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Letters

RESEARCH LETTER

Comprehensive RV Hemodynamic Assessment With Pressure-Volume Analysis During Impella Support

Findings From the CHAMP-IMPELLA Study

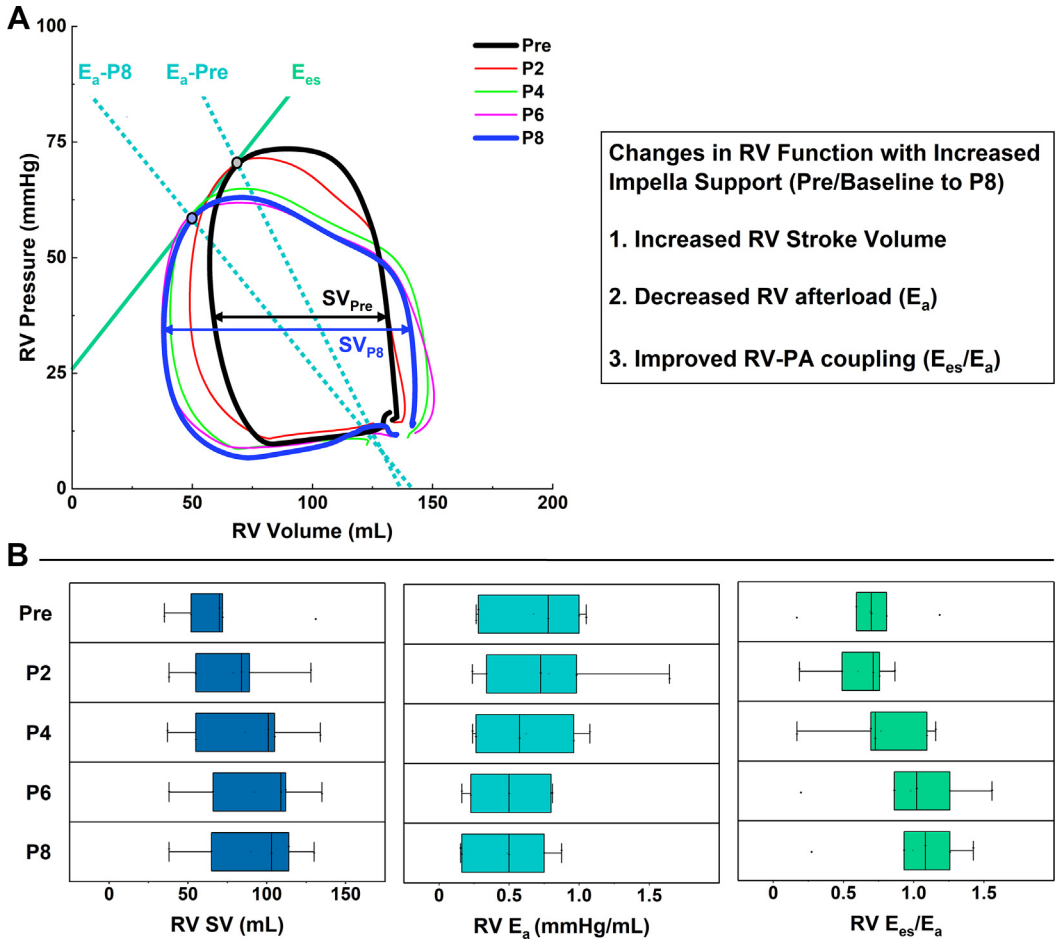
Percutaneous ventricular assist devices (pVADs) such as the Impella CP (Abiomed) are widely used for the prevention and management of cardiogenic shock caused by left ventricular (LV) dysfunction. Pressure-volume (PV) analysis with a conductance catheter has elucidated the LV response to Impella support and provided valuable insights regarding pump-ventricle interactions.[1] However, the right ventricle's (RV) response to an LV pVAD device has not yet been evaluated in humans despite data showing the importance of RV performance on prognosis, especially in patients with LV dysfunction. Large-animal models have shown that LV Impella support improves RV function, but the precise nature and extent of such benefit in humans remains unknown.[2] We sought to resolve this area of uncertainty by performing RV PV analysis in individuals receiving Impella CP LV support during high-risk percutaneous coronary intervention.

