Echocardiographic Indices of Doppler Flow Patterns Compared with MRI or Angiographic Measurements to Detect Significant Coarctation of the Aorta

D. Scott Lim, M.D.,* and Michael A. Ralston, M.D., F.A.C.C.†

*Department of Pediatric Cardiology, Michigan Congenital Heart Center, University of Michigan, Ann Arbor, Michigan, and †Department of Pediatrics, Division of Pediatric Cardiology, Wright State University School of Medicine, Dayton, Ohio

Evaluation for the presence and severity of coarctation of the aorta (CoA) by two-dimensional echocardiography alone can be difficult. The purpose of this study was to use Doppler velocity and pressure gradient half-time in systole and diastole to estimate CoA severity. Doppler echocardiograms of children with suspected CoA and either an aortic angiogram or thoracic magnetic resonance imaging (MRI) performed within 1 month of the echocardiogram were evaluated. Patients with patent ductus arteriosus, significant aortic insufficiency, long tubular CoA, or CoA outside the thorax were excluded. Measured Doppler variables, indexed for heart rate, included systolic velocity half-time (sVHTi), diastolic velocity half-time (dVHTi), systolic pressure half-time (sPHTi), and diastolic pressure half-time (dPHTi). For each of these variables, sensitivity and specificity to detect a significant CoA were determined. A significant CoA was defined as a ratio of the CoA diameter to the diaphragmatic aortic diameter of < 0.5 as imaged by MRI or angiography. Indexed systolic velocity and pressure half-times were found not to be significant predictors for CoA. For the Doppler parameter dVHTi, using a critical value of > 200 msec indexed, we found a positive predictive value of 87% and a negative predictive value of 80%. The parameter dPHTi, using a critical value of > 75 msec indexed, demonstrated positive and negative predictive values of 92% and 79%, respectively. Measurement of dVHTi is a useful predictor for significant CoA, but the parameter dPHTi has an improved positive predictive value for detection of significant CoA. Systolic measurements of velocity or pressure half-times are not adequate to assess severity of CoA. (ECHOCARDIOGRAPHY, Volume 19, January 2002)

coarctation of the aorta, echocardiography, velocity half-time, pressure half-time

Many patients with suspected coarctation of the aorta (CoA) can be adequately evaluated by two-dimensional echocardiography.[1,2] When the thoracic aorta is not well-visualized by two-dimensional echocardiography, however, other techniques must be employed to evaluate the significance of the lesion.[3] One such technique is the analysis of the Doppler signal across the stenotic area.[4] Traditionally, this involves measuring the peak systolic gradient across the coarctation site using either the simplified or expanded Bernoulli equation.[5-7] Recently, investigators proposed other measurements of the Doppler signal, such as velocity half-times.[1,8] Analysis by Doppler echocardiography of the decay in pressure across a stenotic lesion was applied originally to mitral valve lesions.[9,10] Previous investigators have noted that across a significant CoA, there is a prolongation of flow into diastole.[11,12] Carvahlo et al.[8] published an analysis of CoA using both systolic gradient and diastolic velocity decay. They found that severe lesions could be predicted by demonstrating a high systolic gradient and a prolonged diastolic velocity half-time (dVHTi).

Problems remain in identifying those patients with less severe systolic gradients as predicted by Doppler, but still demonstrating a severe CoA by angiography. To date, other Doppler parameters, such as pressure half-

Address for correspondence and reprint requests: Scott Lim, M.D., CS Mott Children's Hospital, University of Michigan, Medical Center, F1310 MCHC, Box 0204, 1500 East Medical Center Drive, Ann Arbor, MI 48109-0204. Fax: 734-936-9470; E-mail: scottlim@umich.edu

time, have not been utilized in determining the severity of CoA. The purpose of this study was to assess the utility of velocity and pressure half-times in systole and diastole to estimate CoA severity.

