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RESEARCH ARTICLE

Evaluation of Common Clinical and Hemodynamic Parameters to Pulmonary Capillary Wedge Pressures in Patients Undergoing Right Heart Catheterization

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ABSTRACT

Introduction: A cornerstone of heart failure assessment is the right heart catheterization and the pulmonary capillary wedge pressure measurement it can provide. Clinical and hemodynamic parameters such as weight and jugular venous distention are less invasive measures often used to diagnose, manage, and treat these patients. To date, there is little data looking at the association of these key parameters to measured pulmonary capillary wedge pressure (PCWP). This is a large, retrospective, secondary analysis of a right heart catheterization database comparing clinical and hemodynamic parameters against measured PCWP in heart failure patients.

Methods: A total of 538 subjects were included in this secondary analysis. Spearman's Rho analysis of each clinical and hemodynamic variable was used to compare their association to the documented PCWP. Variables analyzed included weight, body mass index (BMI), jugular venous distention (JVD), creatinine, edema grade, right atrial pressure (RAP), pulmonary artery systolic pressure (PASP), systemic vascular resistance, pulmonary vascular resistance, cardiac output (thermal and Fick), systolic blood pressure, diastolic blood pressure, heart rate, respiratory rate, oxygen saturation (SpO_2), and pulmonary artery diastolic pressure (PADP).

Results: Ten out of 17 selected parameters had a statistically significant association with measured PCWP values. PADP had the strongest association (0.73, $p<0.0001$), followed by RAP and PASP (0.69, $p<0.0001$ and 0.67, $p<0.0001$, respectively). Other significant parameters included weight (0.2, $p<0.001$), BMI (0.2, $p<0.001$), SpO_2 (-0.17, $p<0.0091$), JVD (0.24, $p<0.005$) and edema grade (0.2, $p<0.0001$).

Conclusion: This retrospective analysis clarifies the associations of commonly used clinical and hemodynamic parameters to the clinically used gold standard for volume assessment in heart failure patients, PCWP.

Keywords: Congestion, heart failure, right heart catheterization, PCWP

Introduction

Heart disease, including heart failure, remains one of the largest contributors to morbidity and mortality in the United States.[1,2] Heart failure (HF) accounts for approximately 6 million hospital admissions in the U.S. annually.[2] While this disease has become an increasingly common cause of premature death and poor quality of life, improvements in monitoring disease progression and treatment response has been limited.[3] Signs and symptoms such as fatigue, edema, and shortness of breath are staples of the physical examination used to triage and manage HF patients.[3,4] Current American Heart Association/American College of Cardiology/ Heart Failure Society of America guidelines still continue to support that these parameters, within a history and physical examination, remain cornerstones in the assessment and management of the HF patient. Unfortunately, these often represent late manifestations of the disease and accurate assessment of heart failure severity using these conditions has proven difficult.[3,5]

Congestion is a primary driver of symptoms and, ultimately, hospitalization in heart failure.[6] Persistent signs of congestion on hospital discharge correlate with increased risk of readmission and death.[7] Systemic signs of congestion are the first to resolve with diuresis and afterload reduction, while pulmonary and hemodynamic congestion can linger and be difficult to detect in chronic heart failure patients.[8] Hemodynamic congestion is the elevation of left ventricular end diastolic pressures (often represented by the pulmonary capillary wedge pressure [PCWP]) and generally precedes exam findings as well as weight and vital sign changes in decompensated heart failure.[3] While invasive hemodynamic measurements are the most reliable to assess persistent hemodynamic congestion, it is neither practical nor safe to perform invasive PCWP measurements on all patients prior to hospital discharge. Given this, the search for surrogates of persistent hemodynamic congestion to help guide therapeutic interventions beyond resolution of system congestion has been an important feature in the heart failure literature.

