International Journal of Cardiology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Cardiology

journal homepage: www.elsevier.com/locate/ijcard

Evaluation of the relationship between ventricular end-diastolic pressure and echocardiographic measures of diastolic function in adults with a Fontan circulation☆

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ARTICLE INFO

Article history:
Received 8 December 2017
Received in revised form 5 February 2018
Accepted 9 February 2018
Available online xxxx

Keywords:
Fontan
Diastolic function
Echocardiography
Ventricular end-diastolic pressure

ABSTRACT

Background: Echocardiographic assessment of diastolic function in the setting of Fontan physiology is not well validated. We recently demonstrated that atrioventricular systolic to diastolic duration ratio (AVV S/D ratio) independently predicts mortality in Fontan-adults and that a value >1.1 was associated with poor prognosis.
Purpose: To correlate echocardiographic measures of diastolic function with direct measurement of ventricular end-diastolic pressure (VEDP).
Methods: A retrospective analysis was undertaken of Fontan-adults who had transthoracic echocardiography (TTE) within 12 months of direct measurement of VEDP during cardiac catheterisation.
Results: Fifteen Fontan adults (3 males, mean age 29 ± 9 years) were evaluated. Thirteen patients had dominant morphologic left ventricle and 2 had morphologic right ventricle. Four had atriopulmonary connection and 11 had total cavopulmonary connection. Twelve patients were NYHA Class I/II and 3 were Class III. Time between TTE and cardiac catheter was 46 ± 113 days; VEDP was 8 ± 5 mmHg. Ten patients had preserved ventricular function, 3 had mild and 2 had moderate systolic impairment by subjective TTE assessment. AVV S/D ratio had the strongest correlation with VEDP ($r = 0.8$, $p = 0.001$). AVV S/D ratio ≥ 1.1 had 100% positive predictive value and 92% negative predictive value for detecting VEDP >10 mmHg. The only conventional echocardiographic measure of diastolic function that correlated with VEDP was pulmonary vein A wave - atrioventricular A wave duration difference ($r = 0.8$, $p = 0.02$).
Conclusions: TTE measures reflect VEDP in adults with a Fontan circulation. AVV S/D ratio is a simple parameter yet to enter standard practice that can be used to identify elevated VEDP.

1. Introduction

Conventional echocardiographic measures of diastolic function are poorly validated in univentricular Fontan physiology although echocardiography is a central imaging modality for routine assessment in these patients [1]. Furthermore, raised diastolic pressure reduces cardiac filling and worsens systemic venous hypertension with important implications for long-term outcome [2]. We recently reported that atrioventricular systolic to diastolic duration ratio (AVV S/D) was the strongest echocardiographic predictor of survival in a relatively large group of Fontan adults [3]. In this study we sought to investigate whether conventional echocardiographic measures of diastolic function and AVV S/D correlated with ventricular end-diastolic pressure (VEDP) measured invasively at cardiac catheterisation.

2. Methods

2.1. Study design and patients

Adults with a Fontan circulation followed at our tertiary referral centres since January 2010 who had cardiac catheterisation and transthoracic echocardiography (TTE) within 12 months were screened for inclusion. Exclusion criteria were Kawashima repair, supraventricular arrhythmia during testing, pregnancy or paced ventricular rhythm. Clinical

☆ Acknowledgements: Dr. Babu-Narayan is supported by the British Heart Foundation (FS/11/38/28864).
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https://doi.org/10.1016/j.ijcard.2018.02.045
0167-5273/

data were collected from hospital records. Echocardiographic analyses were blinded from clinical data. As this was a retrospective analysis of data collected for routine clinical care, individual informed consent was not required. The study was locally registered and approved for audit.

2.2. Echocardiographic measurements

Our Methods have been described in detail previously [3]. In short, Two-dimensional and Doppler echocardiographic assessments were performed using Vivid 7 (General Electric Healthcare, Milwaukee, WI) and IE-33 ultrasound systems (Philips Medical Systems, Andover, MA) according to the recommendations of the American Society of Echocardiography [4–7]. A single cardiologist with expertise in echocardiography and congenital heart disease interpreted the echocardiographic data except for grading of overall ventricular systolic function that was agreed upon by 2 expert cardiologists to minimise potential confounders in analysis. Dominant ventricular morphology was classed as left ventricular, right ventricular or biventricular. Dominant atrioventricular (AV) valve pulsed-wave Doppler was performed in the best-aligned view with the sample volume placed at the tips of the valve leaflets. Early (E) and late (A) velocities and time intervals, E/A ratio and inflow duration were measured from the AV valve inflow profile. Pulmonary venous velocities and A wave duration were measured from the best-aligned pulmonary venous flow profile with the sample volume placed 0.5 to 1 cm into the vein. The myocardial systolic (S′), early diastolic (E′) and late diastolic (A′) velocities and isovolumic contraction time (ICT), isovolumic relaxation time (IRT) and systolic ejection time were obtained at the lateral dominant atrioventricular valve annulus only by placing a tissue Doppler sample volume at the basal part of the respective segment. No tissue Doppler or long-axis function parameters were analyzed for the ventricular septum because the majority of patients had a ventricular septal defect. Tei Index was calculated from tissue Doppler data as (ICT + IRT)/(systolic ejection time). Durations of systole and diastole were measured from the clearest continuous wave Doppler signal of dominant AV valve regurgitation. Effective systolic duration was measured from the onset to the end of AV valve regurgitation. Effective diastolic duration was measured from the end of AV valve regurgitation to the onset of the subsequent AV valve regurgitation signal. The systolic to diastolic duration ratio (AVV S/D) was then calculated (Fig. 1).