Methods

Data from patients at our institution suspected of having a CoA during a recent 7-year period were reviewed retrospectively. Echocardiographic and radiographic (either angiography and/or magnetic resonance imaging [MRI]) studies performed < 1 month apart and with no intervening surgical therapy were analyzed. Patients with lesions affecting the pre-CoA velocity (patent ductus arteriosus, aortic regurgitation, or pseudocoarctation) were excluded. Patients with long-segment CoA were excluded due to the significant effect of viscosity in long-tunnel obstructions leading to inaccuracies in the Doppler-derived pressure gradient measurement.[13]

The echocardiograms and their analyses were performed using Hewlett-Packard ultrasound imaging systems (Sonos 2500, Hewlett-Packard, Inc., Andover, MA, USA). All echocardiograms evaluated in the study utilized both pulsed and continuous-wave Doppler across the CoA segment. The best tracing, as judged by the authors, was used to determine the Doppler variables used in the study. Echocardiographic variables measured during both systole and diastole included peak Doppler velocities, pressure gradients calculated using the simplified Bernoulli equation, velocity half-times, and pressure gradient half-times. Velocity half-time is the time in milliseconds for the velocity to fall to one-half of its peak value (Fig. 1). Pressure half-time was the time in milliseconds for the pressure gradient to fall to $4V^2 / 2$ (Fig. 2). Both velocity and pressure half-times

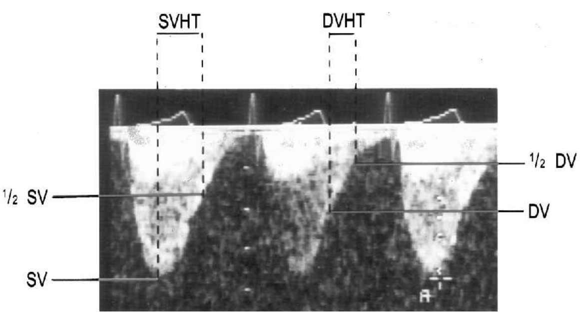

Figure 1. *Diagram of systolic and diastolic velocity half-times.*

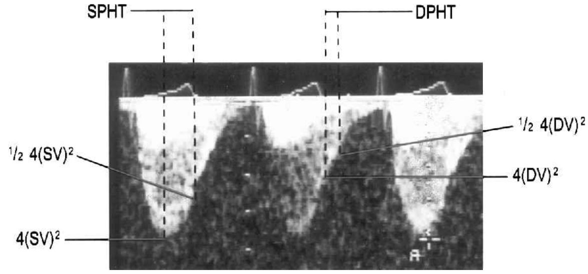

Figure 2. *Diagram of systolic and diastolic pressure half-times.*

were then indexed for heart rate by dividing the half-time by the square root of the electrocardiographic R-R interval.[14]

All echocardiographic studies had simultaneous electrocardiographic monitoring. Onset of diastole was defined as the end of the electrocardiographic T wave. Measurements of peak velocity and peak pressure were measured during both systole and diastole. In all of the echocardiogram studies evaluated, the Doppler low pass filters were set so the lower velocity Doppler signals could be evaluated. Any echocardiogram that had the low pass filters set so as to eliminate this portion of the Doppler spectrum were excluded from the study.

Significant narrowing at the CoA site was defined by a Fredriksen's index of obstruction < 25%.[1] This index is the ratio of the CoA cross-sectional area to that of the aorta at the diaphragm. This is equivalent to a ratio of < 50% of the diameter of the CoA to the diameter of the aorta at the diaphragm. Measurements for this index were taken from either lateral angiograms or thoracic MRI. All MRIs were done utilizing electrocardiogram-gated spin echo and gradient echo MRIs. These images were obtained in multiple planes and angles to obtain the optimal image of the coarctation area.

Analysis of echocardiograms (DSL) and radiographic studies (MAR) was performed with each investigator blinded to the results of the comparative study.

