes in a given individual.

High correlations existed in dogs between Doppler-derived stroke distance and stroke volume measured by thermodilution (13), and stroke distance has been used as an index of stroke volume in clinical studies (2, 6, 11, 14). The minute distance, the product of stroke distance and heart rate, is thus a linear index of cardiac output (11, 14). The acceleration time, ejection time and acceleration time/ejection time ratio (AT/ET) have been studied in various studies (2, 6, 11).

The studies regarding Doppler-derived parameters of LV function have been performed mainly in healthy adults (14-18), and rarely in children (19). Clinical application of these parameters in children requires information on the normal ranges and their variations with age, body size and heart rate. Accordingly, this study was undertaken to determine normal values for Doppler parameters of LV function in healthy children.

MATERIALS AND METHODS

Subjects

The subjects consisted of 63 infants and children (33 boys, 30 girls) with a median age of 2.1 yr (range, 1 day to 8.2 yr) and a median body weight of 12 kg (range, 2.6 to 22 kg). Twenty subjects were <6 months of age. The body surface area (BSA) and sex distribution of the subjects are shown in Fig. 1. All the children studied were healthy without any evidences for cardiac disease at the time of the Doppler examination and a patent arterial duct was excluded in all the neonates <1 week of age.

Methods

The children were studied resting calmly in the supine position. No medication for sedation was used. Doppler echocardiography was performed using an Acuson 128 XP (Acuson Co, Mountain View, CA, U.S.A.). A 5 or 7.5 MHz pulsed wave Doppler transducer was positioned at the suprasternal notch with the sample volume placed approximately 1 cm above the aortic valve, and the highest velocities with the sharp, well-defined signals from

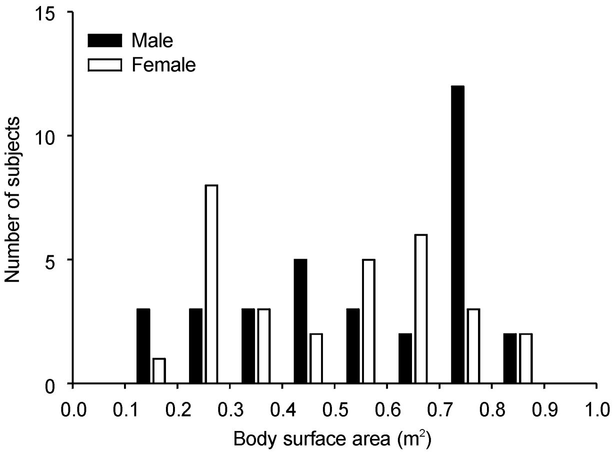

Fig. 1. Body surface area and sex distribution of the subjects.

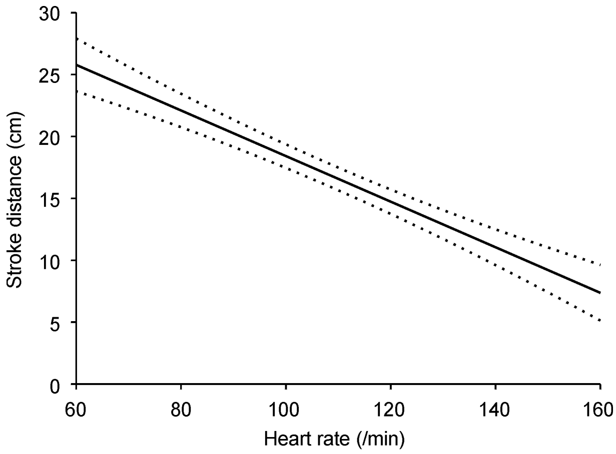

Fig. 2. Relationship between heart rate and stroke distance. The straight line is the regression line and the dotted lines represent 95% confidence interval.

the ascending aorta were obtained. The following measurements were made on each Doppler waveform as described previously (11, 12): peak velocity, mean acceleration, acceleration time, ejection time, AT/ET and stroke distance (area under the velocity curve, also called velocity time integral). Minute distance was obtained by multiplying the stroke distance by the heart rate. For each of these parameters, 3 to 4 high quality waveforms were analyzed and the results averaged. To determine intraobserver variability of Doppler measurements, 10 children with Kawasaki disease (median age, 3 yr) who had normal LV function were studied by one observer on two different examinations. For interobserver variability, these children were examined by two observers, who were unaware of the other's results.