The gold standard in heart failure assessment and management is the right heart catheterization (RHC).[9] This invasive procedure provides granular hemodynamic data to assist in diagnosis, prognosis, and management of heart failure.[9] The most utilized parameter for this purpose is PCWP which represents an estimation of left sided cardiac filling pressures, thus hemodynamic congestion.[10,11] In a porcine volume overload model analyzing both peripheral and central hemodynamic data the PCWP was the most reliable and accurate measurement for monitoring volume overload.[12] However, very little data exists investigating how the commonly used signs and symptoms described above correlate to the heart failure patient's PCWP. A small recent study (n=110) demonstrated that differences in jugular venous pressures, edema scores, and shortness of breath did not correlate with measured pulmonary capillary wedge pressure (PCWP).[13] Previous data supports a threshold of PCWP greater than 18 mmHg as representative of a state of developing pulmonary congestion in the absence of mitral valve disease,[6] which has been validated in a number of subsequent studies.[11,14-17]

Despite its usefulness and accuracy in assessing severity of disease, right heart catheterization is an invasive procedure with inherent costs and risks. Less invasive measures of heart failure severity are commonly utilized but not well validated. The purpose of this study is to help clarify the association between commonly used assessments of heart failure and PCWP, the invasive measure used to assess degree of congestion.

Methods

This is a retrospective analysis of a large database of right heart catheterization reports and patient demographics/vital signs, obtained under an approved IRB protocol. The IRB of record is the University of Alabama Birmingham Institutional Review Board through Vanderbilt University Medical Center Institutional Review Board secondary to institutional conflict of interest. The dataset includes only patients who were at least 18 years old and were scheduled for a RHC. A total of 538 subjects within this dataset had all the necessary data points included and were able to be included in this secondary analysis. The relationship between PCWP and the following common clinical/hemodynamic parameters were analyzed: weight, body mass index (BMI), jugular venous distention (JVD), creatinine, edema grade, right atrial pressure (RAP), pulmonary artery systolic pressure (PASP), systemic vascular resistance (SVR), pulmonary vascular resistance (PVR), cardiac output (CO; thermal and Fick), systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), respiratory rate (RR), oxygen saturation (SpO_2), shortness of breath (SOB), and pulmonary artery diastolic pressure (PADP).

Statistical Analysis

Spearman's Rho analysis, a non-parametric statistical test that measures the strength and significance of an association between two variables, was conducted using JMP Pro 14 (Cary, NC). In this analysis, each clinical and hemodynamic variable was used to compare their association to the documented PCWP. P-values were obtained from this analysis. All PCWP values used in analysis were the values documented in each patient's official RHC report by the procedural cardiologist. Ideal body weight and excess weight were calculated according to three methodologies and then correlated against PCWP. Significance was determined at p values of less than 0.05 in the Spearman Rho analysis, directionality of the association was not a factor here. All the variables that exhibited significance were entered into a stepwise regression model. The following variables passed univariate analysis and were considered for stepwise regression using the minimum Bayesian inclusion criteria: excess weight [Humme], weight, BMI, JVD, SpO^2, creatinine and edema. Variables that passed minimum BIC were then put into a Least Squares Fit against PCWP.

Results

Ten out of 17 selected clinical and hemodynamic parameters had a statistically significant association with measured PCWP value (**Table 1**). Based on directionality, PADP had the strongest association (0.73, $p<0.0001$) to PCWP. RAP and PASP also demonstrated reasonably strong associations (0.69, $p<0.0001$ and 0.67, $p<0.0001$, respectively). Weight and BMI did demonstrate significance ($p<0.001$) with associations of 0.2. JVD (0.24, $p<0.005$) and edema grade (0.2, $p<0.0001$), two commonly used physical signs to assess severity of heart failure, also demonstrated a significant association with PCWP. SOB did not (-0.016, $p=0.71$). When excess body weight was assessed by subtracting each patients calculated estimations of lean body weight using Boer, James, and Hume methods, all three-showed statistical significance to PCWP (0.18, 0.16, and 0.19 respectively; $p<0.0001$). When this excess weight was adjusted for the patients' heights, all three methods still presented with statistical significance to PCWP (0.18, 0.16, and 0.19 respectively; $p<0.0001$, $p<0.0003$, and $p<0.0001$).

Of the vital signs analyzed, SpO_2 (-0.17, $p<0.0091$) demonstrated a significant inverse association with PCWP. SBP, DBP, HR, RR, SVR, PVR, and CO (thermal and Fick) were nonsignificant. A stepwise regression of the significant variables (excess weight [Hume], weight, BMI, JV, SpO^2, creatinine, and edema) was conducted for the minimum Bayesian Inclusion criteria where the following variables passed onto multivariate analysis: weight, JVD, SpO_2. The log worth for these variables were the following: 1.9, 1.7 and 1.2 respectively.