For each of the variables under study, mean and standard deviation were calculated. Using Student's *t*-test, significant difference was defined as $P < 0.05$. For statistical analysis, positive predictive value was defined as the ability of a measured variable to predict a significant CoA, and the negative predictive value was defined as the ability to predict a nonsignificant CoA.

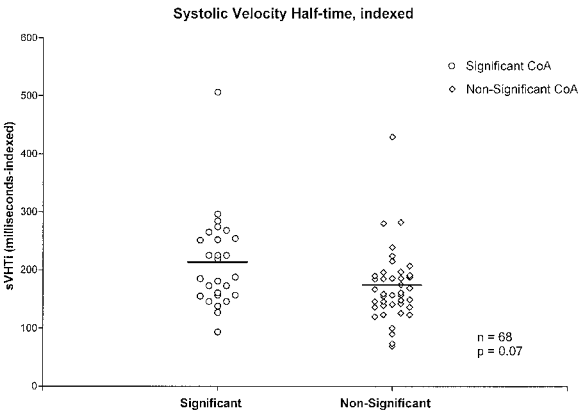

Figure 3. *Systolic velocity half-time (sVHTi) indexed for heart rate in patients with a significant versus nonsignificant coarctation of the aorta.*

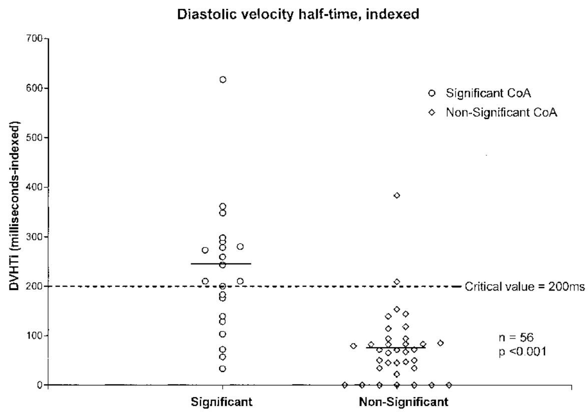

Figure 4. *Diastolic velocity half-time (dVHTi) indexed for heart rate in patients with a significant versus nonsignificant coarctation of the aorta.*

Results

Demographics

Sixty-eight consecutive patients with suspected coarctation or recoarctation of the aorta met inclusion criteria. There were 40 (58%) males and 28 (42%) female patients. Ages ranged from 2 days to 17 years, with a mean of 4.0 years (median of 1.7 years). Seventy-four percent of patients had an angiogram and 26% had an MRI as their comparative anatomic study.

Echocardiographic Data

The systolic velocity half-time (sVHTi) indexed for heart rate measurements was compared to the ratio of the aortic diameters at the CoA and diaphragm (Fig. 3). Data from 68 patients were analyzed. Significant CoA was present in 27 patients. There was no significant difference between the mean value for the data between this group and those patients with nonsignificant CoA ($P = 0.07$).

The dVHTi indexed for heart rate was compared to the ratio of the aortic diameters at the CoA and diaphragm. (Fig. 4) Data from 56 patients were analyzed. The remaining 12 patients had electrocardiograms that did not have definable ends of the T waves, and therefore, were not included in this measurement. Significant CoA was present in 21 of these patients. A dVHTi ≥ 200 msec indexed was noted in 65% of the significant CoA patients, but only in 6% of the patients with nonsignificant CoA. The mean dVHTi was 246 ± 120 msec indexed for significant CoA and 75 ± 73 msec indexed for nonsignificant CoA ($P < 0.001$). Therefore, a critical value of 200 msec indexed would yield a positive predictive value of 87% and a negative predictive value of 80%.

Comparison was done between measurements of pressure half-times in systole (sPHTi) indexed for heart rate and the ratio of the aortic diameters at the CoA and diaphragm (Fig. 5). Data from 68 patients were analyzed. Significant CoA was present in 27 patients. There was no significant difference between the mean values for the sPHTi data between this group and those patients with nonsignificant CoA ($P = 0.18$).

