Title
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Journal
ASAIO Journal, 69(2)

ISSN
1058-2916

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Publication Date
2023-02-01

DOI
10.1097/mat.0000000000001869

OPEN

Pressure Volume Loop Analysis of the Right Ventricle in Heart Failure With Computed Tomography

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Right ventricular (RV) function is an important marker of mortality in chronic left-sided heart failure. Right ventricular function is particularly important for patients receiving left ventricular assist devices as it is a predictor of postoperative RV failure. RV stroke work index (RVSWI), the area enclosed by a pressure–volume (PV) loop, is prognostic of RV failure. However, clinical RVSWI approximates RVSWI as the product of thermodilution-derived stroke volume and the pulmonary pressure gradient. This ignores the energetic contribution of regurgitant flow and does not allow for advanced energetic measures, such as pressure–volume area and efficiency. Estimating RVSWI from forward flow may underestimate the underlying RV function. We created single-beat PV loops by combining data from cine computed tomography (CT) and right heart catheterization in 44 heart failure patients, tested the approximations made by clinical RVSWI and found it to underestimate PV loop RVSWI, primarily due to regurgitant flow in tricuspid regurgitation. The ability of RVSWI to predict post-operative RV failure improved when the single-beat approach was used. Further, RV pressure–volume area and efficiency measures were obtained and show broad agreement with other functional measures. Future work is needed to investigate the utility of these PV metrics in a clinical setting. *ASAIO Journal* 2023; 69;e66–e72

Right ventricular (RV) performance is increasingly recognized as a key metric in the evaluation of patients with left-sided cardiac dysfunction[1] as measures of RV systolic function such as RV ejection fraction (RVEF)[2,3] and RV longitudinal shortening[4,5] have been shown to predict survival in heart failure patients. Pulmonary arterial (PA) pressure measurements have also been shown to improve evaluation with RV volumes alone; Ghio *et al.*[6] found the ability of RVEF to predict freedom from urgent transplantation strengthened in the context of elevated pulmonary pressure.

RV stroke work index (RVSWI) measures the energetic work performed by the ventricle by integrating volume and pressure values during the cardiac cycle. RVSWI has been shown to predict right ventricular dysfunction after implantation of left ventricular assist devices (LVAD), particularly in the case of elevated central venous pressure.[7,8] However, due to poor specificity, RVSWI has had limited prognostic value in preoperative LVAD assessment in follow-up studies.[9] We hypothesize that the limited specificity is due to how RVSWI is measured. Specifically, the gold standard measurement of RVSWI is the area encapsulated in a pressure–volume (PV) loop from RV conductance catheterization[10] normalized by the body surface area (BSA). Clinically, this PV loop area is approximated as a rectangle with forward stroke volume (measured via thermodilution) as the width and mean pulmonary pressure difference (difference between mean pulmonary and right atrial pressure) as the height. While this approximation enables estimation from a right heart catheterization (RHC), it introduces potential pitfalls and precludes measurement of other PV loop-based metrics.

Recently, ECG-gated computed tomography (CT) evaluation of RV function has been shown to predict RV failure after LVAD implantation in heart failure.[11] However, whether this evaluation can be improved by leveraging pressure information is unknown. In this study, we combine CT-derived RV volumetry with RV pressure recordings from contemporaneous RHC to generate single-beat RV PV loops from which we measure RVSWI and other advanced measures. We use this framework to evaluate the assumptions used in clinical RVSWI measurements in heart failure patients undergoing evaluation for advanced therapies. We hypothesize that clinical RVSWI will underestimate RV performance (relative to CT-based estimation) in patients with regurgitant stroke volume. While forward stroke volume and stroke work index may be strongly associated with patient wellness, regurgitant stroke volume and its corresponding stroke work may be an important factor of RV function, which is the most significant predictor of RVF in meta-analysis.[9] Therefore, we expect that incorporating the contribution of regurgitant flow may improve the prognostic ability of RVSWI in predicting RV failure after LVAD implantation, particularly in patients with tricuspid regurgitation (TR). Further, by creating single-beat PV loops, we expect our approach will enable us to further characterize RV function via additional, energetics-based metrics – PV area (PVA)[12] and RV efficiency.[13]

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Submitted for consideration September 2022; accepted for publication in revised form November 2022.

Disclosure: The authors have no conflicts of interest to report.

A.S. and F.C. are supported by National Institute of Health (NIH).