Statistical analysis

All data are expressed as mean±SEM. Comparisons between different groups were analyzed by group t-test. Linear regression was used to determine the effect of age, BSA and heart rate on each Doppler measurement. With multiple regression analysis, the relations between the measurements and all combinations of age, BSA and heart rate were also tested. Variability was calculated as the difference from the mean of the two results and expressed as the percentage of the mean. A p value of <0.05 was considered significant.

RESULTS

There was no significant difference between boys and girls in all the Doppler measurements, and the results are therefore presented for the whole group.

The correlations between each Doppler parameter and age, BSA and heart rate are listed in Table 1. For peak

Table 1. Correlations between Doppler parameters and age, body size and heart rate

Parameters	r	Regression equation
Peak velocity (m/s)		
Age (months)	0.60	
Body surface area (m^2)	0.70	
Heart rate	-0.53	
Mean acceleration (m/s^2)		
Age (months)	0.29	
Body surface area (m^2)	0.30	
Heart rate	NS	
Acceleration time (ms)		
Age (months)	0.40	
Body surface area (m^2)	0.51	
Heart rate	-0.51	
Ejection time (ms)		
Age (months)	0.71	
Body surface area (m^2)	0.77	
Heart rate	-0.86	405.6-(1.43×HR)
Body surface area×Heart rate	0.88	344.5+(43.5×BSA) -(1.1×HR)
Acceleration time/ejection time		
Age (months)	NS	
Body surface area (m^2)	NS	
Heart rate	0.26	
Stroke distance (cm)		
Age (months)	0.77	
Body surface area (m^2)	0.84	7.3+(18.6×BSA)
Heart rate	-0.76	36.8-(0.18×HR)
Body surface area×Heart rate	0.87	17.5+(13.8×BSA) -(0.07×HR)
Minute distance (cm/min)		
Age (months)	0.51	
Body surface area (m^2)	0.59	
Heart rate	-0.26	
Body surface area×Heart rate	0.64	

