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Original Article

Normal patterns of flow in the superior caval, hepatic and pulmonary veins as measured using Doppler echocardiography during childhood

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Abstract To date, no reference values have been provided for right and left atrial filling in normal children. The aim of our study, therefore, was to characterize measurements of superior caval, hepatic, and pulmonary venous flow using Doppler echocardiography in a large group of normal children to reflect the effects of age, body mass index, sex, heart rate and respiration.

Doppler echocardiographic examinations of the superior caval, hepatic and pulmonary veins were performed during inspiration and expiration in 72 healthy children with a mean age of 6.73 ± 5.10 years. The subjects were segregated into four age groups, namely infants <2 years, preschool children between the ages of 2 and 7 years, children of school age between 7 and 11 years, and adolescents older than 11 years.

Age has significant effect on the systolic and reverse atrial flows within the superior caval vein ($p < 0.05$). No change in the Doppler velocities was observed related to body mass index or sex. All peak systolic velocities decreased significantly during expiration ($p < 0.05$). This decrease was most prominent in the hepatic vein (26%), but less remarkable in the superior caval vein (5.7%) and the pulmonary veins (3.9%). During expiration, the peak diastolic flow in the superior caval and the hepatic veins decreased, while the reverse atrial flow in the hepatic vein increased ($p < 0.05$). Pulmonary venous velocities were similar in all age groups ($p > 0.05$). Except for the systolic pulmonary venous velocities, these parameters were not influenced by respiration ($p > 0.05$). The diastolic time, the interval between reverse atrial flow and ventricular systole reflected by the R wave on the electrocardiogram, and the interval between ventricular systole and diastolic flow, were negatively correlated with heart rate ($p < 0.05$; $r = -0.35$, -0.85, and -0.8 respectively), and positively correlated with age ($p < 0.05$; $r = 0.3$, 0.8, and 0.7 respectively). They were not influenced by respiration.

Our study provides data of the patterns and the normal ranges of velocities of superior caval, hepatic, and pulmonary venous flow in a series of normal children. The results can now be used for comparison with the patterns found in the setting of disease.

Keywords: Cross-sectional echocardiography; paediatrics; venous flow

Doppler echocardiography has been used to detect abnormalities of the patterns of filling of the right and left atriums in adult patients.[1–6] These patterns, however, have been much less frequently studied in children.[7–10] Indeed, data are currently lacking for a large series of normal children. The purpose of our study, therefore, was to determine the normal patterns and velocities of flow in the superior caval, hepatic, and pulmonary veins using Doppler echocardiography in children of all ages. Our findings should then prove of value to paediatric cardiologists assessing children with cardiac disease.

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Material and methods

Subjects studied

Newborn infants in the first week of life, older than 3 days, were recruited from the well baby nursery of

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Table 1. The children studied.

	Groups				
	Newborns and infants (<2 years)	Preschool age children (2–7 years)	School age children (7–11 years)	Adolescents (>11 years)	General
Female/Male	9/9	9/9	9/9	9/9	36/36
Age (years)	0.70 ± 0.71	4.35 ± 1.33	7.97 ± 0.94	13.92 ± 2.18	6.74 ± 5.10
Weight (kg)	7.44 ± 4.26	16.68 ± 3.56	26.06 ± 4.71	45.94 ± 11.94	24.03 ± 15.91
Body mass index (kg/m^2)	15.54 ± 3.27	15.98 ± 1.15	16.06 ± 1.49	19.03 ± 3.07	16.65 ± 2.76
Systolic blood pressure (mmHg)	85.6 ± 9.5	94.4 ± 8.2	103.6 ± 8.9	110.3 ± 10.6	98.5 ± 13.1

Values are mean ± SD.

the Hacettepe University Children's Hospital. Older children were recruited from the pediatric clinics of the Hacettepe University during their routine health maintenance visits, and from those referred to the pediatric cardiology unit for innocent murmurs. A few were volunteers or siblings of the patients. No children were acutely ill, nor taking any medications at the time of the study. All were growing normally, in a normal hemodynamic state, and normally hydrated during the echocardiographic study. We excluded children with conditions that may have caused an increased cardiac output, such as anaemia or hepatic or pulmonary disease. Informed consent was obtained for any examination not indicated clinically.

Systemic cardiac pathologies were excluded by means of a thorough physical examination, electrocardiography, and echocardiography. All children were in sinus rhythm and had normal electrocardiographic patterns. We noted the age, sex, height and weight of all patients, along with heart rate and blood pressure. We calculated the body mass index by dividing weight by the square of the height.

In order to define the ranges of normal velocities of flow at different ages, we divided our children into four subgroups in terms of age. Our infants had a mean age of 0.7 years, with a range from birth to 1 9/12 years. The preschool children had a mean age of 4.35 years, with a range from 2 8/12 to 6 5/12 years. Those of school age ranged from 7 to 10 3/12 years, with a mean age of 7.97 years. The adolescents ranged from 11 to 16 9/12 years, with a mean age of 13.92 years (Table 1).

