Original Article

Comparing Certain Echocardiographic Measurements with Catheterization in Children with Pulmonary Hypertension due to Left-to-Right Cardiac Shunt

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Abstract

Background: Children with left-to-right cardiac shunt are at increasing risk of developing pulmonary hypertension and it's degree will guides the line of management of those patients. However, cardiac catheterization is the standard way to investigate PHT, and echocardiography shows an increasing role in diagnosis. **Objectives:** To check the consistency of noninvasive echocardiographic parameters with that is measured by conventional cardiac catheterization in assessing children with pulmonary hypertension due to congenital heart disease (PHT-CHD). **Materials and Methods:** This prospective cross-sectional study included 60 children with PHT-CHD we assessed six echocardiographic parameters; pulmonary vascular resistance (PVR), mean pulmonary artery pressure (MPAP), pulmonary capillary wedge pressure (PCWP), pulmonary to systemic flow (QP/QS), acceleration time of right ventricular outflow tract, and shunt gradients. Then these data were compared with same catheterization parameters. **Results:** There insignificant difference among PVR, MPAP, PCWP, and QP/QS measured by catheterization and the same parameters measured by echocardiography with $P > 0.05$. The total sensitivity of echocardiographic measurements was 94.23%, specificity 91.45%, positive predictive value 90.71%, and negative predictive value 87.35%. **Conclusion:** Echocardiographic measurements show respectable similarity to catheterization results in patients with PHT-CHD.

Keywords: Congenital heart disease, echocardiography, pulmonary hypertension

Introduction

Significant cardiac shunts that lead to blood overflow in pulmonary circulation can result in variable and considerable physiologic and histologic changes in the pulmonary vascular tree resulting in pulmonary hypertension (PHT). Unfortunately, around 5%–10% of patients with congenital heart disease (CHD) (especially when there is delayed or even no correction) develop PHT.[1]

Cardiac catheterization proved to be mandatory to confirm the severity of PHT, type of management, measurement of pulmonary vascular resistance (PVR), mean pulmonary artery pressure (MPAP), pulmonary capillary wedge pressure (PCWP), and systemic-to-pulmonary flow (QP/QS),[2] in addition to do vasoreactivity test.[3] Noninvasive echocardiographic measurements of hemodynamic parameters play an important role in evaluating patients with left-to-right cardiac shunt, and it is the most crucial inexpensive, easy, and noninvasive screening device used to assess sequel and prognosis of PHT.[4] Moreover, it is a reliable way to detect PVR,[5] QP/QS and PCWP[6] that have good correlation with hemodynamics obtained by heart catheterization.[7] Furthermore, echocardiography is a good tool to assess shunt gradient throw cardiac defect and estimation of acceleration time of right ventricular outflow tract (RVOT-AT), which

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could be used for the estimation of right ventricular pressure and pulmonary pressure.[8]

Scheme of clinical, echocardiographic, and catheterization results was suggested by Lopes and O'Leary[9] to detect operability in patients with PHT-CHD.

The aim of this study is to evaluate the diagnostic accuracy of echocardiographic measurements in children with PHT-CHD by comparison with cardiac catheterization.

Materials and Methods

This prospective cross-sectional study was agreed on by the Ethics Committee at AL-Hindiya General Hospital and Babylon College of Medicine with a verbal agreement. All parents were informed regarding the aspects of the study and signed informed consent.

Patients selection

This prospective cross-sectional study includes 60 children with PHT-CHD selected from AL-Hindiya General Hospital/Karbala/Iraq echocardiography Unit and then cardiac catheterization was done to them at Shaheed AL-Mihrab Catheterization Center/Babylon/Iraq during the period from October 2018 to June 2019. Echocardiographic measurements were used to test the concordance with catheterization. Baseline informations of patients are shown in Table 1.

The selection criteria included normal ventricular function, regular rhythm, absence of pulmonary stenosis, and presence of tricuspid regurgitation that enabled echocardiographic assessment of PVR. While exclusion criteria includes; Patients who did not give consent, other causes of PHT rather than cardiac shunt, bad image, single ventricle, aortopulmonary collaterals, after Fontan procedure, heart failure, catheterization revealing PVR >6 WU, change in clinical condition, or >1 month between echocardiography and catheterization.

