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The Journal of
Heart and Lung
Transplantation

http://www.jhltonline.org

ORIGINAL CLINICAL SCIENCE

Elevated left ventricular filling pressures can be estimated with accuracy by a new mathematical model

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KEYWORDS:
Heart failure;
right heart catheterization;
pulmonary capillary wedge pressure;
right atrial pressure;
jugular venous pressure

BACKGROUND: Although the clinical assessment of jugular venous pressure (JVP) provides accurate estimate of right atrial pressure (RAP), there is no reliable non-invasive method for assessing pulmonary capillary wedge pressure (PCWP). Our objective was to evaluate the sensitivity and specificity for detecting elevated left ventricular filling pressures using a model for PCWP estimation, based on the clinical assessment of RAP and association between RAP and PCWP, which is unique for each patient, identified in a recent right heart catheterization (RHC).

METHODS: The study included 377 patients (age, 54.3 ± 13 years) with heart failure with reduced ejection fraction (left ventricular ejection fraction of 30.5 ± 10.8%) who underwent 2 RHCs within 1 year. In Group A (189 randomly selected patients), hemodynamic variables with significant correlation with the current wedge pressure ($PCWP_2$) were identified and an equation estimating $PCWP_2$ based on these variables was formed. The validity of the equation was evaluated in the remaining 188 patients (Group B). The equation was also evaluated, prospectively in 39 new patients where RAP was estimated clinically, by physicians blinded to the results of the RHC.

RESULTS: $PCWP_2$ in Group A correlated with RAP_1, systolic pulmonary artery pressure ($SPAP_1$), and $PCWP_1$ of the first RHC and with RAP_2 and $SPAP_2$ of the second. The equation is $PCWP_2 = [3RAP_2 + (PCWP_1 - RAP_1) + 4]/2$. In Group B, the sensitivity and specificity of estimated $PCWP_2$ for diagnosis of elevated LV filling pressures (invasive values >18 mm Hg) was significant, reflected by an area under the curve (AUC) of 0.954 ($p < 0.001$). In the prospective sub-group, where JVP was entered in the formula as an estimate of RAP_2, correlation between estimated and measured $PCWP_2$ was $r = 0.803$ ($p < 0.001$).

CONCLUSIONS: The current PCWP of a patient with heart failure can be estimated accurately by a simple equation based on measurements of a previous RHC and the current value of clinically assessed JVP.

J Heart Lung Transplant 2013;32:511–517

Approximately 90% of patients hospitalized for decompensated heart failure (HF) present with symptoms of congestion.[1] Clinically, overt congestion is often preceded by a period of 2 to 3 weeks of a gradual rise in ventricular filling pressures that most often go unnoticed clinically.[2–4] The gold standard for left ventricular (LV) filling pressure evaluation is the measurement of pulmonary capillary wedge pressure (PCWP) using right heart catheterization (RHC).

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1053-2498/$ - see front matter
http://dx.doi.org/10.1016/j.healun.2013.01.986

However, the invasive nature of this procedure renders its use in the everyday outpatient setting problematic. A reliable clinical method to non-invasively evaluate LV filling pressures could enable timely enhancement of pharmacologic treatment and thus prevent HF destabilization.

Several clinical signs identified during the physical examination are indicative of congestion.[5,6] However, their weak correlation with a patient's hemodynamic parameters and low sensitivity and positive predictive value for elevated LV filling pressure detection has limited the usefulness of a physical examination for diagnosing elevated LV filling pressures.[7–10] Elevated jugular venous pressure (JVP) seems to be the most sensitive and specific clinical parameter associated with elevated PCWP. It needs to be emphasized that PCWP is the single most important hemodynamic variable associated with a patient's symptoms and prognosis.