Measurements for diastolic pressure half-time (dPHTi) indexed for heart rate were compared to the ratio of the aortic diameters at the CoA and diaphragm (Fig. 6). Data from 56 pa-

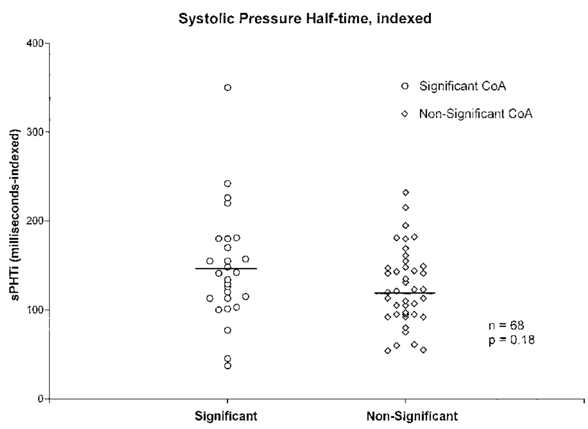

Figure 5. *Systolic pressure gradient half-time (sPHTi) indexed for heart rate in patients with a significant versus nonsignificant coarctation of the aorta.*

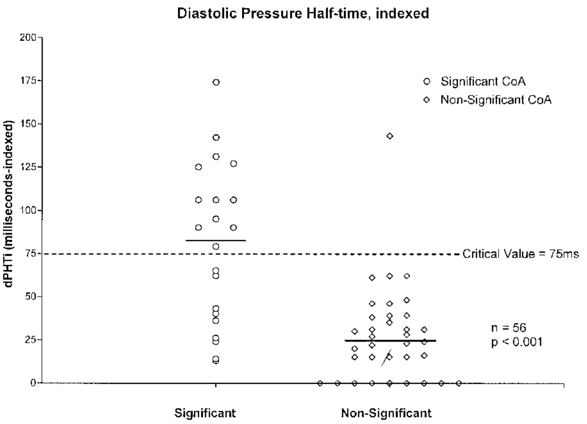

Figure 6. *Diastolic pressure gradient half-time (dPHTi) indexed for heart rate in patients with a significant versus nonsignificant coarctation of the aorta.*

tients were analyzed. Significant CoA was present in 21 patients. A dPHTi 75 msec was noted in 57% of the significant CoA patients, but in only 3% of the patients with nonsignificant CoA. For the evaluation of these measurements, a critical value of 75 msec indexed was used, as it yielded the highest positive and negative predictive values. Using this critical value, only one patient was identified incorrectly as having a significant CoA. In evaluating significant CoA, the mean dPHTi was 81 ± 46, while for nonsignificant CoA, the mean dPHTi was 27 ± 27 ($P < 0.001$). Therefore, a critical value of 75 msec indexed would yield a positive predictive value of 92% and a negative predictive value of 79%.

Discussion

Velocity half-time measurements were first applied to determine the significance of mitral stenosis.[9,10] The application of this technique was first extended to CoA by Carvalho et al. in 1990.[8] They demonstrated that a dVHTi greater than 100 msec but not indexed to heart rate and coupled with a peak systolic gradient > 40 mmHg was highly sensitive and specific for identifying significant CoA. Since then, there is a paucity of published data regarding this technique in analysis of CoA. In addition, no published data exist regarding the use of pressure half-time in CoA. The purpose of this study was to evaluate the predictive value of both velocity and pressure half-times in patients with suspected CoA.