Echocardiographic study

Echocardiography was performed using Vivid E9 Ultrasound (GE Milwaukee, WI Medical System) with pediatric 1.5–4.3 MHz phased array S6 transducers. Measurements were done according to the American Society of Echocardiography guidelines[10] with accompanied electrocardiography from typical views of suggested windows. Minimum of three heart cycles was measured and the average was taken; sweep speed of 50 mm/s for continuous and pulsed wave Doppler was used. Estimation of ejection fraction was performed using biplane modified Simpson's method.

Table 1: Baseline information of the patients

Characteristics	Value
Age (year), mean±SD	11.289±2.368
Gender	
Male, *n* (%)	26 (43.3)
Female, *n* (%)	34 (56.6)
Cause of pulmonary hypertension	
VSD, *n* (%)	23 (38.3)
PDA, *n* (%)	19 (31.6)
AVSD, *n* (%)	11 (18.3)
PDA + VSD, *n* (%)	7 (11.6)
EF (%), mean±SD	66.7±4.6
BSA (m^2), mean±SD	1.021±0.4

Null hypothesis was tested in this table which is rejected when $P<0.05$. SD: Standard deviation, VSD: Ventricular septal defect, AVSD: Atrioventricular septal defect, PDA: Patent ductus arteriosus, EF: Ejection fraction, BSA: Body surface area

For the estimation of PVR, continuous wave Doppler was used to detect the highest velocity of tricuspid regurgitation (TRV) (m/s). Then, the pulse wave from the basal level of short-axis views (just within the pulmonary valve) was used to detect time velocity integral (TVI) RVOT (cm) and PVR can assessed by this formulation; PVR = Highest TR v/TVIRVOT × 10 + 0.16. This method was performed as described previously by Abbas *et al*.[11]

For the estimation of MPAP, we used the early signals of pulmonary valve regurgitation, which is common in PHT using the Bernoulli's equation and then adding the right atrial pressure (RAP) according to this formula: MPAP = 4 × (initial peak velocity of pulmonary regurgitation) ^{2} + RAP.[12]

To assess PCWP, the mitral valve peak E wave velocity obtain four-chamber view by means of pulse wave Doppler through small sample volume of 1–3 mm at the cusped tips of mitral valve. From the same view, the medium of lateral and septal wall tissue (Doppler index 1 cm, below the mitral annulus) was taken to estimate (è); so PCWP can be calculated from this equation; PCWP = E/è ×1.24 + 1.9.[13]

Estimation of QP/QS was done by obtaining aortic level of the parasternal short-axis view then TVI of the RVOT (cm) was measured by carefully tracing the wave obtained from pulsed wave Doppler, then carefully measure the RVOT diameter. Using apical 5-chamber view, we could measure TVI of left ventricular outflow tract (LVOT) just under the aortic valve, whereas the diameter of LVOT was obtained from parasternal long-axis view 0.5 cm proximal to the aortic cusps in mid-systole frame. The cross-sectional area of RVOT and LVOT can be measured from this equation: Cross-sectional area = 0.785× $(\text{diameter})^2$ and then by multiplying the corresponding TVI by cross-sectional area, we can obtain pulmonary flow QP and systemic flow QS.[14]

For the estimation of acceleration time of the right ventricular outflow from parasternal short-axis view (aortic level) at end expiration, we used pulse wave Doppler at the RVOT and measured the time from the beginning of the flow to the maximum velocity in milliseconds.[15]

For the assessment of shunt gradient, the cursor of continuous wave Doppler should be well aligned with the defect and shunt gradient calculated by Bernoulli's equation.[16]

Cardiac catheterization

A retrograde catheterization performed by Swan–Ganz catheter through the femoral vein, MPAP, RAP, PCWP, oxygen saturation from different sites, and that from the pulmonary

and femoral arteries for intracardiac shunts. Cardiac output was perceived by thermodilution. PVR was estimated from this formulation MPAP-PCWP/cardiac output. When PVR was measured by catheterization more than 6 WU, the echocardiographic PVR will be more than 0.275 WU, so by multiplying the echocardiographic result by a constant factor (21.8), we can get the approximate PVR measured by catheterization.[11,17,18]

Statistical analysis

The data were collected, arranged, and statistically explored via SPSS system version 21 (SPSS, IBM Company, Chicago, IL 60606, USA). Continuous variables were expressed as mean ± standard deviation, whereas other qualitative parameters were stated as frequencies and correlated percentages; linear regression analysis was used to evaluate the relationships of the different echocardiographic parameters and catheterization hemodynamic measurements. In cases where the null hypothesis was rejected, $P < 0.05$ was considered as statistically significant.