The objective of the present study was to use relationship between right and left sided filling pressures, which is unique for each HF patient, identified by a recent RHC (within 1 year), to estimate the current PCWP by applying a diagnostic mathematic model based on the measurement of current right atrial pressure (RAP) only. If this approach were feasible and the model had adequate sensitivity, specificity, and positive predictive value for elevated PCWP diagnosis, then clinically assessed JVP (which has been shown to accurately represent RAP), together with invasive measurements obtained within the previous year, would be used to estimate a patient's PCWP. This would allow clinicians to detect early elevations of left ventricular filling pressures and intervene in time to avert clinical decompensation.

Materials and methods

The protocol for this study was approved by the hospital's Investigational Review Board

Study sample

During the 20-year period from March 1992 through February 2011, approximately 2,000 patients were monitored in the outpatient HF clinic of our institute. All patients who had a history of symptomatic HF and underwent 2 RHCs within a 1-year interval were identified in our database. The analysis excluded patients with predominantly right-sided HF (those with congenital heart disease, pulmonary disease, idiopathic pulmonary arterial hypertension, coronary disease or any other condition primarily affecting the right side of the heart) and patients with HF secondary to restrictive cardiomyopathy, receiving continuous inotrope infusion, circulatory support with an intra-aortic balloon pump, or mechanical ventilation. We identified 377 patients (~20% of all patients), 322 men and 55 women, who fulfilled the predefined criteria.

All RHCs were performed because of clinical indications by a trained cardiologist in the catheterization laboratory or the intensive care unit (ICU). The same standard protocols of our institution were used for the procedure (irrespective of the site where the RHC was performed), which included careful validation of the zero level. Both RHCs in the same patient were performed in the same setting (ICU or catheterization laboratory). For the RHCs that were performed in the ICU, the pulmonary artery catheter (PAC) was removed after the hemodynamic measurements were acquired, so only data from one assessment were used. Data from critically ill patients under continuous hemodynamic monitoring were not used in this study.

Study design

Medical history, clinical and echocardiography data (only when performed within 2 months from the first RHC) from all patients were recorded. RAP, systolic pulmonary artery pressure (SPAP), and PCWP from the RHCs of all patients were collected. For patients who had undergone more than 2 RHCs within the same year, the 2 RHCs with the shortest time interval between them were selected for the analysis. The cohort of the 377 patients was randomly divided into 2 equal groups: the first 189 patients consisted Group A, the main group used for detection of correlations between the various hemodynamic parameters and formulation of the mathematic model. Group B consisted of 188 patients who served as a control group to confirm the sensitivity, specificity, and positive predictive value of the pre-defined equation in predicting PCWP above certain clinically important thresholds. Finally, to demonstrate that this equation can be used in a clinically relevant setting, a sub-group of 39 patients who had undergone a RHC within the previous year and were scheduled for a new RHC because of clinical indications were used for prospective model evaluation. The JVP in these patients was clinically assessed by a physician blinded to the results of the RHC, and this value was entered in the equation as the current RAP to calculate PCWP and compare the resulting values with the ones directly measured by the RHC.

JVP measurements

JVP was assessed in all patients by trained physicians experienced in HF management and blinded to the results of the RHCs. Patients were lying on a bed and were initially put at a 45° upright position to locate the venous pulse of the right internal jugular vein. When the pulse was identified, the vertical distance between the highest point of the most obvious pulsation and the sternal angle was measured in centimeters using a ruler. The sternal angle was by convention considered to be 5 cm above the level of the right atrium.[11] The distance of the point of the most obvious jugular pulse from the sternal angle was added to 5 and the result was converted to mm Hg by dividing by 1.36. If a venous pulse was not identified at 45°, the bed was slowly moved to 0°, because if venous pressures were <5 cm H_2O, the pulse would be below the clavicle and sternal angle at 45°. If a pulse was not identified again, the bed was slowly tilted to 90° to identify the venous pulse generated by higher central pressures. When central venous pressures are very high, the pulse may be hidden in the jaw angle with the patient at 45°.

Statistical analyses

Continuous variables were compared using Student's *t*-test and are presented as means ± standard deviation, whereas categoric variables were compared using the chi-square test and are presented as percentages. Because all studied variables were normally distributed, the correlation between them was assessed using Pearson's correlation, and linear regression analysis was used