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DOI: 10.1097/MAT.0000000000001869

Methods

Population

With IRB waiver of informed consent, records of non-congenital heart failure patients who underwent cardiac cineCT scanning between September 2017 and September 2021 were retrospectively reviewed to identify patients undergoing workup for advanced therapies. Patients were included if they received a right heart catheterization within two weeks of the cineCT scan. Exclusion criteria included incomplete or missing pressure waveform recordings, the poor contrast-to-noise ratio in the CT images, defined as the ratio of the absolute difference between blood pool and myocardial pixel intensity to the standard deviation of the image noise as less than 5, or documented changes in appearance or care that would affect either pressure or volume readings between the two studies, such as changes in cardiac silhouette and documented changes in diuretics or urinary output. RV failure in patients who received a left ventricular assist device (LVAD) was determined using the updated consensus of adverse events of mechanical circulatory support.[14]

CT-Derived Parameters

CineCT imaging was performed on a 256-slice Revolution CT scanner (GE Healthcare, Chicago, IL). All patients were examined in the supine position. After a scout image was taken, a single axial slice was selected to monitor contrast arrival. About 80 to 120 ml of contrast agent (Omnipaque; GE Healthcare, Chicago, IL) was injected, followed by a saline flush, all at 4 ml/s. The scans were performed during a single breath-hold, using retrospective ECG gating. The kVp (80–120 kV) and X-ray tube current (400–600 mA) were determined based on a clinical imaging protocol. Axial images were reconstructed at 10% intervals across the cardiac cycle (0 to 90% of the R-R). Effective dose length product was estimated to be between 200 and 500 mGy*cm. Ventricular volumes such as right ventricular end-diastolic volume (RVEDV), end-systolic volume (RVESV), and stroke volume (SV_{CT}), as well as ejection fraction (RVEF) were obtained from a volume curve, V(t), spanning one cardiac cycle. Right ventricular blood pool volume was derived using a U-Net-based deep learning framework that has been previously shown to accurately segment blood chambers in cardiac CT angiograms.[15] Segmentations generated by the deep learning approach were visually inspected to verify that segmented blood volumes were anatomically correct and temporally consistent.

RHC Waveform Analysis

RHC records within 2 weeks of the cineCT scan were reviewed to extract a thermodilution-based estimate of cardiac output (CO_{RHC}), heart rate (HR), mean pulmonary artery pressure (mPAP), right atrial pressure (RAP), end-systolic and end-diastolic right ventricular pressures (RVSP and RVDP). From these values, we derived right ventricular pulse pressure (RVPP) as the difference between RVSP and RVDP, stroke volume (SV_{RHC}) as the ratio of thermodilution-based cardiac output (CO_{RHC}) to HR, and stroke volume index (SVI_{RHC}) as the SV_{RHC} indexed by body surface area (BSA). As described earlier, SV_{RHC} only captures forward flow through the pulmonary artery. An RHC-based estimate of RVSWI ($RVSWI_{RHC}$) was calculated as the product of SVI_{RHC} and the difference between mPAP and RAP. For PV loop analysis, the RV pressure waveforms obtained during RHC were digitized using plot digitizing software.[16]

Pressure–Volume Loop Estimation

To synchronize RV pressure and volume waveforms and generate PV loops, both signals were resampled to a standard number of points ($n = 60$) using the percentage of the cardiac cycle (%RR) as a shared reference. The %RR was determined using ECG signals already synchronized with both the RHC and CT studies. Heart rates were compared to account for possible differences in cardiac function as heart rate increases or decreases. PV loop-based estimation of RVSWI was obtained by integrating the P(t) vs V(t) signal and normalizing by patient BSA. RVSWI calculated using CT PV loops is denoted $RVSWI_{CT}$.

Comparison of Clinical RVSWI With Single-Beat CT-RHC Synthesis

We compared the catheter-based estimate of pressure difference (mPAP-RAP) to the right ventricular pulse pressure (RVPP) to evaluate the assumption that the right ventricular pulse pressure is the same as the pulmonary and right atrial pressure difference. We also compared thermodilution-derived SV_{RHC} to CT-derived SV_{CT} to evaluate the assumption that thermodilution-derived stroke volume captures the blood volume ejected by the RV. Finally, the resulting RVSWI estimates - clinical $RVSWI_{RHC}$ and $RVSWI_{CT}$ – were compared. Differences between SV_{RHC} and SV_{CT} as well as $RVSWI_{RHC}$ and $RVSWI_{CT}$ were evaluated as a function of tricuspid regurgitation (none-mild vs moderate-severe) as assessed by the most recent clinical echocardiography study.

To evaluate the impact of assuming the PV loop is rectangular in shape, we created a hybrid RVSWI estimate ($RVSWI_{COMB}$) defined as the product of SVI_{CT} and RV pulse pressure. This metric still assumes a rectangular loop shape but corrects for discrepancies introduced by the use SVI_{RHC} and pulmonary pressure. $RVSWI_{COMB}$ was compared to $RVSWI_{CT}$. $RVSWI_{COMB}$ does not require full volumetric or hemodynamic waveforms so can be more easily obtained. Therefore, its ability to predict right ventricle failure in patients who went on to receive an LVAD was compared directly against $RVSWI_{RHC}$ and tricuspid regurgitation.