Ethical consideration

The study was conducted in accordance with the ethical principles that have their origin in the Declaration of Helsinki. It was carried out with patients' verbal and analytical approval before the sample was taken. The study protocol and the subject information and consent form were reviewed and approved by the local ethics committee.

Results

Baseline information about patients

The characteristic parameters of 60 patients demonstrated that the mean age of presentation was 11.289 years ± 2.368, female patients represented 56.6%, and male-to-female ratio was 0.76; the most frequent congenital heart shunt defect causing PHT was VSD which presents in 23 children (38.3%); the mean ejection fraction of patients was 66.7 ± 4.6; and the mean body surface area was 1.021 ± 0.4, as shown in Table 1.

Comparison between catheterization and echocardiographic measurements

The results revealed that there was no statistically significant difference between mean PVR measured by catheterization (7.465 ± 1.519) and mean PVR measured by echocardiography (0.327 ± 0.064) after multiplying the echocardiographic results by constant factor 21.8 ($P > 0.05$); there was no statistically significant difference among MPAP measured by catheterization (52.406 ± 13.280) and mean MPAP measured by echocardiography (63.450 ± 13) ($P > 0.05$); there was no statistically significant difference between PCWP measured by catheterization (15.612 ± 1.147) and mean PCWP measured by echocardiography (14.359 ± 1.283) ($P > 0.05$); and there was no statistically significant differences between QP/QS measured by catheterization (1.471 ± 0.425) and mean QP/QS measured by echocardiography (1.621 ± 0.399) ($P > 0.05$). The mean RVOT-AT was 89.656 ± 20.612 and the mean shunt gradient was 21.612 ± 14.388, whereas the last two measurements (RVOT-AT and shunt gradient) cannot be measured by catheterization, as shown in Table 2.

Validity of echocardiographic measurements

The echocardiographic results of PVR, MPAP, PCWP, and QP/QS in comparison with catheterization results display sensitivity of 94.23%, specificity of 91.45%, positive predictive value of 90.71%, and negative predictive value of 87.35%, as shown in Figure 1.

Discussion

The most frequent CHD associated with PHT was VSD. It was found alone in 23 patients, as part of AVSD in 11 patients, and in combination with PDA in 7 patients out of a total number 41 (68.33%) [Table 1]. This finding was proved by Paladini *et al*.[19] and Beghetti.[20] The second most frequent CHD-PHT was PDA, found alone in 19 patients and in combination with VSD in 7 patients. Hence, VSD and PDA are the most frequent causes of PHT. This was proved by Frank and Hanna.[21]

The results of echocardiographic measurements of PVR revealed no significant differences with PVR measured in accordance with catheterization. This outcome was noticed by many studies.[11,17,18,22]

There is a worthy relation between catheterization and echocardiographic measurements of MPAP with no

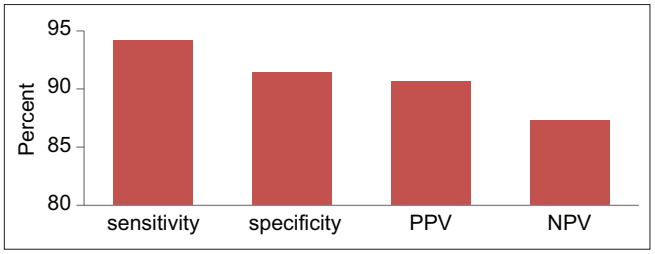

Figure 1: Validity of echocardiographic measurements. Binary classification test (2 × 2 contingency table) used. PPV: Positive predictive value, NPV: Negative predictive value

Table 2: Echocardiographic and catheterization measurements

Measurements	Units	Mean±SD		*P*
		Echocardiography	Catheterization	
PVR	WU/m²	0.327±0.064*	7.465±1.519	>0.05
MPAP	mmHg	63.450±13.211	52.406±13.280	>0.05
PCWP	mmHg	14.359±1.283	15.612±1.147	>0.05
QP/QS	%	1.621±0.399	1.471±0.425	>0.05
RVOT-AT	ms	89.656±20.612		
Shunt gradient	mmHg	21.612±14.388		

