Am J Cardiovasc Dis 2025;15(2):100-107
www.AJCD.us /ISSN:2160-200X/AJCD0161726

Original Article

Significant deviation between reported wedge pressure and diastolic pulmonary arterial pressure found during right heart catheterization in patients undergoing cardiac transplant evaluation

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Received November 4, 2024; Accepted March 4, 2025; Epub April 15, 2025; Published April 30, 2025

Abstract: Objectives: Diastolic pulmonary arterial pressure should be the same as wedge pressure in patients with cardiomyopathy without a known history of pulmonary vein occlusive disease. The goal of this study was to study the correlation between reported wedge pressure and pulmonary arterial diastolic pressure in patients with end-stage cardiomyopathy to evaluate the accuracy of right heart pressure reporting. Methods: Pre-cardiac transplant patients who underwent cardiac catheterization before their heart transplantation at our institution between 2003 and 2005 (n = 159) were retrospectively reviewed. Reported diastolic pulmonary arterial pressure was correlated with reported wedge pressure. Results: The correlation between reported diastolic pulmonary arterial pressure with wedge pressure was modest with $r^2 = 0.75$. There was wide variation with some division up to 40 mmHg. Most discrepancies occurred in the lower and higher-pressure measurements. Conclusions: Among patients referred for heart transplant evaluation, a correlation between reported diastolic pulmonary pressure and wedge pressure is only modest suggesting a significant error in the reporting or measuring right-sided pressures during right heart catheterization warranting further investigation to reduce errors.

Keywords: Pulmonary arterial pressure, right heart catheterization, cardiomyopathy, pre-heart transplantation, heart transplantation, wedge pressure, pulmonary hypertension, cardiac catheterization

Introduction

In the USA and around the world, heart failure (HF) is one of the leading causes of morbidity and mortality. More than 10% of individuals with heart failure have advanced heart failure [1]. Cardiomyopathies are a diverse set of heart muscle illnesses and are known as significant contributory causes of heart failure (HF) [2]. The last resort for treating severe heart failure is heart transplantation (HTx) which enhances the prognosis and quality of life of the patients [3].

To reduce complications, strict selection criteria are adopted [4]. Eligibility for an HTx is limited due to many contraindications. Absolute contraindications comprise a limited life expectancy of less than two years following a cardiac transplant [5]. Systemic illnesses that indicate a life expectancy of less than two years include significant pulmonary disease, a history of malignancy within the past five years, irreversible kidney and liver disease, and fixed pulmonary hypertension (PH) [6-9]. PH is a heterogeneous disease with the original definition of PH using a mean pulmonary artery pressure (mPAP) ≥ 25 mmHg. This was derived from expert opinion without sufficient clinical data. With the emergence of more data linking adverse outcomes to PA pressure, an mPAP > 20 mmHg is now considered pulmonary hypertension measured during right heart catheterization [10].

Hence, pre-transplant evaluations are important in reducing complications and enhancing the prognosis. Right heart catheterization is performed to identify PH by measuring pulmonary arterial pressures including pulmonary

https://doi.org/10.62347/NEDV9140

arterial diastolic (dPAP) and pulmonary wedge pressure (PCWP). Therefore, measuring and recording accurate hemodynamics during right heart catheterization is crucial for pre-transplant evaluation. Unfortunately, measuring hemodynamics during right heart catheterization has some pitfalls and can be challenging, leading to inaccurate pressure reporting. These limitations are multifactorial and can be operator and device-related. To evaluate the accuracy of pressure reporting in pre-transplant patients, we used a comparison of reported dPAP to PCWP that should be equal in patients with cardiomyopathy without pulmonary arterial occlusive disease retrospectively.