2.3. Cardiac catheterisation

Measurements were taken whilst patients were awake but fasting for at least 4 h prior to the procedure with maintenance intravenous fluids running during the procedure. VEDP was measured via a 6F fluid-filled pig-tail catheter connected to a pressure transducer that had been carefully zeroed at the patient's mid-thoracic level as per our standard practice. VEDP was taken as the point just prior to the rapid upstroke on the ventricular pressure trace that corresponds to contraction and averaged over at least 1 respiratory cycle. A VEDP of 10 mmHg was considered pathological [8,9].

2.4. Cardiopulmonary exercise testing

If maximal cardiopulmonary exercise testing had been performed within 12 months of echocardiography (RER > 1.1), a secondary analysis was undertaken to characterise the relationship between peak oxygen uptake and the most significant echocardiographic measure of VEDP. Symptom-limited maximal exercise tests were performed on an electronically braked ergometer cycle. Carbon dioxide elimination, VO_2, and minute ventilation were measured with a computerised breath-by-breath analyzer as described previously [10].

2.5. Statistical analysis

Statistical analyses were performed using SPSS Version 21 (IBM, New York, United States). Data are reported as number (percentage) for categorical variables and mean ± SD or median [25th, 75th percentile] for continuous variables, as appropriate. Data were tested for normality using the Shapiro-Wilk test. Pearson Product-Moment Correlation was used to assess for a correlation between echocardiographic measures and VEDP. Comparisons between groups were made using Student's *t*-test or Mann–Whitney *U* test as appropriate. A p-value < 0.05 was considered significant.

3. Results

In total, 15 patients were included; 3 were male (20%). Mean age was 29 ± 9 years. Thirteen patients had dominant morphologic left ventricle and 2 had morphologic right ventricle. Four had atriopulmonary connection (APC) and 7 had total cavopulmonary connection (TCPC) with intracardiac tunnel (2 were post adult APC to TCPC conversion) and 4 had extracardiac conduit. Twelve patients were NYHA Class I/II and 3 were Class III. Baseline characteristics are shown in Table 1. Time between TTE and cardiac catheter was 46 ± 113 days. Mean VEDP was 8 ± 5 mmHg. TTE results comparing the groups with VEDP above and below 10 mmHg are shown in Appendix Table 1. AVV S/D was higher (0.85 ± 0.17 in VEDP <10 mmHg vs. 1.33 ± 0.32, p = 0.002) and aortic regurgitation was worse in the high VEDP group.

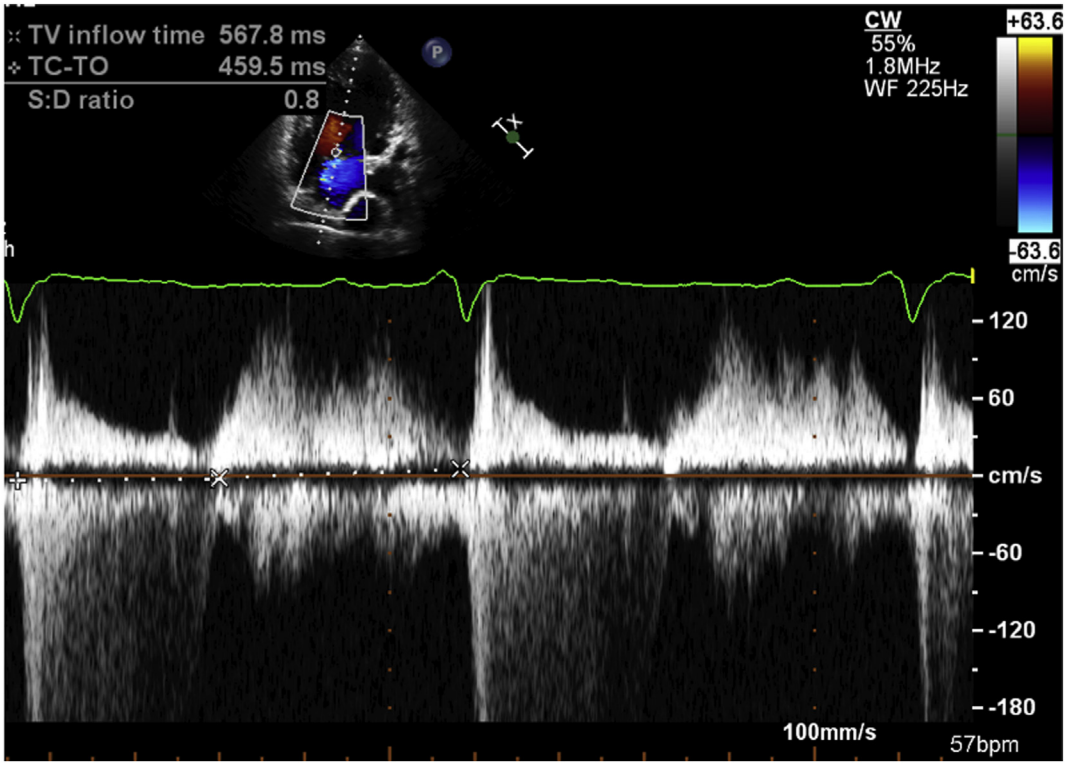

Fig. 1. Measurement of the atrioventricular systolic to diastolic duration ratio from the continuous wave Doppler signal. The atrioventricular systolic to diastolic duration ratio is calculated from the continuous wave Doppler signal of the dominant atrioventricular valve. S:D-systolic to diastolic duration, TC-TO-tricuspid valve closure to tricuspid valve opening, TV-tricuspid valve.

Please cite this article as: R. Cordina, et al., Evaluation of the relationship between ventricular end-diastolic pressure and echocardiographic measures of diastolic function in ..., Int J Cardiol (2017), https://doi.org/10.1016/j.ijcard.2018.02.045