r, correlation coefficient

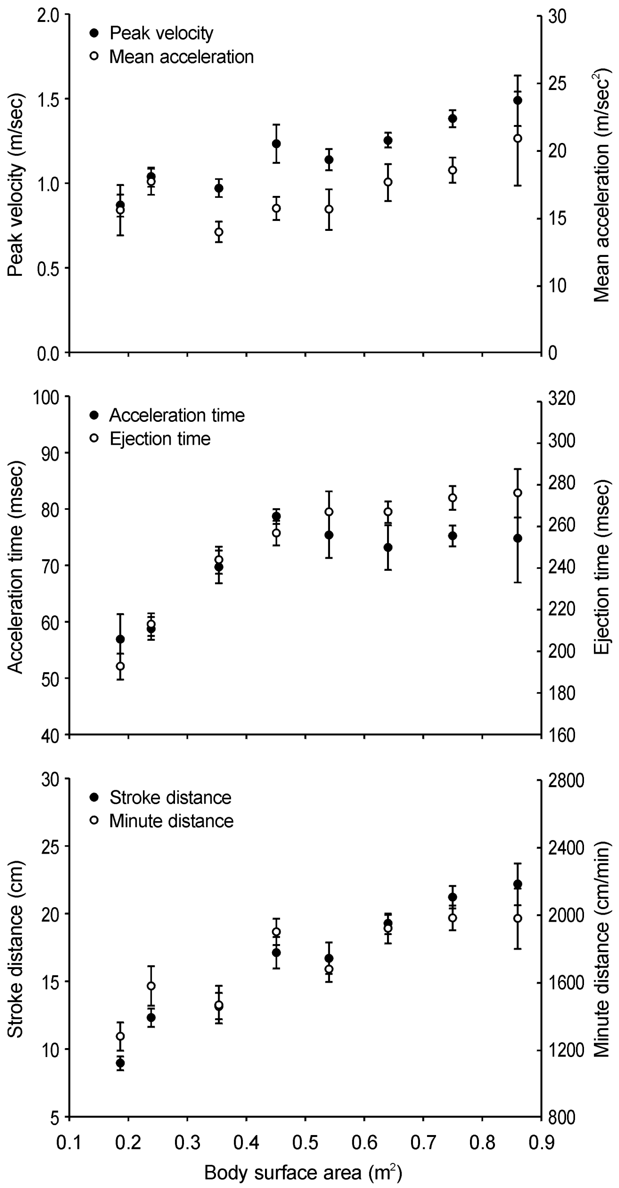

Fig. 3. Changes in each Doppler parameter related to body surface area. Values are mean±SEM.

velocity, a linear correlation with BSA was found. For mean acceleration and AT/ET, weak or no significant correlations were found with age, BSA and heart rate. For acceleration time and minute distance, correlations were fairly weak. Ejection time was found to have a positive correlation with age and BSA, and a negative correlation with heart rate. Multiple regression analysis indicated that both BSA ($p=0.002$) and heart rate ($p<0.0001$) were significant variables. Stroke distance was also directly related to BSA and inversely to heart rate: the multiple correlation coefficient for stroke distance against age, BSA and heart rate was $r=0.87$ ($p<0.0001$), but the partial regression coefficient for age was not significant ($t=0.58$, $p=0.564$). The partial regression coefficient for BSA and heart rate against stroke distance was highly significant (BSA: $t=3.66$, $p=0.0005$; heart rate: $t=3.03$, $p=0.0036$). The normal range of stroke distance related to heart rate is shown in Fig. 2. The changes in the mean values of each Doppler parameter related to BSA are illustrated in Fig. 3, and the relationship between peak aortic velocity and mean acceleration is shown in Fig. 4.

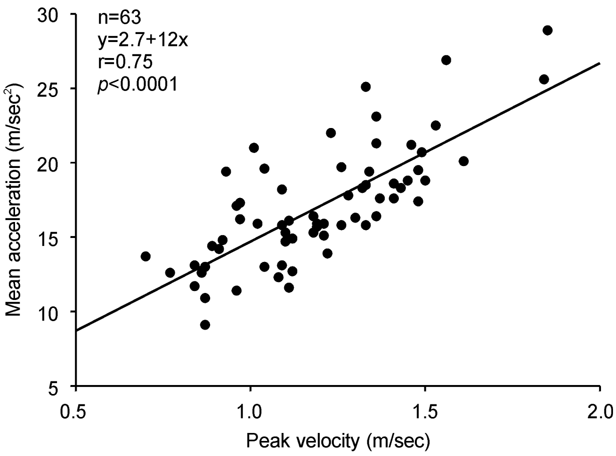

Fig. 4. Relationship between peak velocity and mean acceleration.

Table 2. Intra- and interobserver variability (n=10)*

Parameters	Intraobserver (% difference)	Interobserver (% difference)
Peak velocity	2.7±2.2%	2.9±2.2%
Mean acceleration	8.7±4.3%	9.7±6.0%
Acceleration time	9.1±6.5%	12.9±8.1%
Ejection time	3.1±2.3%	5.4±2.9%
AT/ET	8.7±6.6%	8.9±5.5%
Stroke distance	3.2±2.0%	6.3±5.0%
Minute distance	3.1±1.8%	6.8±3.8%

*Values are mean±SD. AT/ET, acceleration time/ejection time

Table 2 summarizes intra- and interobserver variability of measurements. The variability of intra- and interobservation was small for peak velocity, ejection time, stroke and minute distance but greater for measures of acceleration, acceleration time and AT/ET. The variation of intraobserver was smaller than that of interobserver.