Method

Patients' selection

To evaluate any discrepancy between the pulmonary arterial wedge and diastolic pulmonary arterial pressure, we designed our study to correlate reported pulmonary arterial wedge pressure with recorded pulmonary diastolic pressure measured during right heart catheterization in patients before heart transplantation retrospectively. The study included 159 people diagnosed with end-stage cardiomyopathy who were being considered for heart transplantation. The Inclusion criteria were as follows: Patients who had been evaluated via right and if needed left heart catheterization as part of their pre-transplant evaluation were included. All Patients diagnosed with end-stage cardiomyopathy who are being considered for heart transplantation, who have undergone right-side cardiac catheterization and perioperative examination as part of their evaluation for a heart transplant during the years 2003 to 2005, with available documented data on diastolic pulmonary pressure, pulmonary capillary wedge pressure (PCWP) and pulmonary arterial pressures (PAP). Documented wedge and diastolic pulmonary arterial pressure from reported right heart catheterization procedures were utilized [11-16]. Exclusion criteria were as follows: Patients who did not undergo right heart catheterization before their transplantation or did not have recorded wedge or pulmonary arterial pressures were excluded.

Ethical considerations

The study followed the principles specified in the Declaration of Helsinki [17]. We used retrospective data collection and analysis. This study was approved by the University of Arizona Institutional Review Board (IRB). Patient confidentiality was rigorously maintained, and all data were anonymized before analysis.

Procedural detail

A typical procedure was performed as follows: An 8.5 Fr dilator using an introducer sheath is placed over the wire and into the vein. The dilator and wire assembly needed to be withdrawn as a unit, keeping the introducer sheath intact. Once the introducer sheath is in place, enter the pulmonary artery (PA) catheter and advance it up to 20 cm. This should put its distal tip inside the right atrium, as shown on the monitor by a right atrial pressure waveform. After confirming the balloon's position within the right atrium, a 1.5 mm syringe was used to inflate it with air. The catheter is subsequently pushed entering the right ventricle through the pulmonary artery. The positioning is verified by examining the suitable pressures and waveforms on the display. The balloon is supposed to be deflated once the catheter has been positioned into the pulmonary artery and the waveform has changed to a wedge shape. The pressure recording then shows the PA pressures. After acquiring the necessary PA pressures, a PCWP/pulmonary artery occlusion pressure can be measured. This is accomplished by slowly inflating the balloon while watching the monitor. The balloon is only inflated until the PA pressure waveform shows a wedged waveform. When inflated, the balloon forms a static column of blood between the artery distal to the pulmonary vein and the catheter. The post-capillary pressure (PCWP) represents an indirect measurement of the pressure inside the left atrium.

After balloon inflation, the Swan-Ganz catheter was withdrawn into the right ventricle, right atrium, and IVC with pressure measurement during each step of pullback. Pressure was measured when appropriate pressure curves were observed with the least artifact. After the procedure, a chest X-ray might be performed to verify the catheter's location and check for any problems. The PA catheter's tip is typically located within the mediastinal shadow [13]. Final reported pressures were made after the cardiologist reviewed the tracers and made

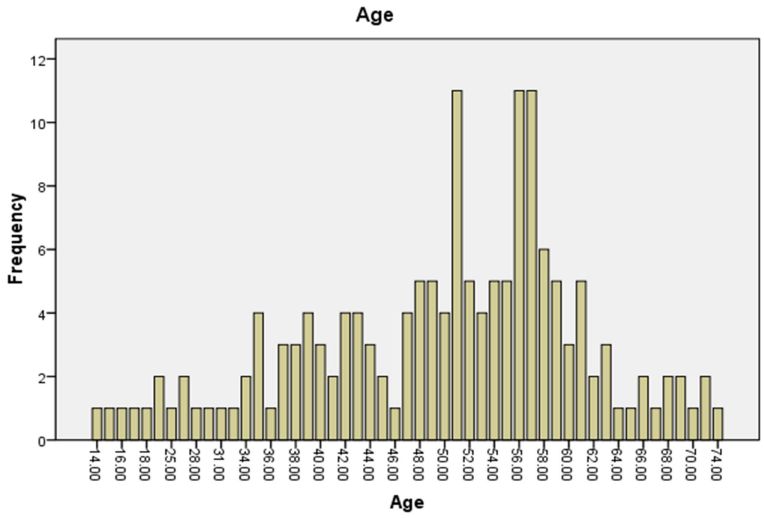

Figure 1. Age-related characteristics of patients undergoing right heart catheterization for heart failure caused by end-stage cardiomyopathy.

final reports based on his interpretation of the data.

