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ORIGINAL ARTICLE

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Systolic/diastolic ratio correlates with end diastolic pressures in pediatric patients with single right ventricles

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Abstract

Background: Increased ventricular end-diastolic pressure (VEDP) is a known risk factor for morbidity and mortality in patients with single right ventricle (RV) physiology. Previous studies have shown mixed results correlating echocardiographic measurements with catheter-derived VEDP in this population. Goal of this study was to evaluate if echocardiographic systolic/diastolic ratio (S/D) correlated with VEDP.

Methods: Patients with single RV physiology who underwent simultaneous echocardiography and catheterization were evaluated. Systolic and diastolic durations were measured using tricuspid inflow durations from Doppler analysis to calculate the S/D ratio. VEDP was obtained from the catheterization report.

Results: Twenty-seven studies were performed on patients with single RV physiology. Median age at time of catheterization was 11.4 months (range, 0-132 months). Mean VEDP was 9.9 ± 4.5 mm Hg. S/D ratio was 1.8 ± 0.5. S/D ratio significantly correlated with VEDP ($r = 0.63$, $P < .01$). Optimum value of S/D ratio for discriminating between patients with high (>10 mm Hg) vs low EDP was found to be 1.9. High S/D ratio had an area under the curve of 0.82 (0.65, 1.0), with 75% sensitivity and 89% specificity for predicting elevated VEDP.

Conclusion: In patients with single RV physiology, S/D significantly correlated with VEDP. S/D ratio is a simple technique that may be useful in both estimating and discriminating between high and low VEDP in this complex patient population.

KEYWORDS

catheterization, echocardiography, hypoplastic left heart syndrome, single right ventricle, systolic/diastolic ratio

1 | INTRODUCTION

Elevated ventricular end-diastolic pressure (VEDP) is a marker for diastolic dysfunction. Increased VEDP is a known to be associated with morbidity and mortality in patients with single ventricle physiology.[1-4] Cardiac catheterization is the gold standard used to assess VEDP in patients with single ventricle physiology. Estimating VEDP in patients with single right ventricle (RV) physiology using various echocardiographic measurements have had mixed results.[5-7] An easily obtainable noninvasive measurement that could accurately estimate VEDP in the single RV patient population would assist in caring for this complex population.

A relatively new, but simple measurement to evaluate cardiac function in the single RV population is the systolic to diastolic duration ratio (S/D) obtained via Doppler analysis of the tricuspid valve inflow pattern.[8,9] This value is easily obtainable and does not require sophisticated echocardiographic analysis. Correlations between S/D ratio with VEDP in patients with single ventricle physiology have had mixed results in previous publications with significant correlations noted in the adult population, but not in the pediatric population.[8,10]

However, both studies cited were limited by the fact that echocardiographic and catheterization data were not obtained during the same steady state conditions.

The goal of this study was to determine if the S/D ratio in patients with single RV physiology obtained via echocardiography correlated with VEDP obtained via cardiac catheterization under steady state conditions.

2 | METHODS

The institutional review board approved this retrospective study based on previously obtained prospective data.[7] Methods are detailed in the previous report. Briefly, all patients with single RV physiology who underwent cardiac catheterization for any indication were evaluated from the previous study. Patients were excluded if there were poor echocardiographic images, absent or near absent interventricular septum, nonatrial rhythm, or failure to obtain consent.

2.1 | Echocardiographic analysis

All echocardiographic studies were obtained using a Vivid I or Vivid 7 machine (GE Healthcare, Wauwatosa, Wisconsin) after the patient was under general anesthesia and just before the start of the cardiac catheterization. Views equivalent to a standard apical four chamber were obtained (Figure 1). Postprocessing of all images was completed offline using the EchoPAC version10 (GE Healthcare). All measurements were made in triplicate by a single observer blinded to the results of the cardiac catheterization measurements.

To obtain the S/D ratio, the Doppler inflow pattern of the tricuspid valve was evaluated by a single observer (CC) blinded to the catheterization results. The systolic interval was defined as the end of the tricuspid valve A wave to the beginning of the subsequent E wave. Systolic time interval thus included the isovolumetric relaxation and contraction time as well as the ejection period. The diastolic interval was defined as the beginning of the tricuspid valve E wave used for the systolic measurement to the end of the tricuspid valve A wave (Figure 2).[11] This would thus encompass one cardiac cycle.