Demographic	P-value	Directionality
Weight (kg)	<0.001	
BMI	<0.001	
JVD (cm)	0.0045	
Creatinine	<0.0001	
Edema Grade	<0.0001	
RAP (mmHg)	<0.0001	
PASP (mmHg)	<0.0001	
SVR (woods units)	0.05	
PVR(woods units)	0.39	
CO (L/min) Thermal	0.72	
CO (L/min) Fick	0.65	
SBP (mmHg)	0.92	
DBP (mmHg)	0.09	
HR (bpm)	0.67	
RR (brpm)	0.35	
SpO_2 (%)	0.0091	
PADP (mmHg)	<0.0001	
SOB	0.71	

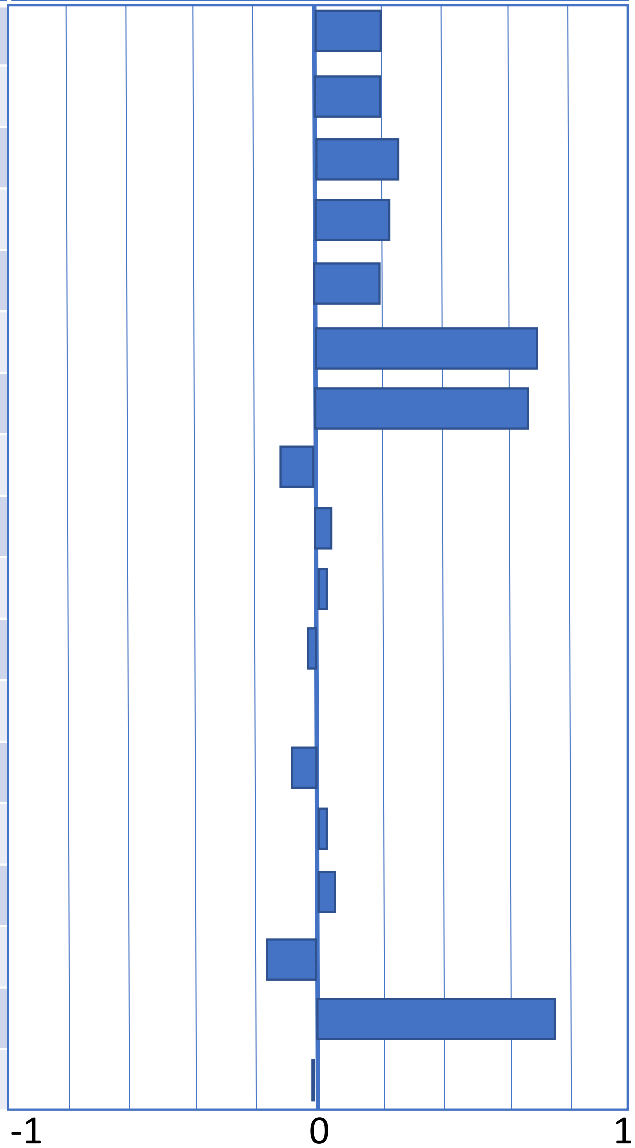

Table 1. Spearman's Rho analysis of key clinical and hemodynamic variables in heart failure compared to their association to pulmonary capillary wedge pressure (PCWP). Secondary analysis of patients undergoing right heart catheterization (n=538) clinical/hemodynamic variables to their measured PCWP demonstrated that 10 out of 17 selected variables had statistically significant association with the measured PCWP. Their association directionality is represented visually in the third column where the closer the horizontal bar graph is to 1 the closer that association is to a perfect positive correlation. The closer to -1 an association achieves the closer that association is to a perfect negative correlation. Abbreviations: kg= kilograms, BMI= body mass index, JVD= jugular venous distention, RAP= right atrial pressure, mmHg= millimeters of mercury, PASP= pulmonary artery systolic pressure, SVR= systemic vascular resistance, PVR= pulmonary vascular resistance, CO= cardiac output, L= liters, min= minute, SBP= systolic blood pressure, DBP= diastolic blood pressure, HR= heart rate, bpm= beats per minutes, RR= respiratory rate, brpm= breaths per minute, SpO_2= oxygen saturation, %= percentage, PADP= pulmonary artery diastolic pressure, SOB= shortness of breath.