Statistical analysis

The statistical analysis was performed using SPSS version 17 software. The accordance was tested using regression analysis with a significance level of $P < 0.05$. The correlation's strength was measured using the coefficient of determination (r^2). A paired t-test was used where appropriate. Data are reported as mean ± standard deviation of the mean for each parameter. Discrepancies in reported pressures were examined. Regression analysis and ANOVA tests were employed to study the relationship between these two critical hemodynamic parameters. Linear regression models were developed to explore the relationship between PCWP and diastolic pulmonary arterial pressure. Furthermore, descriptive statistics were employed to characterize the clinical characteristics of the study patients. Furthermore, descriptive statistics were employed to characterize the clinical characteristics of the study patients.

Results

Demographics

In our retrospective cohort study of 159 patients who underwent pre-operative evaluation referred to as right-side heart catheterization before heart transplant due to heart failure as a result of end-stage cardiomyopathy, we evaluated various demographics parameters such as age, gender, the etiology of end-stage cardiomyopathy, and hemodynamic parameters. The majority of the patients about 81.1% were men (129 cases), with women accounting for 18.9% (30 cases). The participants had an average age of 49±12.16 years (**Figure 1**), ranging from 14 to 74 years. Etiologically, CAD was present in 45.3% (72 patients) of the patients, and also the remaining 54.7% (87 patients) had cardiomyopathies of other etiologies, underscoring the diverse causes leading to heart failure necessitating transplantation.

Echocardiographic and hemodynamic parameters

LV ventricular ejection fraction (EF) by echocardiography had a mean of 22.30±11.50% ranging from a minimum of 0.18% to a maximum of 57.50%, indicating severe systolic dysfunction among candidates (**Figures 2** and **3**). On the other hand, diastolic PAP averaged 19.61±9.58 mmHg, with values ranging from very low to moderately high (2 to 50 mmHg), indicating varied amounts of pressure within the lungs among these individuals. The mean PAP across patients was 28.24±11.61 mmHg, with a range of low to high values (5 to 65 mmHg), and 73.7% of patients had a mean PAP greater than 20 mmHg (**Figures 4** and **5**). The statistical analysis focused on the discordance and concordance between Diastolic PAP by catheterization and PCWP by catheterization. Regression analysis and ANOVA tests were employed to examine the relationship between these two critical hemodynamic parameters. The linear regression indicated a modest correlation ($r^2 = 0.75$) with significant variability in the measurements, suggesting discrepancies in reported pressures (**Figure 6**). Notably, discrepancies were more pronounced at the lower and higher ends of the pressure spectrum, with some divisions reaching up to 40 mmHg.

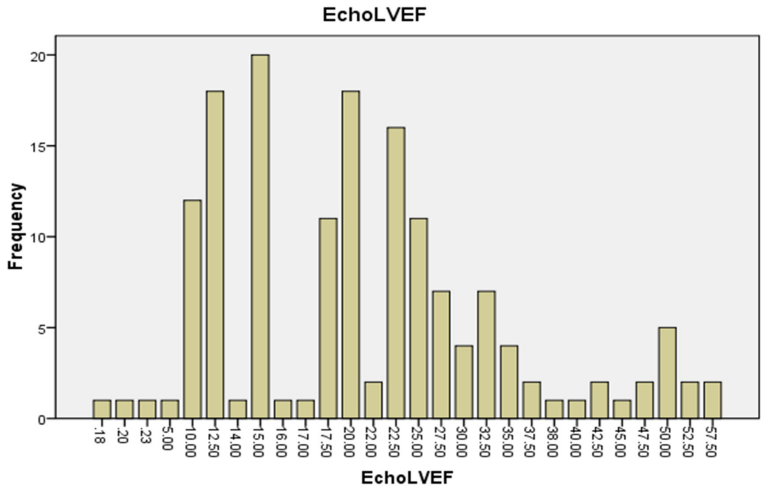

Figure 2. The values related to Left Ventricle Ejection Fraction by echocardiography of patients who underwent right heart catheterization for heart failure caused by end-stage cardiomyopathy ranged from 0.18% to 57.50%.