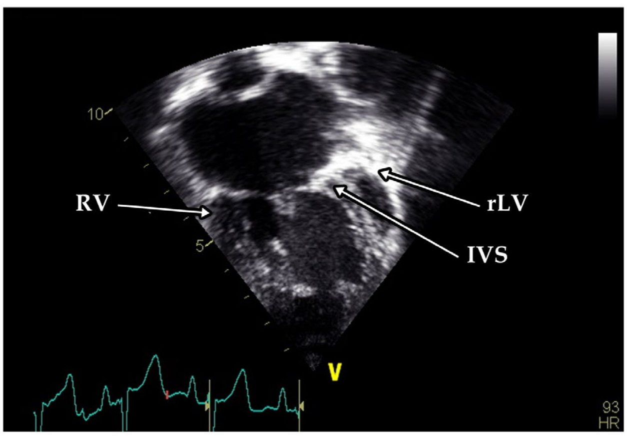

FIGURE 1 Apical four-chamber view. Abbreviations: IVS, interventricular septum; RV, right ventricle; rLV, rudimentary left ventricle

2.2 | Cardiac catheterization

All hemodynamic measurements were obtained under general anesthesia under the same steady state conditions as for the echocardiography. VEDP of the single RV was measured on the ventricular pressure tracing as the point just before the rapid rise in ventricular pressure corresponding to ventricular systole. VEDP numeric values were obtained from the cardiac catheterization reports. All cardiac catheterization data were obtained before any interventional procedure was performed.

2.3 | Statistical analysis

Associations were assessed using Pearson correlation coefficients and linear regression. Logistic regression with ROC curve analysis was used to estimate area under the receiver operator characteristic curve (AUC) values, and an optimum threshold of S/D ratio for discriminating between patients with high (>10 mm Hg) vs low (≤10 mm Hg) V EDP was determined using Youden's J statistic. Intraclass correlation coefficients were used to evaluate intrarater reliability. All analyses were conducted using SAS 9.4 (SAS Institute, Cary, North Carolina) with two-sided P values $< .05$ considered statistically significant.

3 | RESULTS

As previously noted, 40 patients were enrolled and 13 studies were excluded.[7] There were no significant differences in baseline characteristics between the excluded patients compared to the included patients. A total of 27 studies were thus included for analysis. Baseline demographics are presented in Table 1. Individual data for the patients have previously been presented.[7] Most patients had the diagnosis of hypoplastic left heart syndrome. The majority of patients were in their early postoperative period from the hybrid stage I procedure with the rest being either postoperative comprehensive Stage II procedure/Glenn or Fontan procedure.[12-14]

Systemic arterial oxygen saturation was 78% ± 10%, heart rate was 129 ± 21 bpm, and VEDP was 9.9 ± 4.5 mm Hg. Eight patients had VEDP > 10 mm Hg. Echocardiographic systolic duration was 298 ± 46 ms, diastolic duration was 182 ± 56 ms, and S/D was 1.8 ± 0.5.

S/D ratio significantly correlated with VEDP ($r = 0.6$, $P < .01$) (Figure 3). S/D ratio also had a good ability to discriminate patients with a high (>10 mm Hg) VEDP from a low (≤10 mm Hg) V EDP. Prior to categorizing S/D ratio, AUC was 0.81 (0.61, 1.0). The optimum value of S/D ratio for discriminating between patients with high vs