Advanced Energetic Evaluation: RV Pressure Volume Area and Efficiency

Pressure volume area (PVA) is defined as the sum of the two nonoverlapping areas of the PV-loop diagram: $RVSW_{CT}$ and the ventricular potential energy. Potential energy is the area enclosed by the end-systolic and end-diastolic pressure–volume relationship curves (ESPVR and EDPVR, respectively), which can be approximated as the triangular area between the origin, the end-systolic point, and the end-diastolic point.[17] The end-systolic and end-diastolic points were defined as the points with maximum and minimum instantaneous elastance respectively. Right ventricular efficiency is defined as the ratio of stroke work to total PVA. To analyze broad agreement between advanced energetic evaluations and established measures of RV function, RV PVA and efficiency were compared to RV ejection fraction. To evaluate the impact of estimating ESPVR and EDPVR as straight lines which intersect at the origin (*i.e.*, $V_0 = 0$), we compared PVA and RV efficiency measures to values obtained when V_0 was estimated using two single-beat approaches – a pressure-based estimation that calculates a theoretical maximum ventricular pressure[18] and a nonlinear modeling approach.[19]

Statistical Analysis

Continuous values are reported as mean and standard deviation if normally distributed and as the median and first and third quartile if non-normally distributed. Binary variables are reported as proportions. Correlations between measures are measured using Pearson's correlation coefficient for continuous variables. Student's t-test was used to test whether the correlation coefficient was significantly different than 0. The difference in stroke volume and difference in stroke work index between different grades of tricuspid regurgitation were compared using an unpaired t-test. The correlations between continuous variables were also analyzed using linear regression modeling. The relationships between the variables were considered strong for absolute correlation values above 0.7, moderate for absolute values above 0.5, mild for values above 0.3, and weak for all lower values. Comparison of predictive potential was done using area under the curve (AUC) of receiver operating characteristic (ROC) curves. AUCs are reported with a 95% confidence interval. A p value of less than 0.05 was considered significant. All statistical analyses were performed in Matlab R2018b (The Math Works, Inc, Natick, MA).

Results

Patient Population

Fifty-four patients had RHC and CT scanning performed contemporaneously (within 2 weeks) as part of work-up for advanced therapies. Five patients were excluded due to insufficient RV pressure waveforms. Five patients had insufficient contrast-to-noise ratio on cineCT imaging. None of the 44 patients experienced a significant change in cardiac silhouette or urinary output in the time between cineCT and RHC (Figure 1). The median time between CT and RHC was 2 (interquartile range: 0–4) days. Heart rates were not significantly different between the CT and RHC study (CT HR: 84 ± 12 bpm *vs*. RHC HR: 85 ± 18 bpm, $p > 0.05$). The difference between CT and RHC heart rate was −1 ± 10 bpm. Demographics of the 44 patients, our study population, are described in Table 1. Of the patients, 14 went on to receive an LVAD with RHC and CT scans within 2 weeks and for whom $RVSWI_{COMB}$ could be measured. Of the 14, 6 (46%) went on to have postoperative right ventricular failure.

Accuracy of Pressure Approximation

Mean pulmonary arterial pressure was highly correlated ($\rho = 0.81, p < 0.001$) with RV pulse pressure. However, Right ventricular pulse pressure was greater, on average, by 21 mmHg. The standard deviation of the difference was 7 mmHg (Figure 2B).

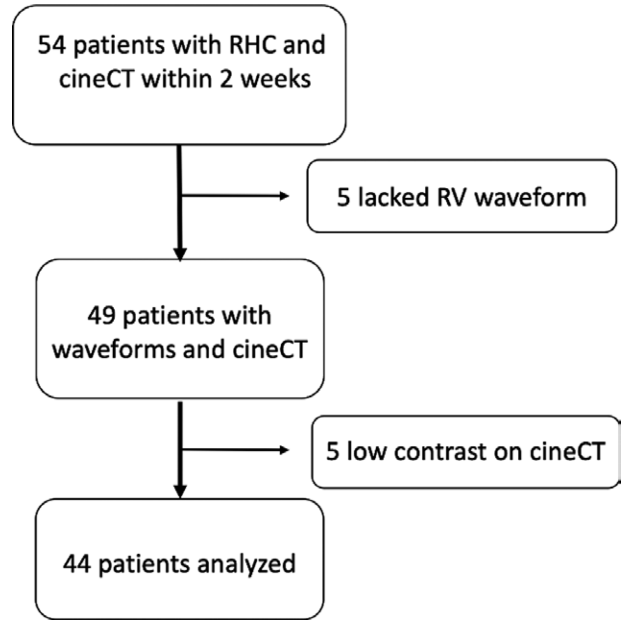

Figure 1. Flowchart of patients evaluated in this study. 44 patients were evaluated after the removal of patients who had low right ventricular (RV) contrast on imaging (n = 5) and patients with right heart catheterization (RHC) studies that did not have RV pressure waveforms available for analysis (n = 5).