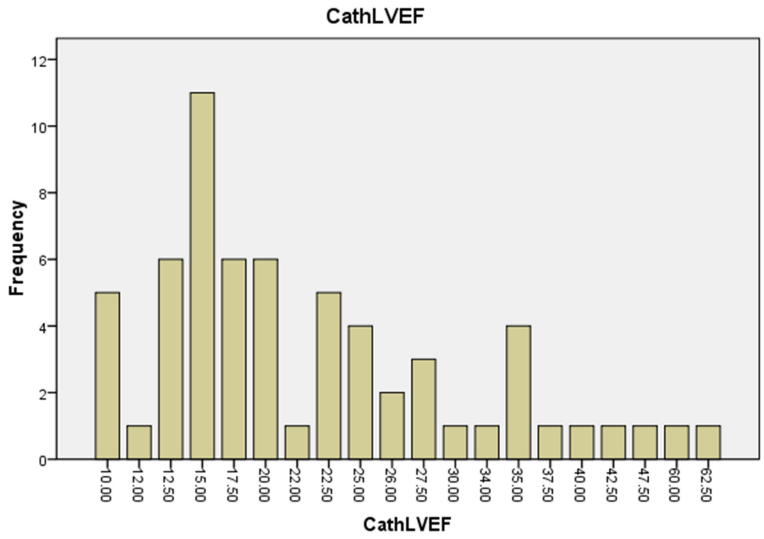

Figure 3. The values related to Left Ventricle Ejection Fraction by catheterization of patients who underwent right heart catheterization for heart failure caused by end-stage cardiomyopathy ranged from 10% to 62.50%.

Discussion

The present study evaluated the right heart catheterization findings in candidates for HTx without a history of prior PH. In the absence of known PH or any pulmonary vascular diseases, it is supposed that the dPAP is highly influenced by the backward pressure of left arterial pressure, evaluated by the PAWP, and that the dPAP and PCWP are tightly correlated and should be the same. Nevertheless, in our study, the correlation between reported dPAP and PCWP was modest with r^2 = 0.75.

In a study by Rapp et al. on over 200 patients with PAP ≤ 20 mmHg, the dPAP and PCWR values were highly similar (11±2 and 9±3) respectively [18]. They also reported that 93% of the dPAP values in these patients were within the 5 mmHg of PCWP values. In patients with higher PAP levels, the discordances between the dPAP and PCWR increased, dropping the closeness from 93% to 46% in patients with PAP > 40 mmHg [18]. In contrast to the findings of Rapp et al. that the high variations were limited to high PAP levels, our study revealed a wide PCWR-dPAP variation with some discordances up to 40 mmHg, and the most dissociations occurred in the lower and higher-pressure measurements. Nevertheless, as far as none of the patients in our study had precapillary PH, we expected a very high correlation between dPAP and PCWP, which was not fulfilled with r^2 = 0.75 suggesting a significant error in recording or documenting the pressures.

Heart catheterization is a gold standard for diagnosing and characterizing PH; however, several factors can impose errors. To ensure the accuracy of right heart catheterization, the following critical factors need to be considered. These include the proficiency and skill of the operators. It is important that an accurate technique is utilized and the functional integrity of the device is confirmed. Studies have shown that a significant number of critical care trained attendings struggle to accurately read RHC data, with surveys indicating that 50% of them are unable to accurately detect PCWP from a clear chart recording [19]. In addition, differences in operator technique contribute to the