Null hypothesis was tested in this table which is rejected when $P<0.05$. PVR: Pulmonary vascular resistance, MPAP: Mean pulmonary artery pressure, PCWP: Pulmonary capillary wedge pressure, QP/QS: Pulmonary to systemic flow, RVOT-AT: Acceleration time of right ventricular outflow tract, SD: Standard deviation, *By multiplying the echocardiographic results by constant factor 21.8 give result of 7.128 which is statistically insignificant from catheterization results

statistically significant difference; this result goes with that described by Lopes.[9,23] Estimation of PCWP also shows no statistically significant difference between catheterization and echocardiography, corresponding to the finding of Sugimoto *et al*.[24]

Estimation of QP/QS also demonstrates no significant difference between catheterization and echocardiography. These results were compatible with those obtained by Cloez *et al*. who found a very good relation between QP/QS estimated by catheterization and echocardiography.[25] Measurements of RVOT-AT provide dependable estimation of pulmonary hemodynamics as described by Levy *et al*.;[26] however, it has low sensitivity and specificity to predict PVR >6, as achieved in a study done by Roushdy *et al*.[27] Finally, we found that echocardiographic assessment of shunt gradients plays a major role in the evaluation of flow and cardiac chamber pressure and the presence of high-shunt gradients may indicate that the patients are operable. This result was supported by several authors worldwide such as Awasthy and Radhakrishnan.[16] However, this study gives high sensitivity and specificity in comparison with catheterization result, but still there is a chance to false positive and false negative results, which may be explained by procedural influences such as cooperation of the patient or getting perfect echocardiographic windows and typical views.

Conclusion

The estimated Doppler echocardiographic parameters display high sensitivity, specificity, positive predictive value, and negative predictive value in the evaluation and selection of the best way of management of patients with PHT-CHD, with excellent correlation with reference catheterization parameters which could be a simple noninvasive alternative to catheterization.