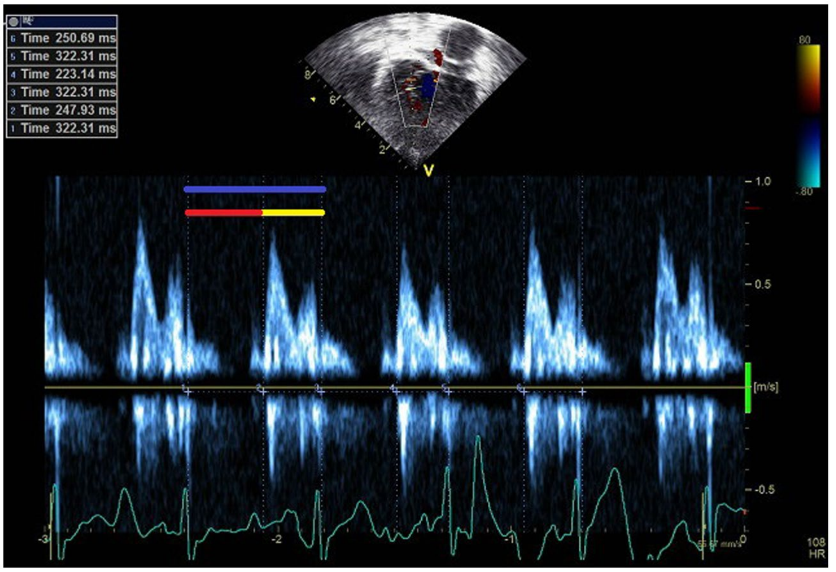

FIGURE 2 Duration measurements. Purple bar = one complete cardiac cycle; red bar = systolic duration, that is, isovolumetric contraction + ejection period + isovolumetric relaxation time; yellow bar = diastolic duration

TABLE 1 Baseline demographics

Age (month), median (range)	11.4 (0-132)
Male: female	17:10
Clinical diagnosis	
Hypoplastic left heart syndrome	20
Double outlet right ventricle	5
Unbalanced atrioventricular septal defect	2
Surgical palliation	
Hybrid stage I	12
Comprehensive Stage II/bidirectional Glenn	7
Fontan	8

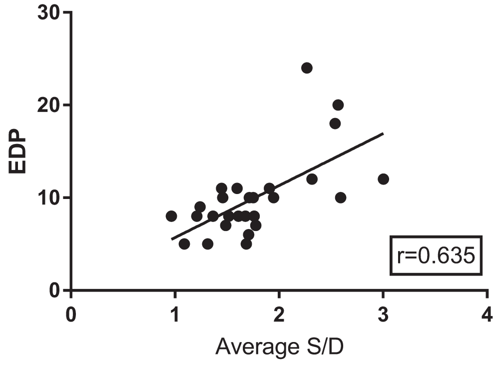

FIGURE 3 Correlation between EDP vs S/D. Abbreviations: EDP, end diastolic ventricular pressure; S/D, systolic/diastolic duration ratio

low EDP was found to be 1.9. High S/D ratio had an AUC of 0.82 (0.65, 1.0), with 75% sensitivity and 89% specificity (Figure 4).

Intrarater reliability values using intraclass correlation coefficients (95% confidence intervals) was 0.94 (0.89, 0.97) for S/D ratio, 0.95 (0.91, 0.98) for systolic duration, and 0.98 (0.96, 0.99) for diastolic. ICC values > 0.75 show excellent reliability.

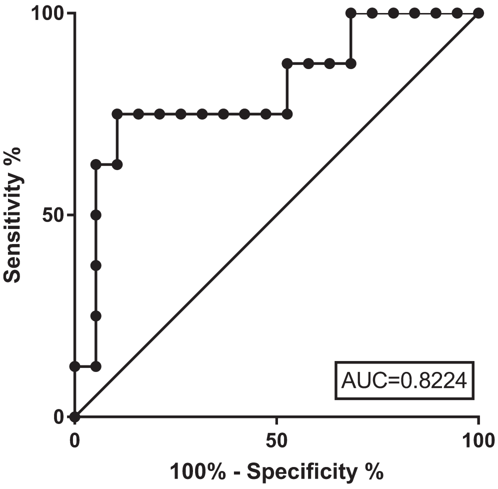

FIGURE 4 ROC curve. AUC, area under the curve. Abbreviation: ROC, receiver operator characteristic curve

4 | DISCUSSION

Evaluating diastolic function in patients with single ventricle physiology noninvasively is usually subjective despite the fact that diastolic dysfunction may be associated morbidity and mortality in this complex patient population.[1-4,15,16] Previous studies have shown mixed results with correlating echocardiographic values with catheterization VEDP.[5-8,10] In this study, S/D ratio correlated significantly with catheter derived VEDP in patients with single RV physiology.

In the previous study using the exact same patient population, atrioventricular valve inflow A wave (r = 0.48), global strain rate e wave (r = −0.52), global strain rate e wave/global strain rate a wave (r = −0.42), and atrioventricular valve E wave/global strain rate e wave (r = 0.88) were the only values that had significant correlation with VEDP.[7] However, only atrioventricular valve E wave/global strain rate e wave had a better correlation than the S/D ratio with

VEDP. Though the former value had better correlation, the ability to obtain this value is somewhat limited by image quality. Deformation analysis is limited by the need to have relatively high frame rates in relation to heart rate to allow adequate tracking. In addition, there is a relatively high noise to signal output when obtaining strain rate values. The initial report excluded 5/40 patients due to poor image quality. In contrast, no patient was excluded from this study because obtaining the inflow velocity Doppler pattern is a relatively simple process. This would suggest that despite the slightly lower correlation for the S/D ratio compared to the deformation indices, the S/D ratio may be more practical measurement to obtain in this patient population when attempting to estimate VEDP.