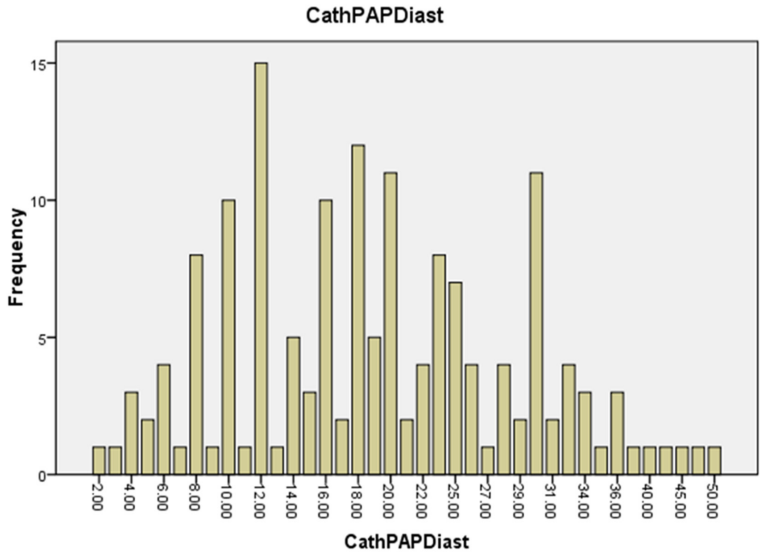

Figure 4. Mean pulmonary artery pressure (PAP) was evaluated during right heart catheterization, and its values ranged from 5 to 59 mmHg, and about 73.3% of patients had pulmonary hypertension.

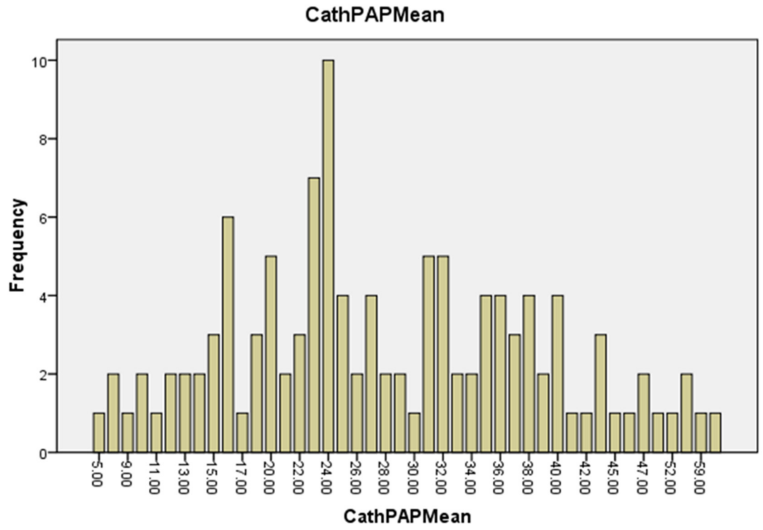

Figure 5. Mean pulmonary artery pressure (PAP) was evaluated during right heart catheterization, and its values ranged from 5 to 59 mmHg, and about 73.3% of patients had pulmonary hypertension (PH).

variation in interpreting RHC tracings, especially in identifying PCWP. It is crucial to analyze the data of RHC with the patient's clinical condition and the anticipated data, such as expecting a low PCWP in an individual treated with diuretics and being now clinically euvolemic. Operators may encounter the issue of "partial wedging", when an incompletely blocked pulmonary artery results in an overestimation of real PCWP owing to the reflection of pulmonary artery pressure and left atrial [20]. A study on individuals with PH found that different balloon volumes, sometimes half of normal, were required when measuring pulmonary artery occlusion or wedge pressures. The study suggested that a deformed pulmonary vascular bed proximally would hinder full occlusion [21].

Johnson et al. found that nearly 15% of RHCs performed at a prominent academic institutional lab reported unintentional alternative wedge pressures [22]. The agreement between LVEDP and alternative PCWP in cases where LVEDP was measured suggested that the alternative PCWP is more accurate than the reported PCWP, which may be incomplete and deceptively high. Experienced operators may mistakenly report erroneously elevated "incomplete" wedge pressures due to inadequate occlusion of PA branch arteries during balloon inflation. When the balloon is deflated, the catheter may unintentionally and momentarily shift forward, completely blocking a pulmonary artery branch, resulting in a more precise and lower "alternative" wedge pressure. This phenomenon, often unrecognized by operators, can significantly impact the classification of PH and subsequent treatment decisions. In this study, the specific techniques of catheterization were not reported. As RHC was performed by multiple operators, we could not discriminate the origination of any errors. There are a few steps that can be taken to reduce errors. Any operator performing RHC should always be patient and only record pressures when an artifact is reduced and pressure curves are consistent with the chamber recorded. Under-damping