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Conflicts of interest

There are no conflicts of interest

References

1. Hoeper MM, Bogaard HJ, Condliffe R, Frantz R, Khanna D, Kurzyna M, *et al*. Definitions and diagnosis of pulmonary hypertension. Turk Kardiyol Dern Ars 2014;42 Suppl 1:55-66.
2. Beghetti M, Adatia I. Inhaled nitric oxide and congenital cardiac disease. Cardiol Young 2001;11:142-52.
3. Myers PO, Tissot C, Beghetti M. Assessment of operability of patients with pulmonary arterial hypertension associated with congenital heart disease. Circ J 2014;78:4-11.
4. Quiñones MA, Otto CM, Stoddard M, Waggoner A, Zoghbi WA, Doppler Quantification Task Force of the Nomenclature and Standards Committee of the American Society of Echocardiography. Recommendations for quantification of Doppler echocardiography: A report from the Doppler Quantification Task Force of the Nomenclature and Standards Committee of the American Society of Echocardiography. J Am Soc Echocardiogr 2002;15:167-84.
5. Bhyravavajhala S, Velam V, Polapragada NV, Pallempati P, Iragavarapu TR, Patnaik AN, *et al*. Reliability of Doppler-based measurement of pulmonary vascular resistance in congenital heart disease with left-to-right shunt lesions. Echocardiography 2015;32:1009-14.
6. Malhotra R, Hess D, Lewis GD, Bloch KD, Waxman AB, Semigran MJ. Vasoreactivity to inhaled nitric oxide with oxygen predicts long-term survival in pulmonary arterial hypertension. Pulm Circ 2011;1:250-8.
7. Rabinovitch M, Keane JF, Norwood WI, Castaneda AR, Reid L. Vascular structure in lung tissue obtained at biopsy correlated with pulmonary hemodynamic findings after repair of congenital heart defects. Circulation 1984;69:655-67.
8. Yared K, Noseworthy P, Weyman AE, McCabe E, Picard MH, Baggish AL. Pulmonary artery acceleration time provides an accurate estimate of systolic pulmonary arterial pressure during transthoracic echocardiography. J Am Soc Echocardiogr 2011;24:687-92.
9. Lopes AA, O'Leary PW. Measurement, interpretation and use of haemodynamic parameters in pulmonary hypertension associated with congenital cardiac disease. Cardiol Young 2009;19:431-5.
10. Gersh BJ, Maron BJ, Bonow RO, Dearani JA, Fifer MA, Link MS, *et al*. 2011 ACCF/AHA Guideline for the diagnosis and treatment of hypertrophic cardiomyopathy: A report of the American College of Cardiology Foundation/American Heart Association task force on practice guidelines. Developed in collaboration with the American Association for Thoracic Surgery, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Failure Society of America, heart rhythm society, society for cardiovascular angiography and interventions, and society of thoracic surgeons. J Am Coll Cardiol 2011;58:e212-60.
11. Abbas AE, Fortuin FD, Schiller NB, Appleton CP, Moreno CA, Lester SJ. A simple method for noninvasive estimation of pulmonary vascular resistance. J Am Coll Cardiol 2003;41:1021-7.
12. Masuyama T, Kodama K, Kitabatake A, Sato H, Nanto S, Inoue M. Continuous-wave Doppler echocardiographic detection of pulmonary regurgitation and its application to noninvasive estimation of pulmonary artery pressure. Circulation 1986;74:484-92.
13. Ommen SR, Nishimura RA, Appleton CP, Miller FA, Oh JK, Redfield MM, *et al*. Clinical utility of Doppler echocardiography and tissue Doppler imaging in the estimation of left ventricular filling pressures: A comparative simultaneous Doppler-catheterization study. Circulation 2000;102:1788-94.
14. Sanders SP, Yeager S, Williams RG. Measurement of systemic and pulmonary blood flow and QP/QS ratio using Doppler and two-dimensional echocardiography. Am J Cardiol 1983;51:952-6.
15. Marra AM, Benjamin N, Ferrara F, Vriz O, D'Alto M, D'Andrea A, *et al*. Reference ranges and determinants of right ventricle outflow tract acceleration time in healthy adults by two-dimensional echocardiography. Int J Cardiovasc Imaging 2017;33:219-26.
16. Awasthy N, Radhakrishnan S. Stepwise evaluation of left to right shunts by echocardiography. Indian Heart J 2013;65:201-18.
17. Lindqvist P, Söderberg S, Gonzalez MC, Tossavainen E, Henein MY. Echocardiography based estimation of pulmonary vascular resistance in patients with pulmonary hypertension: A simultaneous Doppler echocardiography and cardiac catheterization study. Eur J Echocardiogr 2011;12:961-6.
18. Roule V, Labombarda F, Pellissier A, Sabatier R, Lognoné T, Gomes S, *et al*. Echocardiographic assessment of pulmonary vascular resistance in pulmonary arterial hypertension. Cardiovasc Ultrasound 2010;8:21.
19. Paladini D, Palmieri S, Lamberti A, Teodoro A, Martinelli P, Nappi C. Characterization and natural history of ventricular septal defects in the fetus. Ultrasound Obstet Gynecol 2000;16:118-22.
20. Beghetti M. Pulmonary arterial hypertension related to congenital heart disease. Elsevier, Urban and FischerVerlag; 2006.
21. Frank DB, Hanna BD. Pulmonary arterial hypertension associated with

congenital heart disease and Eisenmenger syndrome: Current practice in pediatrics. Minerva Pediatr 2015;67:169-85.
22. Dahiya A, Vollbon W, Jellis C, Prior D, Wahi S, Marwick T. Echocardiographic assessment of raised pulmonary vascular resistance: Application to diagnosis and follow-up of pulmonary hypertension. Heart 2010;96:2005-9.
23. Lopes AA. Pre-operative pulmonary hypertension in congenital heart disease and aspects of Eisenmenger's syndrome in children. In: Beghetti, M, ed. Pediatric pulmonary hypertension. Munich: Elsevier Urban & Fischer 2011:187-207.
24. Sugimoto T, Dohi K, Tanabe M, Watanabe K, Sugiura E, Nakamori S, *et al*. Echocardiographic estimation of pulmonary capillary wedge pressure using the combination of diastolic annular and mitral inflow velocities. J Echocardiogr 2013;11:1-8.
25. Cloez JL, Schmidt KG, Birk E, Silverman NH. Determination of pulmonary to systemic blood flow ratio in children by a simplified Doppler echocardiographic method. J Am Coll Cardiol 1988;11:825-30.
26. Levy PT, Patel MD, Groh G, Choudhry S, Murphy J, Holland MR, *et al*. Pulmonary artery acceleration time provides a reliable estimate of invasive pulmonary hemodynamics in children. J Am Soc Echocardiogr 2016;29:1056-65.
27. Roushdy AM, Ragab I, Abd El Raouf W. Noninvasive assessment of elevated pulmonary vascular resistance in children with pulmonary hypertension secondary to congenital heart disease: A comparative study between five different Doppler indices. J Saudi Heart Assoc 2012;24:233-41.