Patients with CoA can present across a wide age range, and therefore, with a wide range in heart rates. Since the measurement of these Doppler variables can be influenced by the length of the cardiac cycle, this study attempted to correct for this using Bazett's correction factor of the square root formula. This normalized the data range to a standard heart rate, and therefore, allowed comparison across a wide range of heart rates. However, other investigations have demonstrated that this correction factor might be inadequate with the lower heart rates of adolescents.[15]

Based on the data from this study, systolic measurements of velocity and pressure half-times are not useful in predicting a significant CoA. The parameters of ventricular systolic performance and degree of obstruction determine the systolic pressure gradient as estimated by Doppler echocardiography. As the obstruction becomes more severe, the pressure gradient increases, eventually extending into diastole. The duration of velocity, and therefore, pressure decay through an obstruction in systole is affected more by parameters of cardiac function rather than by absolute degree of the obstruction. The use of these systolic parameters results in inherent inaccuracies in the evaluation of suspected CoA. Therefore, diastolic parameters may be a more useful adjunct in evaluating the severity of CoA.

In this study, diastolic measurements were much more useful in predicting a significant CoA. A dVHTi of greater than 200 msec indexed was found to be highly predictive of a significant CoA (the positive and negative predictive values were 87% and 80%, respectively). By utilizing the dVHTi, only two patients in this study would have been identified incorrectly as having a significant CoA. However, 20% of the patients with a significant CoA would have been identified falsely as having a nonsignificant CoA by this parameter.

The diastolic decay of the pressure gradient was analyzed to determine if it improved prediction of significant CoA. The positive and negative predictive values were 92% and 79%, respectively. Only one patient in this study would have been incorrectly identified as having a significant CoA by utilizing dPHTi. By using dPHTi, an investigator can be reasonably certain of the diagnosis of CoA when the value is greater than 75 msec indexed. However, it is less specific in discriminating between the significant and nonsignificant CoA when the dPHTi is less than 75 msec indexed, as there is a 21% false negative rate.

This study used as a gold standard either

MRI or angiography. In prior studies,[16] an extremely high correlation (r = 0.97) was found between these two modalities to determine coarctation diameters. For determination of severity of the CoA, Fredriksen's index of obstruction[1] was utilized, as it has been referenced by other investigators evaluating CoA.[8,16]

Limitations of this study include using the simplified Bernoulli equation rather than the modified Bernoulli equation to calculate pressure gradients. For pre-CoA velocities of less than one m/sec, the simplified Bernoulli equation has been generally accepted as accurate.[5] However, using both pre- and post-CoA velocities to calculate the pressure gradient would allow measurement of the decay to be further along the tail of the decay curve. This may better help to distinguish significant versus nonsignificant CoA. This retrospective study did not have sufficient numbers of patients with pre-CoA velocities measured in order to make this statistical evaluation. A prospective evaluation would focus on this data acquisition and is warranted.

An additional study limitation is that the patients were not sedated uniformly. The infants and toddlers undergoing the echocardiograms received sedation to ensure a technically good-quality echocardiogram. The older children were not sedated for their echocardiograms, but were in the calm physiologic state. Since there is a potential for difference in hemodynamic status and therefore, measurement of the Doppler-derived pressure gradient between the sedated infant and unsedated but still physiologically calm older child, this should be noted. However, these levels of sedation and hemodynamic states will be similar to those encountered in the clinical setting, and therefore, this data still bears relevance. Additionally, the gold standard used in this study (MRI or angiogram) evaluated the degree of anatomic narrowing of the coarctation. This type of measurement was not influenced by the level of sedation.

This study also does not adequately address the evaluation of patients with significant collateralization of their CoA. The assumption was made that in the adolescent patient presenting with a diagnosed coarctation, there would have been the formation of collaterals over time. Thus, a difference in the Doppler decay profiles of these patients in comparison with younger patients might be expected. However, this study does not have the necessary number of adolescent patients to appropriately evaluate this assumption. Further investigation specifically evaluating this subset of patients is needed.

Conclusion

Diastolic Doppler variables make a useful adjunct in the assessment of the patient with suspected CoA. As has been previously shown,[8] dVHTi is particularly useful in predicting significant CoA. Diastolic pressure half-time, when indexed for heart rate, provides a more sensitive predictor for significant CoA when the dPHTi is greater than 75 msec indexed. Its ease of use coupled with high positive and negative predictive values allow the clinician to accurately diagnose significant CoA.

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