Echocardiographic examination

A complete echocardiographic study was performed, using multiple planes to confirm normal cardiac anatomy and function. Each child was examined in the supine position so as to exclude any variation in flow caused by changes in body position. No sedatives were used, and the studies were performed in a quiet, dimly lit, room with the infants and children in an awake and calm state. The same pediatric cardiologist performed all the echocardiographic examinations using a General Electric Vingmed System Five Performance using 10, 3.5, and 2.5 mHz probes. All the studies were recorded on the hard disc of the echocardiographic scanner for later analysis.

Velocities of superior caval venous flow were recorded from the subxyphoid sagittal view. The 2 mm-pulse wave Doppler sample volume was placed in the superior caval vein just proximal to the cavo-atrial junction (Fig. 1). For assessing the velocity of hepatic venous flow, we studied the hepatic vein most closely aligned with the ultrasound beam as seen using the subcostal sagittal view. The sample volume was placed within 1 cm of the inferior cavo-atrial junction. Only studies with adequate recordings showing the triphasic waveform were included (Fig. 2).

Pulmonary venous flow was recorded in the orifice of the right upper pulmonary vein using the sub-xyphoid four-chamber view, placing the sample volume within 1 cm of the venoatrial junction. Angle correction of the velocities was not used (Fig. 3).

For each vein, we measured:

- Peak velocity of the antegrade systolic wave resulting from movement of the atrioventricular annulus toward the cardiac apex shortly after the QRS complex.
- Peak velocity of the antegrade early diastolic wave resulting from opening of the atrioventricular valve shortly after the T wave.
- Peak velocity of the late diastolic, retrograde atrial contraction wave resulting from atrial contraction immediately after the P wave.

The mean velocity of blood flow was calculated from the integral of the Doppler velocity tracings. To time the flow events, we simultaneously recorded an electrocardiogram, measuring the interval between the beginning of atrial and ventricular contraction as revealed by the following R wave on the electrocardiogram, the interval between the R wave and the end

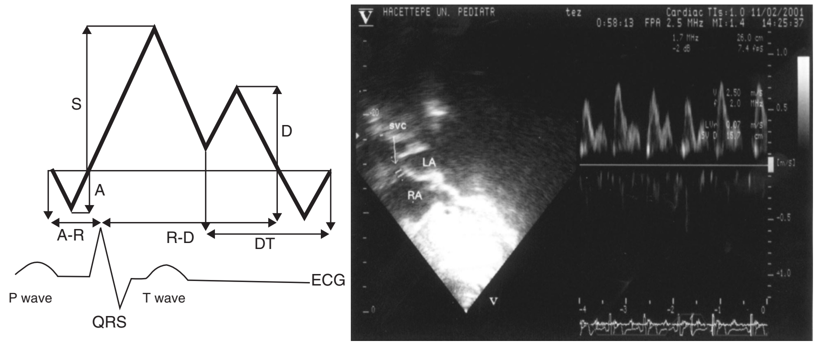

Figure 1.
Measurements of the superior caval vein. (Left) Schematic drawing showing the superior caval venous velocities and the timed events. S: peak systolic flow; D: peak diastolic flow; A: peak reverse atrial systolic flow; A-R: the interval between the beginning of atrial contraction velocity and the beginning of ventricular contraction (the following R wave on the ECG); R-D: the interval between the R wave on the ECG (ventricular contraction) and the end of diastolic velocity; DT: interval from the beginning of early diastolic wave to the end of atrial contraction wave (diastolic time). (Right) Cross-sectional echocardiographic image of the superior caval vein (left) and the velocities measured by pulsed-wave Doppler echocardiography (right). svc: superior caval vein; LA: left atrium; RA: right atrium.