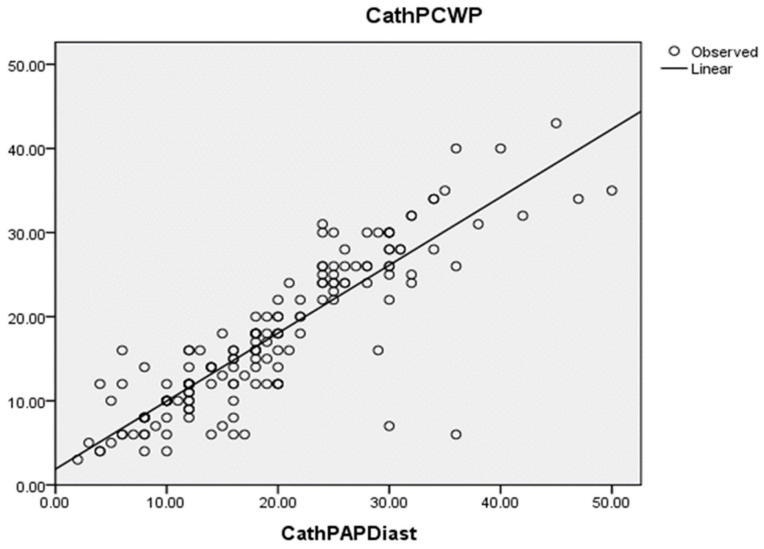

Figure 6. Estimated pulmonary artery diastolic pressure by catheterization versus pulmonary capillary wedge pressure (PCWP) that assessed by right heart catheterization in heart failure patients caused by end-stage cardiomyopathy ($r^2 = 0.75$).

should be avoided by adding contrast or blood to the pressure lines and avoid over-damping by removing any bubbles from the pressure lines. When measuring pressures, the operator should appropriately sedate the patient to avoid moving artifacts. Excessive respiratory effects on the pressures during recording such as snoring should be minimized by instructing shallow breathing during recording. Finally, pressure curves should be analyzed in detail, and the best pressure recording with the least artifacts should be used for the final documentation. In up to 10% of cases, accurate wedge pressure can only be obtained using the contralateral lung [23]. This fact emphasizes that if accurate wedge pressure recording cannot be obtained initially, contralateral lung should be attempted to reduce error. Detailed attention should be paid to positioning the transducer at the correct level when measuring right-sided ventricular pressure [24]. As reported errors are common during right heart catheterization while measuring pressures and reporting, cardiology societies should offer more educational courses and seminars and design standard algorithms that can be used in the cardiac catheterization laboratories to reduce errors. A recent web-based application in patients with pulmonary hypertension undergoing right heart catheterization was successful [25] suggesting that technical advancement could improve the accuracy of right heart catheterization.

Based on our results, we suggest that transplant cardiologists review the original recording of their patients' right heart pressures, particularly if there are significant discrepancies between PA pressure measured during echocardiography and PA pressure measured during right heart catheterization, to avoid mistreating their patients. In other cardiac conditions requiring accurate knowledge of pulmonary arterial pressures, pressure recording should also be reviewed in cases of discrepancy with echocardiographic findings to avoid errors.

Limitations

The study may have been conducted on a specific set of people, making it difficult to generalize the findings to all patients waiting for heart transplants. Differences in how wedge pressure and diastolic pulmonary pressure were measured could result in mistakes in data gathering, techniques, technician mistakes, failure of tools, and technical problems of equipment. This study does not follow patients over time, so we don't know what differences in wedge and diastolic lung pressures signify for patients' long-term health consequences.

Conclusion

The study findings revealed only a modest correlation between reported dPAP and PCWP among end-stage cardiomyopathy patients being evaluated for HTx, with an r^2 of 0.75 despte the fact that those two pressures should be the same in patients with pulmonary arterial occlusive disease. Notable discrepancies were more prominent in low and high measurements. These discrepancies in patients without precapillary PH underscore the potential for significant errors in the measurement or reporting of right-sided heart pressures during catheterization. This highlights an urgent need for further research to identify and mitigate

these errors, ensuring more accurate assessment and management of patients undergoing evaluation for HTx. We suggest that cardiology training programs should make a stronger effort to teach fellows to take time during right heart catheterization. They should familiarize themselves with hemodynamics and how to prevent errors in interpreting and reporting right-sided heart pressures.

Disclosure of conflict of interest

None.

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