In previous reports, the tricuspid regurgitation jet Doppler pattern was obtained via continuous wave Doppler. This led to exclusion of some patients because of an inadequate regurgitation jet pattern.[8,9,17] In this report, the tricuspid valve inflow pattern was used for timing purposes, thus negating the need for tricuspid regurgitation. Despite this slight difference in technique, the timing parameters were exactly the same as previously described.[11] We do not believe this change in technique significantly affected the general results since the main concept was maintained and the overall durations measured were equivalent to previous reports.

Only two previous reports have evaluated correlations between the S/D ratio and VEDP in patients with single ventricle physiology, one in a pediatric population and the other in an adult population.[8,10] There was no correlation between S/D ratio and VEDP in the pediatric article.[8] This may be due to the fact that the echocardiogram and catheterization data were not obtained at the same procedure and thus hemodynamics were likely not equivalent. Catheterization data were used in this latter article if it was performed within 60 days. Though not explicitly stated, it could be assumed that the echocardiogram was performed unsedated, whereas the catheterization was likely performed with sedation or general anesthesia considering the age for patients was 3.1 ± 4.5 years in that study. This would significantly change hemodynamics between settings. Conversely, the article evaluating adult patients with single ventricle physiology did find significant correlations between S/D ratio and catheterization VEDP despite the fact that catheterization and echocardiographic data were separated by an average of 57 ± 125 days.[10] The significant correlation noted despite this limitation may be due to the fact that the catheterization procedures were performed with the patient awake, similar to their echocardiogram. It is likely there were less differences in the hemodynamic states during the two procedures, even though the procedures were separated by a significant amount of time.

In the adult article, an S/D ratio > 1.1 had a 100% positive predictive value and a 92% negative predictive value for detecting a VEDP > 10 mm Hg. In this article, an S/D ratio > 1.9 was the optimal value for sensitivity and specificity in detecting VEDP > 10 mm Hg. The higher cutoff value noted in this article is likely due to the differences in heart rates between the two populations. The average heart rate in this study was 129 bpm. The heart rate was not documented in the adult article, but the average age was 29 ± 9 years. One could reasonably assume that the heart rates for those patients would be significantly lower than the 129 bpm in this report. A previous article documented that there was a significant positive correlation between S/D ratio and heart rate.[11] Thus, heart rates likely need to be accounted for if one attempts to use absolute S/D ratios as cutoffs for predicting VEDP > 10 mm Hg.

There were several limitations to this study. The study group was small with heterogeneous anatomic and surgical diagnoses, though all had single-RV physiology. Strong clinical conclusions cannot be definitively made because of the small sample size evaluated, but the correlation presented is promising and deserves further investigation. The small sample size may also limit the amount of confidence in the significant correlation presented and only larger studies will verify if this correlation is reproducible. Because cutoff values were initially obtained in this group to determine VEDP > 10 mm Hg and not tested prospectively in another group of patients with single-RV physiology, the true predictive power of this value has yet to be determined. Provocative measures to increase filling pressures, such as fluid boluses to determine if S/D ratios changed accordingly would have been useful for validation purposes, but this was not performed. Future studies are needed to evaluate the diagnostic performance of specific S/D ratio threshold values for distinguishing patients with VEDP above or below 10 mm Hg at specific heart rate ranges. The technique to obtain timing intervals was not performed exactly as previously described, but for practical purposes as described above, the timing intervals obtained are equivalent to previously published descriptions.

In conclusion, in patients with single RV physiology, S/D significantly correlated with VEDP. S/D ratio is a simple technique that may be useful in both estimating and discriminating between high and low VEDP in this complex patient population. Future studies are needed to determine how useful this measurement is at various heart rates for discerning elevated VEDP.

CONFLICT OF INTEREST

None.

AUTHOR CONTRIBUTIONS

Conception: CLC, NH, JG
Statistics: MMC
Writing and approval: CLC, MMC, NH, RH, JPC, JG
All authors have read and approved the final manuscript.

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