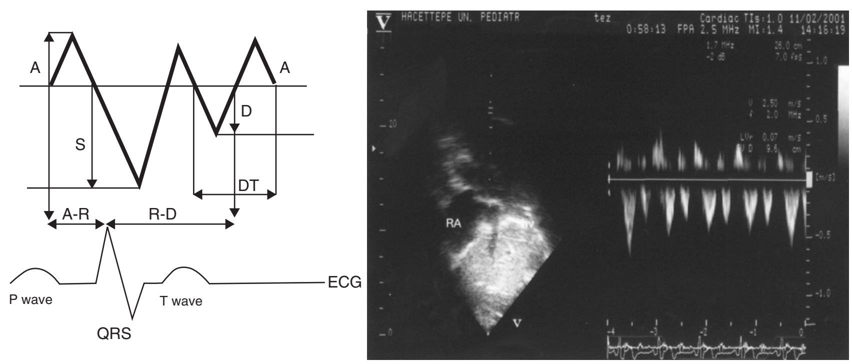

Figure 2.
Measurements of the hepatic vein. (Left) Schematic drawing of the velocities of hepatic venous flow and the timed events. S: peak systolic flow; D: peak diastolic flow; A: peak reverse atrial systolic flow; A-R: the interval between the beginning of atrial contraction velocity and the beginning of ventricular contraction (the following R wave on the ECG); R-D: the interval between the R wave on the ECG (ventricular contraction) and the end of diastolic velocity; DT: interval from the beginning of early diastolic wave to the end of atrial contraction wave (diastolic time). (Right) Cross-sectional echocardiographic image of the hepatic vein (left) and the velocities of flow as measured by pulsed-wave Doppler echocardiography (right). hv: hepatic vein; RA: right atrium.

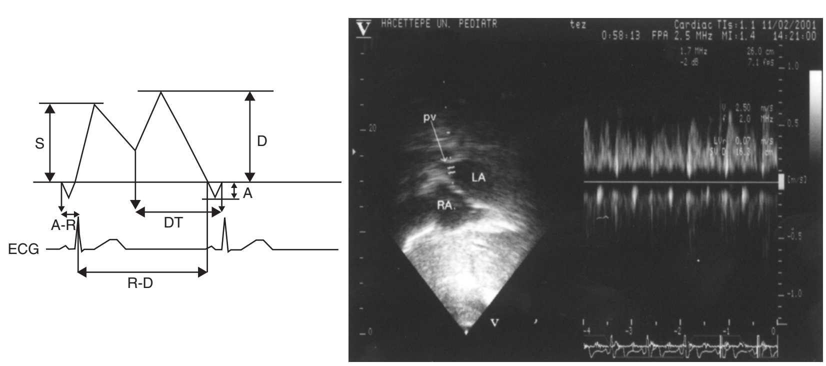

Figure 3.
Measurements of the pulmonary vein. (Left) Schematic drawing of the velocities of pulmonary venous flow and the timed events. S: peak systolic flow; D: peak diastolic flow; A: peak reverse atrial systolic flow; A-R: the interval between the beginning of atrial contraction velocity and the beginning of ventricular contraction (the following R wave on the ECG); R-D: the interval between the R wave on the ECG (ventricular contraction) and the end of diastolic velocity; DT: interval from the beginning of early diastolic wave to the end of atrial contraction wave (diastolic time). (Right) Cross-sectional echocardiographic image of the pulmonary vein (left) and the velocities measured by pulsed-wave Doppler echocardiography (right). pv: hepatic vein; LA: left atrium; RA: right atrium.

of diastolic velocity, and the interval from the beginning of the diastolic wave to the end of the atrial contraction wave, the latter representing the diastolic time (Figs 1–3). A phonocardiogram probe was placed in the xyphoid notch to determine systole and diastole, and a respiratory probe was placed in one of the nostrils to differentiate the phases of respiration.

Each Doppler measurement was made twice in end-inspiration, and twice in end-expiration. We averaged the measurements in inspiration and expiration, and also averaged all four measurements to give the total mean.

Statistics

The data is given as mean and standard deviation. The comparison of the echocardiographic measurements in different subgroups was made with analysis of variance and Student's t test. The Mann–Whitney U test with Bonn Feroni correction was applied to data with a non-normal distribution. The correlation of the measured data with variables like heart rate and body mass index were analyzed using the Pearson correlation constant, using the Spearman correlation constant for data with a non-normal distribution. A p value of <0.05 was considered significant.

Results

The mean age of the children studied was 6.74 years, the mean weight was 24.03 kg, the mean body mass index was 16.65 kg/m^2, and the mean systolic blood pressure was 98.5 mmHg (Table 1). The normal measurements from the superior caval, hepatic and pulmonary veins are shown in Table 2. Tables 3–5 show the flows in the superior caval, hepatic, and pulmonary veins, respectively, detailed according to the groups.

The peak systolic velocities were greater than the peak diastolic velocities in all the veins. The systolic velocity integrals were similarly greater than the diastolic velocity integrals (Table 2). The mean ratio of maximum systolic velocity to maximum diastolic velocity was 1.55, with a range from 0.97 to 2.33, in the superior caval vein, 1.38, with a range from 0.67 to 2.69, in the pulmonary vein, and 1.24, with a range from 0.79 to 2.01, in the hepatic vein. All the peak systolic velocities decreased significantly during expiration ($p < 0.05$) (Fig. 4). This decrease was most prominent in the hepatic vein, with a mean decrease of 26%. The changes with respiration were less remarkable in the superior caval and pulmonary venous waveforms, with a mean decrease in the superior caval vein of 5.7%, and in the pulmonary vein of 3.9%. The velocity integral of the systolic flow in the superior caval and hepatic veins diminished significantly in expiration ($p < 0.05$). A similar decrement was observed in velocity integrals of the diastolic and atrial reverse flows in the hepatic vein ($p < 0.05$). Pulmonary diastolic flows, both during early diastole and during atrial contraction, did not change significantly with respiration ($p > 0.05$) (Fig. 4), whereas the peak early diastolic inflow to the right atrium from the superior caval and hepatic veins decreased in expiration ($p < 0.05$). In contrast, the reverse atrial flow in the hepatic vein was slightly increased in expiration ($p < 0.05$), while that in the superior caval vein did not change ($p > 0.05$) (Fig. 4).