DISCUSSION

Several investigators (2, 5-8, 10, 11) have demonstrated that Doppler measurement of blood flow velocity and acceleration in the ascending aorta provides a useful method for the noninvasive hemodynamic evaluation of patients with cardiovascular disease and the assessment for quantitative hemodynamic responses to therapy. For clinical use of these parameters in children, however, we need to know the normal range of measurements and their variations with age, BSA and heart rate.

For peak velocity, correlations with age, BSA and heart rate were noted, but only BSA was related to peak velocity by multiple regression analysis. In children >6 months of age studied by Hanseus et al. (19) the mean peak velocity was 1.2 m/sec, and the mean value for our group of subjects with the same age was 1.3±0.03 m/sec.

For mean acceleration, the correlations with age and BSA were weak. Our normal values of mean acceleration were close to those reported by Hanseus et al. (19). Jewitt et al. (20) showed a very close correlation between peak velocity and acceleration (r=0.92), but in our subjects the correlation was weaker (r=0.75). Doppler studies demonstrated that mean and peak acceleration were equally sensitive indicators of LV performance (3, 5), and we measured mean rather than peak acceleration in this study. This may account for a relatively weaker correlation of mean acceleration with peak velocity.

Little work has been produced on the clinical usefulness of time intervals. Acceleration time had a fairly weak inverse correlation with heart rate, whereas ejection time had a stronger inverse correlation with it (r=0.86). In the study by Hanseus et al. (19) AT/ET was 0.23, while that in our study was 0.28. No significant relationship was found between AT/ET and either age or BSA.

The significant correlations of stroke distance with BSA and heart rate indicate that the measurements of stroke distance should be evaluated in relation to BSA and heart rate. The mean stroke distance at the age of 1-4 days was 9.6 cm in the study by Hirsimaki et al. (21) and 11.2 cm by Hanseus et al. (19), while that for our subjects aged 1-5 days was 8.8±0.4 cm. In addition, the mean stroke distance at the heart rate of 70 bpm was 24.2 cm in our study calculated from the equation in Table 1, which is comparable with 24.1 cm by Mowat et al. (15) and 23 cm by Hanseus et al. (19).

Our normal values of minute distance were close to those reported by Hanseus et al. (19) in children >6 months of age.

When Doppler echocardiography is used to evaluate cardiac function serially, it is important to estabilish the intra- and interobserver variability to determine whether the percent changes in Doppler parameters are due to just variability of measurement or true changes. Mean intra- and interobserver variability for peak velocity, ejection time, stroke and minute distance ranged from 3 to 7%, whereas variability for acceleration time (especially interobserver variability) was greater. Since mean acceleration is calculated by dividing peak velocity by acceleration time, it reflects the variability for the determination of acceleration time. The variability of intra- and interobservation in this study is compatible with those in other studies (19, 22). Gardin et al. (22) demonstrated that differences in peak velocity, ejection time and stroke distance greater than 13% reflected true hemodynamic changes on serial measurements.

There are several limitations in this study. Firstly, because of a small number of subjects with narrow range of age and body size, our study had a limited spectrum of changes in Doppler variables with age or BSA. Secondly, the variability of heart rate affected the measurements of stroke and minute distance and ejection time. In our study of variability, the heart rate did not change significantly between the examinations in each subject. Thirdly, considerable variations may exist in measuring techniques between the studies. We followed the method of Hanseus et al. (19): the outer part of the Doppler velocity waveform was used for all measurements and tracings. Finally, Doppler parameters are influenced by changes in preload, afterload and LV contractility (1-3, 6-12). Our study is on the assumption that there is no change in these hemodynamic factors at the time of the examinations.

Despite these limitations, our data may be used as reference values for the assessment of pre- and postoperative hemodynamic states in young children with cardiac disease.

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