Discussion

This large retrospective analysis helps to further clarify the relationship between several commonly measured clinical and hemodynamic parameters and degree of elevation in PCWP in heart failure patients. The variable with the strongest association to the measured PCWP was the measured PADP, followed by RAP and PASP. These data support the common clinical practice of using PADP as a PCWP surrogate. This association, while clinically practiced, has not been rigorously investigated.

Animal models of varying hemodynamics states have been helpful in better understanding intracardiac filling pressures in response to volume changes. A porcine analysis of acute hemorrhage did support the strong association between, PADP and PCWP, demonstrating that both were sensitive to small acute volume loss (~200 mL).[18] However, no volume overload relationship was described.[18] Wise et. al., showed that in a porcine volume overload model mean pulmonary artery pressure (MPAP) had a strong linear relationship (r2= 0.89) to severity of volume overload state, but the association was not as strong as PCWP (r^2= 0.98).[12] Unfortunately, the discrete systolic and diastolic pressures were not described or analyzed.[12]

Intracardiac hemodynamic derangements drive a large majority of symptoms in acute decompensated heart failure. The subjective SOB found was consistent with previously published data[3] in which no appreciable association with PCWP was demonstrated. Potentially the most interesting finding is how the SpO_2 demonstrated a significant inverse relationship with PCWP. While clinically logical that a decrease in SpO_2 may reflect a rising PCWP, this inverse relationship has not been previously reported in the literature. This finding supports the idea that, rather than relying on the subjective evaluation of SOB, a patient's measured SpO^2 may be a more reliable indicator of developing congestion or signal of persistent pulmonary congestion.

Common physical examination signs and symptoms, though limited by their subjective nature, do seem to carry some association to the cardiac filling pressures of a patient with heart failure based on this analysis. The JVD, edema grade, weight, and BMI carried a statistically significant association to the patient's measured PCWP while SOB was the only sign/symptom that did not. Outside of the SOB evaluation, these data support the guidelines that these evaluations remain a cornerstone in the assessment of the heart failure patient. Additionally, none of the clinically important vital signs other than SpO_2 carried a statistically significant association to PCWP. The intention of reporting this is not to discourage the performance of vital signs in heart failure assessment, as these data points are key in optimization of guideline directed medical therapy and can signal the development of hypoperfusion or shock in this high-risk patient population. The intention of reporting this is to help provide a general sense of the relationship between PCWP and a patient's vital signs when assessing the severity of congestion in the absence of shock. Often, clinical signs and symptoms, vital signs, and central hemodynamic measurements show valuable information that may or may not be colinear with other measured information. To discern this, a stepwise regression was conducted on the variables that displayed significance on the univariate level. This stepwise regression used a minimum Bayesian inclusion criterion which is often used to prevent overfitting of models by adding too many variables to a multivariate model. The multivariate stepwise regression and least squares fit confirmed that weight, JVD, and SpO_2 were significantly correlated with PCWP across a large group of data.

A clinically important parameter, Cardiac Output (CO), did not demonstrate significant correlation with the measured PCWP, no matter the method of measurement. Based on physiological relationships, one could reasonably hypothesize that as someone's PCWP increases an appreciable decrease in their CO (either thermal or Fick) would be seen. However, there was no statistically significant relationship demonstrated with this analysis. One logical rational for this is that no patient within the analyzed dataset was in cardiogenic shock. Therefore, much like the vital signs, the CO remained physiologically preserved and only with the development of shock would a significant inverse relationship be witnessed. Therefore, CO does not appear to be a good data point for assessing the development of congestion; but the utility of it as a data point for the assessment of severity of cardiogenic shock likely remains.

This study does have significant limitations, including the retrospective nature of this analysis. Second, these variables where not controlled for factors that could affect their association with PCWP. For example, PADP data was not controlled for the presence of pulmonary arterial hypertension (group 1) diagnosis. It is reasonable, that if this would have been done then a stronger association may have been appreciated. Finally, there may be some variability in PCWP values inherent to the number of proceduralists that obtained this data.

Conclusions

Heart failure continues to be a major cause of morbidity and mortality in the U.S. This retrospective analysis clarifies the associations of commonly used clinical and hemodynamic parameters to the clinical gold standard, PCWP.

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Competing Interests Statement: None

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