The differences in duration of the timed events, namely the interval between atrial and ventricular contractions, the interval between ventricular contraction and diastolic flow, and the total diastolic time, were significant in all age groups, and they increased with age as the heart rate decreased ($p < 0.05$). It is of note that the heart rate also decreased significantly in expiration, although the timed events were similar in inspiration and expiration ($p > 0.05$).

Table 2. Normal measurements from the superior caval vein, hepatic vein and pulmonary vein.

	Superior caval vein			Hepatic vein			Pulmonary vein		
	Mean insp	Mean exp	Total mean	Mean insp	Mean exp	Total mean	Mean insp	Mean exp	Total mean
A (cm/sec)	0.34 ± 0.10	0.33 ± 0.10	0.33 ± 0.10	0.26 ± 0.07**	0.28 ± 0.09**	0.28 ± 0.07	0.31 ± 0.09	0.30 ± 0.08	0.30 ± 0.08
VTI A (cm)	3.15 ± 1.48	3.0 ± 0.95	3.08 ± 1.07	2.71 ± 1.41*	2.89 ± 1.17*	2.80 ± 1.14	2.71 ± 0.90	2.68 ± 0.92	2.69 ± 0.85
S (cm/sec)	0.73 ± 0.14*	0.68 ± 0.10*	0.71 ± 0.11	1.03 ± 0.38*	0.73 ± 0.24*	0.88 ± 0.29	0.69 ± 0.17*	0.66 ± 0.17*	0.67 ± 0.16
VTI S (cm)	17.2 ± 3.65*	16.0 ± 2.84*	16.6 ± 2.90	23.7 ± 8.64*	16.1 ± 5.49*	19.8 ± 6.57	15.64 ± 4.55	15.26 ± 4.65	15.45 ± 4.47
D (cm/sec)	0.48 ± 0.12*	0.45 ± 0.11*	0.47 ± 0.10	0.88 ± 0.31*	0.56 ± 0.23*	0.72 ± 0.22	0.51 ± 0.11	0.49 ± 0.12	0.50 ± 0.11
VTI D (cm)	8.50 ± 2.48	8.22 ± 2.55	8.36 ± 2.14	15.0 ± 5.67*	9.62 ± 4.66*	12.3 ± 4.31	8.58 ± 3.01	8.74 ± 3.05	8.66 ± 2.89
A-R (sec)	0.08 ± 0.03	0.08 ± 0.03	0.08 ± 0.03	0.10 ± 0.03	0.10 ± 0.02	0.10 ± 0.02	0.09 ± 0.03	0.09 ± 0.03	0.09 ± 0.03
R-D (sec)	0.44 ± 0.07	0.45 ± 0.08	0.45 ± 0.07	0.41 ± 0.08	0.43 ± 0.09	0.42 ± 0.08	0.44 ± 0.07	0.44 ± 0.07	0.44 ± 0.07
DT (sec)	0.32 ± 0.09	0.33 ± 0.09	0.33 ± 0.09	0.32 ± 0.09	0.35 ± 0.23	0.32 ± 0.14	0.31 ± 0.08	0.33 ± 0.11	0.32 ± 0.09

*Significant decrease is observed from inspiration to expiration ($p < 0.05$), **significant increase is observed from inspiration to expiration ($p < 0.05$).
Abbreviations: insp: inspiration; exp: expiration; S: peak systolic flow; D: peak diastolic flow; A: peak reverse atrial flow; A-R: interval between atrial reverse flow and R wave on ECG; R-D: interval between R wave on ECG and early diastolic flow; DT: diastolic time (interval from the beginning of early diastolic wave to the end of atrial wave)

Table 3. Measurements of superior caval venous flow.