Six individuals, ranging in age from 59 to 80 years, were recruited. The study protocol was approved by the Institutional Review Board at Columbia University. In brief, RV PV analysis was performed prior to percutaneous coronary intervention according to a prespecified protocol that adhered to published best practices.[3] A 7-F conductance catheter (CD Leycom) was inserted into the RV via the internal jugular vein prior to Impella insertion. The catheter was calibrated in the usual fashion with hypertonic saline, and then PV loops were recorded at baseline and after the Impella CP was inserted. Recordings were performed for each patient at P2, P4, P6, and P8, with a 2-minute equilibration period between ramp stages. RV PV loops were analyzed to determine RV stroke volume (SV), RV total effective arterial elastance (E_a; a measure of afterload that integrates pulmonary vascular resistance and downstream pressure [ie, pulmonary capillary wedge pressure], and finally, the RV-PA coupling ratio (RV end-systolic elastance [E_{es}]/E_a). RV E_{es} (a measure of RV contractile function) was calculated using the single-beat method from end-systolic coordinates recorded when RV volumes changed during the Impella ramp. Generalized linear mixed models for repeated measures with a compound symmetry covariance structure were used to evaluate changes in the aforementioned PV loop-derived parameters throughout the Impella ramp from baseline to P8. The model assumed non-normal distribution of the data and included baseline values and P level as fixed effects. A secondary generalized linear mixed model excluded baseline measurements in order to isolate the effects of changing Impella P level. The project was sponsored by Abiomed, but the investigators had complete control of the data at all times, performed the analysis, and drafted the manuscript without oversight from the sponsor.

Figure 1A highlights PV loops from 1 participant that illustrate the stereotypical response to increasing Impella P level. Changes in RV SV, E_a, and E_{es}/E_a among all 6 participants are featured in the boxplots in **Figure 1B**. RV SV increased significantly from baseline to P8, evidenced by a widening of the PV loop. These changes were statistically significant in the primary model (RV SV at baseline, 72.0 mL [Q1-Q3: 36.5-107.5 mL]; RV SV at P8, 90.0 mL [Q1-Q3: 54.5-125.5]; $P = 0.009$) and remained significant in the secondary model as well ($P = 0.018$). There was a substantial and statistically significant decline in RV E_a (RV E_a at baseline, 0.676 mm Hg/mL [Q1-Q3: 0.292-1.059 mm Hg/mL]; RV E_a at P8, 0.488 mm Hg/mL [Q1-Q3: 0.102-0.871 mm Hg/mL]; $P = 0.013$). Consequently, the RV-PA coupling ratio improved significantly as well (E_{es}/E_a at baseline, 0.691 [Q1-Q3: 0.306-1.075]; E_{es}/E_a at P8, 0.994 [Q1-Q3: 0.610-1.379]; $P < 0.001$).

This study builds on a prior case report[4] and presents the first ever series of RV PV analyses performed during LV unloading with an Impella CP. The data demonstrate the feasibility of obtaining

FIGURE 1 Right Ventricular Pressure-Volume Loops During Left Ventricular Unloading With an Impella CP



(A) Right ventricular (RV) pressure-volume (PV) loops from 1 study participant illustrating characteristic changes in RV size and function with increasing Impella P level. The key changes in the RV PV loop are that: 1) RV stroke volume (SV) increased; 2) afterload (effective arterial elastance [E_a]) declined significantly; and 3) the RV-PA coupling ratio (end-systolic elastance [E_{es}]/E_a) decreased. Note that the E_{es} and E_a headings in the PV diagram represent the slopes of the end-systolic PV relationship (ESPVR) and effective E_a lines. (B) Box plots depicting the ranges of RV SV, E_a, and the RV coupling ratio among all study participants according to P level.

high-fidelity hemodynamic measurements in the RV, but any conclusions should be understood within the context of the study's very small and curated sample size. These limitations notwithstanding, PV analysis demonstrates that there are significant changes in RV morphology and function with LV unloading. Serial interactions between the left- and right-sided circulations cause RV SV to increase as overall cardiac output rises with greater Impella CP support. Although this appeared to be well tolerated in a sample of patients with grossly normal RV function, the inability to augment SV in response to increased preload may occur in patients with RV dysfunction and precipitate RV failure. These potentially unfavorable effects may be mitigated by a decline in RV afterload, which resulted in improved RV-PA coupling with LV unloading. We have previously postulated that the change in RV afterload is driven by changes in downstream pressure in the right heart (ie, pulmonary capillary wedge pressure) rather than changes in intrinsic pulmonary properties.[5] Further research is needed to evaluate the physiological impact of short-term pVAD use in broader cohorts, including patients with pulmonary hypertension and RV dysfunction, and to ascertain if they are similar to the effects of durable mechanical circulatory support devices.

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The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

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