Groups	S (m/sec)	VTI S	D (m/sec)	VTI D	A (m/sec)	VTI A	A-R (sec)	R-D (sec)	DT (sec)
	Measured parameter								
Infants									
Mean inspiration	0.80 ± 0.17	16.16 ± 4.0	0.50 ± 0.18	7.14 ± 2.71	0.32 ± 0.13	2.50 ± 0.97	0.077 ± 0.018	0.38 ± 0.038	0.25 ± 0.026
Mean expiration	0.72 ± 0.12	14.52 ± 3.59	0.48 ± 0.17	7.08 ± 3.01	0.31 ± 0.12	2.44 ± 0.81	0.075 ± 0.021	0.39 ± 0.059	0.26 ± 0.086
Total mean	0.76 ± 0.13	15.34 ± 3.54	0.49 ± 0.16	7.11 ± 2.60	0.32 ± 0.13	2.47 ± 0.87	0.076 ± 0.018	0.38 ± 0.046	0.26 ± 0.053
Preschool children									
Mean inspiration	0.88 ± 0.13	17.64 ± 3.62	0.51 ± 0.12	8.69 ± 2.91	0.40 ± 0.097	3.46 ± 1.01	0.071 ± 0.029	0.44 ± 0.051	0.29 ± 0.042
Mean expiration	0.71 ± 0.085	16.45 ± 2.57	0.46 ± 0.097	7.40 ± 2.34	0.41 ± 0.098	3.35 ± 0.82	0.075 ± 0.030	0.44 ± 0.062	0.29 ± 0.051
Total mean	0.74 ± 0.092	17.04 ± 2.76	0.48 ± 0.092	8.04 ± 2.08	0.40 ± 0.088	3.41 ± 0.82	0.073 ± 0.027	0.44 ± 0.054	0.29 ± 0.043
School aged children									
Mean inspiration	0.70 ± 0.094	17.24 ± 1.90	0.45 ± 0.084	8.54 ± 1.73	0.32 ± 0.090	3.49 ± 2.38	0.083 ± 0.028	0.47 ± 0.058	0.36 ± 0.078
Mean expiration	0.68 ± 0.096	16.45 ± 2.56	0.45 ± 0.064	9.25 ± 1.82	0.31 ± 0.092	3.11 ± 1.21	0.083 ± 0.039	0.47 ± 0.076	0.38 ± 0.077
Total mean	0.69 ± 0.088	16.85 ± 1.97	0.45 ± 0.055	8.90 ± 1.23	0.32 ± 0.089	3.30 ± 1.50	0.083 ± 0.031	0.47 ± 0.059	0.37 ± 0.074
Adolescents									
Mean inspiration	0.65 ± 0.12	17.88 ± 4.60	0.47 ± 0.095	9.62 ± 1.90	0.30 ± 0.057	3.18 ± 0.94	0.099 ± 0.022	0.51 ± 0.049	0.40 ± 0.097
Mean expiration	0.61 ± 0.076	16.66 ± 2.11	0.41 ± 0.079	9.17 ± 2.28	0.29 ± 0.055	3.11 ± 0.72	0.099 ± 0.026	0.52 ± 0.043	0.39 ± 0.080
Total mean	0.63 ± 0.085	17.27 ± 2.92	0.44 ± 0.076	9.39 ± 1.83	0.29 ± 0.054	3.14 ± 0.79	0.099 ± 0.022	0.51 ± 0.044	0.40 ± 0.086

Abbreviations: S: systolic flow; D: early diastolic flow; A: flow during atrial contraction; VTI: velocity–time integral; A-R: interval between atrial flow and R wave on ECG; R-D: interval between R wave on ECG and diastolic flow; DT: diastolic time (interval from the beginning of early diastolic wave to the end of atrial contraction wave)

Table 4. Measurements of hepatic venous flow.

Groups	S (m/sec)	VTI S	D (m/sec)	VTI D	A (m/sec)	VTI A	A-R (sec)	R-D (sec)	DT (sec)
	Measured parameter								
Infants									
Mean inspiration	1.29 ± 0.47	26.61 ± 8.80	1.03 ± 0.38	14.70 ± 5.26	0.25 ± 0.073	2.16 ± 0.96	0.085 ± 0.022	0.33 ± 0.043	0.25 ± 0.037
Mean expiration	0.82 ± 0.32	16.20 ± 5.41	0.63 ± 0.23	8.18 ± 2.77	0.29 ± 0.110	2.16 ± 0.99	0.082 ± 0.018	0.34 ± 0.056	0.23 ± 0.043
Total mean	1.05 ± 0.37	21.41 ± 6.78	0.83 ± 0.29	11.44 ± 3.65	0.27 ± 0.086	2.16 ± 0.94	0.084 ± 0.018	0.33 ± 0.035	0.24 ± 0.036
Preschool children									
Mean inspiration	1.01 ± 0.27	23.58 ± 7.96	0.82 ± 0.21	13.44 ± 4.12	0.28 ± 0.073	2.59 ± 0.91	0.10 ± 0.027	0.39 ± 0.071	0.30 ± 0.049
Mean expiration	0.73 ± 0.17	16.04 ± 4.86	0.55 ± 0.26	8.96 ± 4.18	0.31 ± 0.080	2.96 ± 0.97	0.10 ± 0.026	0.41 ± 0.065	0.40 ± 0.430
Total mean	0.87 ± 0.20	19.81 ± 5.86	0.68 ± 0.15	11.20 ± 3.24	0.30 ± 0.071	2.77 ± 0.87	0.098 ± 0.025	0.40 ± 0.066	0.35 ± 0.220
School aged children									
Mean inspiration	0.87 ± 0.31	19.54 ± 7.74	0.75 ± 0.31	13.38 ± 6.38	0.25 ± 0.069	3.28 ± 2.25	0.10 ± 0.031	0.45 ± 0.056	0.35 ± 0.090
Mean expiration	0.66 ± 0.17	14.48 ± 4.65	0.50 ± 0.19	9.47 ± 5.44	0.29 ± 0.089	3.14 ± 1.18	0.10 ± 0.030	0.47 ± 0.048	0.38 ± 0.100
Total mean	0.76 ± 0.23	17.01 ± 5.79	0.63 ± 0.21	11.43 ± 4.82	0.27 ± 0.066	3.21 ± 1.46	0.10 ± 0.030	0.46 ± 0.049	0.37 ± 0.093
Adolescents									
Mean inspiration	0.96 ± 0.32	25.06 ± 9.05	0.91 ± 0.25	18.31 ± 5.62	0.27 ± 0.048	2.80 ± 0.88	0.11 ± 0.024	0.48 ± 0.038	0.39 ± 0.090
Mean expiration	0.69 ± 0.27	17.09 ± 6.89	0.56 ± 0.24	11.87 ± 5.31	0.28 ± 0.072	3.29 ± 1.26	0.10 ± 0.014	0.51 ± 0.045	0.40 ± 0.075
Total mean	0.83 ± 0.27	21.08 ± 7.34	0.73 ± 0.20	15.09 ± 4.43	0.27 ± 0.055	3.05 ± 1.00	0.10 ± 0.019	0.50 ± 0.036	0.40 ± 0.080

Abbreviations: S: systolic flow; D: early diastolic flow; A: flow during atrial contraction; VTI: velocity–time integral; A-R: interval between atrial flow and R wave on ECG; R-D: interval between R wave on ECG and diastolic flow; DT: diastolic time (interval from the beginning of early diastolic wave to the end of atrial contraction wave)

Table 5. Measurements of pulmonary venous flow.

Groups	Measured parameter								
	S (m/sec)	VTI S	D (m/sec)	VTI D	A (m/sec)	VTI A	A-R (sec)	R-D (sec)	DT (sec)
Infants									
Mean inspiration	0.61 ± 0.14	11.17 ± 3.22	0.47 ± 0.076	6.32 ± 2.00	0.31 ± 0.065	2.41 ± 0.70	0.073 ± 0.020	0.36 ± 0.047	0.24 ± 0.040
Mean expiration	0.56 ± 0.13	10.71 ± 3.35	0.45 ± 0.088	6.31 ± 1.98	0.29 ± 0.062	2.26 ± 0.76	0.073 ± 0.021	0.36 ± 0.047	0.24 ± 0.041
Total mean	0.59 ± 0.13	10.94 ± 3.17	0.46 ± 0.078	6.31 ± 1.91	0.30 ± 0.060	2.33 ± 0.71	0.073 ± 0.019	0.36 ± 0.046	0.24 ± 0.040
Preschool children									
Mean inspiration	0.78 ± 0.18	17.64 ± 4.24	0.53 ± 0.110	8.03 ± 2.00	0.32 ± 0.11	2.67 ± 1.05	0.083 ± 0.025	0.45 ± 0.060	0.28 ± 0.055
Mean expiration	0.73 ± 0.15	17.19 ± 3.56	0.50 ± 0.097	8.15 ± 2.09	0.31 ± 0.067	2.56 ± 0.87	0.093 ± 0.027	0.45 ± 0.035	0.30 ± 0.082
Total mean	0.76 ± 0.15	17.42 ± 3.63	0.52 ± 0.097	8.09 ± 1.75	0.31 ± 0.081	2.61 ± 0.85	0.082 ± 0.025	0.45 ± 0.039	0.29 ± 0.063
School aged children									
Mean inspiration	0.65 ± 0.14	16.27 ± 3.62	0.48 ± 0.095	8.58 ± 2.28	0.29 ± 0.092	2.63 ± 0.82	0.082 ± 0.032	0.46 ± 0.071	0.36 ± 0.075
Mean expiration	0.64 ± 0.14	15.38 ± 3.11	0.47 ± 0.110	9.06 ± 2.43	0.29 ± 0.087	2.76 ± 1.00	0.084 ± 0.032	0.47 ± 0.052	0.40 ± 0.110
Total mean	0.64 ± 0.14	15.83 ± 3.23	0.48 ± 0.095	8.82 ± 2.11	0.29 ± 0.086	2.70 ± 0.87	0.083 ± 0.031	0.47 ± 0.059	0.38 ± 0.088
Adolescents									
Mean inspiration	0.71 ± 0.18	17.49 ± 3.92	0.55 ± 0.15	11.41 ± 3.22	0.31 ± 0.077	3.13 ± 0.90	0.11 ± 0.020	0.49 ± 0.038	0.38 ± 0.074
Mean expiration	0.70 ± 0.20	17.75 ± 4.91	0.54 ± 0.13	11.44 ± 3.19	0.31 ± 0.087	3.13 ± 0.87	0.11 ± 0.019	0.50 ± 0.027	0.40 ± 0.095
Total mean	0.70 ± 0.19	17.62 ± 4.35	0.55 ± 0.13	11.43 ± 3.06	0.31 ± 0.081	3.13 ± 0.82	0.11 ± 0.018	0.49 ± 0.030	0.39 ± 0.080

Abbreviations: S: systolic flow; D: early diastolic flow; A: flow during atrial contraction; VTI: velocity–time integral; A-R: interval between atrial flow and R wave on ECG; R-D: interval between R wave on ECG and diastolic flow; DT: diastolic time (interval from the beginning of early diastolic wave to the end of atrial contraction wave)

Comparing the parameters for superior caval and hepatic venous flow showed that peak systolic flows and reverse atrial flows had significant, but weak, correlations with each other ($p < 0.05$, $r = 0.5$ for atrial flows; $r = 0.4$ for systolic flows). On the other hand, diastolic flows were not correlated in the systemic veins. There was no correlation between flows into the right as opposed to the left atriums.

None of the indexes of Doppler flow, nor the timed events, was influenced by sex ($p > 0.05$). Age, however, had important effects on the systolic flow and the reverse atrial flow in the superior caval vein, but only the inspiratory systolic flow in the hepatic vein was significantly influenced by age ($p < 0.05$). All these parameters decreased significantly with age, yet only the systolic flow in the superior caval vein had a weak significant correlation with age ($p < 0.05$, $r = -0.43$). All pulmonary venous velocities were similar in all age groups ($p > 0.05$).

None of the velocities were correlated with the index of body mass ($p > 0.05$). The systolic flow in the right atrium was weakly correlated with heart rate ($p < 0.05$; $r = 0.3$ for hepatic vein and $r = 0.45$ for superior caval vein).

Among the timed events, diastolic times, and the intervals between ventricular systole and early diastole had good correlation with each other for all the veins ($p < 0.05$, $r = 0.8$ for all the values), whereas the interval between atrial contraction and ventricular systole had weaker correlations ($p < 0.05$, $r = 0.5$ for all the values). All the timed events were negatively correlated with heart rate ($p < 0.05$; $r = -0.85$ for diastolic time, $r = -0.8$ for the interval between ventricular systole and early diastole, and $r = -0.35$ for the interval between atrial contraction and ventricular systole), and positively correlated with age ($p < 0.05$; $r = 0.7$ for diastolic time, $r = 0.8$ for the interval between ventricular systole and early diastole, and $r = 0.3$ for the interval between atrial contraction and ventricular systole).

Discussion

Our study was designed to determine the indexes of superior caval, hepatic, and pulmonary venous flow as measured using Doppler echocardiography in infants and children. Such studies have been made for the superior caval vein,[11–13] the hepatic vein,[14–17] and the pulmonary vein[18–20] in adults, but as far as we know, such indexes have yet to be provided for a large group of normal children. The studies carried out in adults showed that the normal pattern of flow was triphasic, with systolic velocity amplitude greater than that of diastolic velocity, and minimal reversal occurring with atrial contraction.[10–20] We found similar patterns in our group of children.

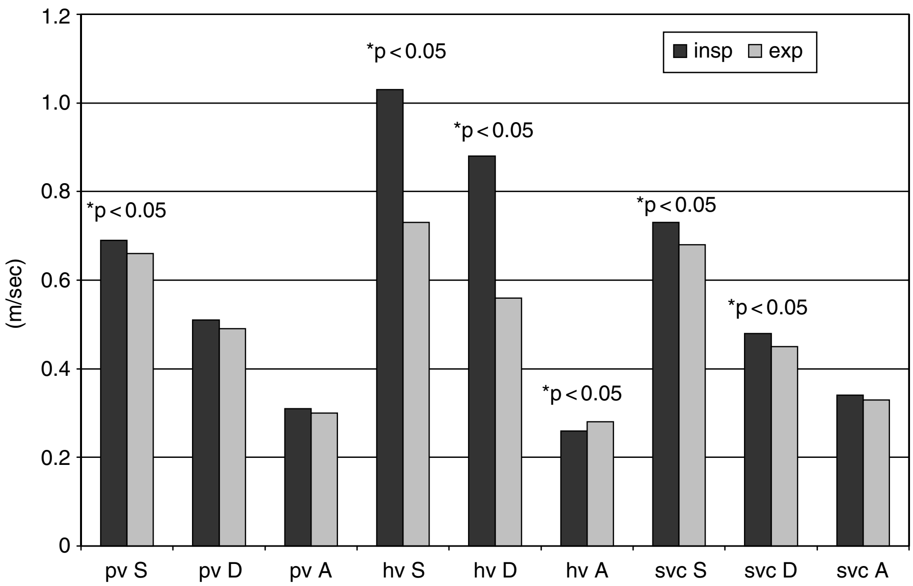

Figure 4.
Change in measurements with respiration. pv: pulmonary vein, hv: hepatic vein, svc: superior caval vein; S: peak systolic flow; D: peak diastolic flow; A: peak reverse atrial systolic flow. $^{*}p < 0.05$*: change with respiration is statistically significant.*

The systolic flow in the superior caval vein, and the reversed atrial flow, decreased with age. This is in keeping with the findings of Salim et al.,[21] who demonstrated an age dependent relationship of the superior caval venous contribution to the total cardiac output. They found that this contribution was 49% at birth, and had increased to 55% by the age of 2.5–3 years. Afterwards, it declined, presumably as the inferior caval venous contribution increased. Since the newborn babies are not considered in a separate group in our study, and all the children less than 2 years old are included in one group, the increase in the contribution of superior caval vein to the cardiac output could not be observed. The subsequent expected decrease, however, was evident in our population.

While the inspiratory systolic flow in the hepatic veins significantly decreased with age, the expiratory component did not change. One reason could be that liver compliance is greater in children than in adults. Accordingly, the range and value of hepatic venous velocities vary more in children.[10] Changes in hepatic venous velocities with age, therefore, were less remarkable than those measured in the superior caval vein. On the other hand, the respiratory changes were most prominent in the hepatic vein, with a mean decrease in systolic flow of 26%, compared to decreases of 5.7% and 3.9% in the superior caval and pulmonary veins, respectively. The pulmonary diastolic flows did not change with respiration, whereas peak diastolic flow in the hepatic and superior caval veins increased. This is due to the augmentation of the right ventricular filling with inspiration. The mechanisms proposed for this include the increase in systemic afterload secondary to negative pleural pressure, and the shift in position of the ventricular septum towards the left ventricle following the increased right ventricular filling. Furthermore, the increase in venous capacitance of the pulmonary vessels creates a relatively decreased left ventricular inflow.[22] The larger tricuspid valvar orifice may also contribute to the increased diastolic inflows to the right atrium.[23] The reverse atrial flow in the hepatic vein was slightly increased in inspiration, which may be attributed to the increased right atrial pressure in inspiration with the increased right ventricular filling. Zhang-An et al.[3] have observed that patients with increased right heart pressures, as in pulmonary hypertension, had higher reversed atrial velocities in the hepatic vein.

The patterns of pulmonary venous flow, except for the systolic flow, were unaltered by respiration and all the velocities were uniform at all ages. Aging causes an increase in pulmonary venous systolic and atrial contraction flows, together with a decrease in pulmonary diastolic flow in adults, owing most likely to the decreased compliance and relaxation of the left ventricle with age.[24] As children get older, however, the velocities in the pulmonary veins are not significantly changed. One may hypothesize that the patterns of left ventricular compliance and relaxation possibly start deteriorating after adulthood, and do not represent a continuous process from birth.

Among all the measured velocities of flow, only the systolic flow in the right atrium was weakly correlated with heart rate. The lower difference in pressure between the right atrium and right ventricle contributes to the slower relaxation of the right ventricle in diastole. The increased heart rate while decreasing the diastolic filling time may augment the systolic filling fraction of the right atrium as the tricuspid annulus moves towards the apex.[25]

The differences in the measured timed events, namely the interval between atrial and ventricular contractions, the interval between ventricular contraction and early diastolic flow, and the diastolic time, were significant among all the age groups. The duration of these events increased with age as the heart rate decreased. Diastolic time, and the interval between ventricular contraction and diastolic flow, had good negative correlation, while the interval between atrial and ventricular contractions had weaker correlation with heart rate. Similar, but positive, correlations were observed between these timed intervals and age. This was primarily attributed to the decrease in heart rate that is normally observed as the child gets older. On the other hand, although the heart rate of the subjects studied significantly decreased in expiration, the duration of these events was similar in inspiration and expiration. The impact of respiration on the heart rate is probably less obvious and short lived than the change observed in heart rate with age. The timed events, therefore, are influenced more by age-related changes in heart rate.

There is limited data currently available concerning the patterns of venous flow in disease states, and how they differ from normal. The studies available are mostly related to the hemodynamic changes after establishment of the Fontan circulation, where there is marked respiratory dependence of systemic and hepatic venous return, and where detrimental effect of gravity on the lower body venous return is significant.[26–29] Understanding the normal hemodynamic in healthy individuals will surely make easier the understanding of the complex hemodynamic states in pre-and-post operative patients with congenital cardiac malformations.

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