Table 1. Patient Parameters

Parameter	Mean/Median	SD/IQR (25–75%)
Demographic		
Age (years)	58	50–68
Female (%)	21	-
BMI (kg/m²)	27.1	22.9–29.5
Ischemic HF (%)	14	-
RHC to CT time (days)	2	0–4
RHC		
CO (L/min)	3.7	1.2
HR (bpm)	85	18
MPAP (mmHg)	31	11
RAP (mmHg)	10	5
PCWP (mmHg)	22	9
PVR (mmHg*min/ L)	2.1	1.4–3.6
Echocardiography		
LV enlargement (%)	38.6	-
LV dysfunction (%)	90.9	-
RV enlargement (%)	11.4	-
RV dysfunction (%)	54.5	-
Mod-sev TR (%)	29.5	-
CT		
LVEDVI (ml/m²)	142	120–199
LVESVI (ml/m²)	110	82–188
LVEF (%)	20	5
RVEDVI (ml/m²)	123	38
RVESVI (ml/m²)	86	36
RVEF (%)	32	11

BMI, body mass index; CO, cardiac output; EF, ejection fraction; EDVI, end-diastolic volume index; ESVI, end-systolic volume index; HR, heart rate; LV, left ventricle; MPAP, mean pulmonary arterial pressure; PCWP, pulmonary capillary wedge pressure; PVR, pulmonary vascular resistance; RAP, right atrial pressure; RV, right ventricle; TR, tricuspid regurgitation.

Accuracy of Stroke Volume Approximation and the Impact of Loop Shape

The correlation between SV_{RHC} and SV_{CT} was not statistically significant ($\rho = 0.14, p = 0.35$). Thermodilution-derived SV_{RHC} underestimated SV_{CT} by 30 ml with a standard deviation of 29 ml (Figure 2C). Clinical $RVSWI_{RHC}$ was mildly correlated with PV loop-derived $RVSWI_{CT}$ ($\rho = 0.36, p = 0.017$) (Figure 2D). $RVSWI_{COMB}$ was strongly correlated with PV loop-derived $RVSWI_{CT}$ ($\rho = 0.78, p < 0.001, RVSWI_{COMB} = 1.2\ RVSWI_{CT} + 3.5, R^2 = 0.10$).

Impact of Tricuspid Regurgitation on Stroke Volume and Stroke Work

Patients with moderate-to-severe tricuspid regurgitation (TR) had a significantly higher discrepancy in stroke volume between CT and RHC compared to patients with no-to-mild tricuspid regurgitation (median: 40 ml *vs*. 23 ml difference, $p = 0.003$). Patients with moderate- to-severe TR also had a larger discrepancy between $RVSWI_{RHC}$ and $RVSWI_{CT}$ than patients with less TR (median: 2 and 6 g/beat/m², $p = 0.003$) (Figure 2E).

Patients with mild or no tricuspid regurgitation (n = 30, 68%) had a significant and moderate correlation between $RVSWI_{RHC}$ and PV-derived $RVSWI_{CT}$ ($\rho = 0.56, p = 0.001$). The correlation for patients with moderate or severe tricuspid regurgitation (n = 14, 32%) did not achieve statistical significance ($\rho = 0.39, p = 0.086$).

Effect of Corrected Stroke Work Index on Patient Outcomes

Of the 14 patients, six (43%) had post-LVAD RVF. Patients with RVF after LVAD implantation did not have significantly different $RVSWI_{RHC}$ than those without (RVF: 6.1 ± 2.9 *vs*. non-RVF: 6.9 ± 3.4, $p = 0.33$). However, patients with RVF had significantly higher $RVSWI_{COMB}$ than those without RVF (RVF: 21 ± 9 *vs*. non-RVF: 13 ± 5, $p = 0.0149$) (Figure 2F).

The AUC for $RVSWI_{COMB}$ (0.81, 95% CI: 0.60–1.0), as a predictor of postoperative failure, was significantly higher than $RVSWI_{RHC}$, (0.50, 95% CI: 0.23–0.77).

Of the 14 patients, four (29%) had moderate to severe tricuspid regurgitation. Prediction of RVF based on the presence of

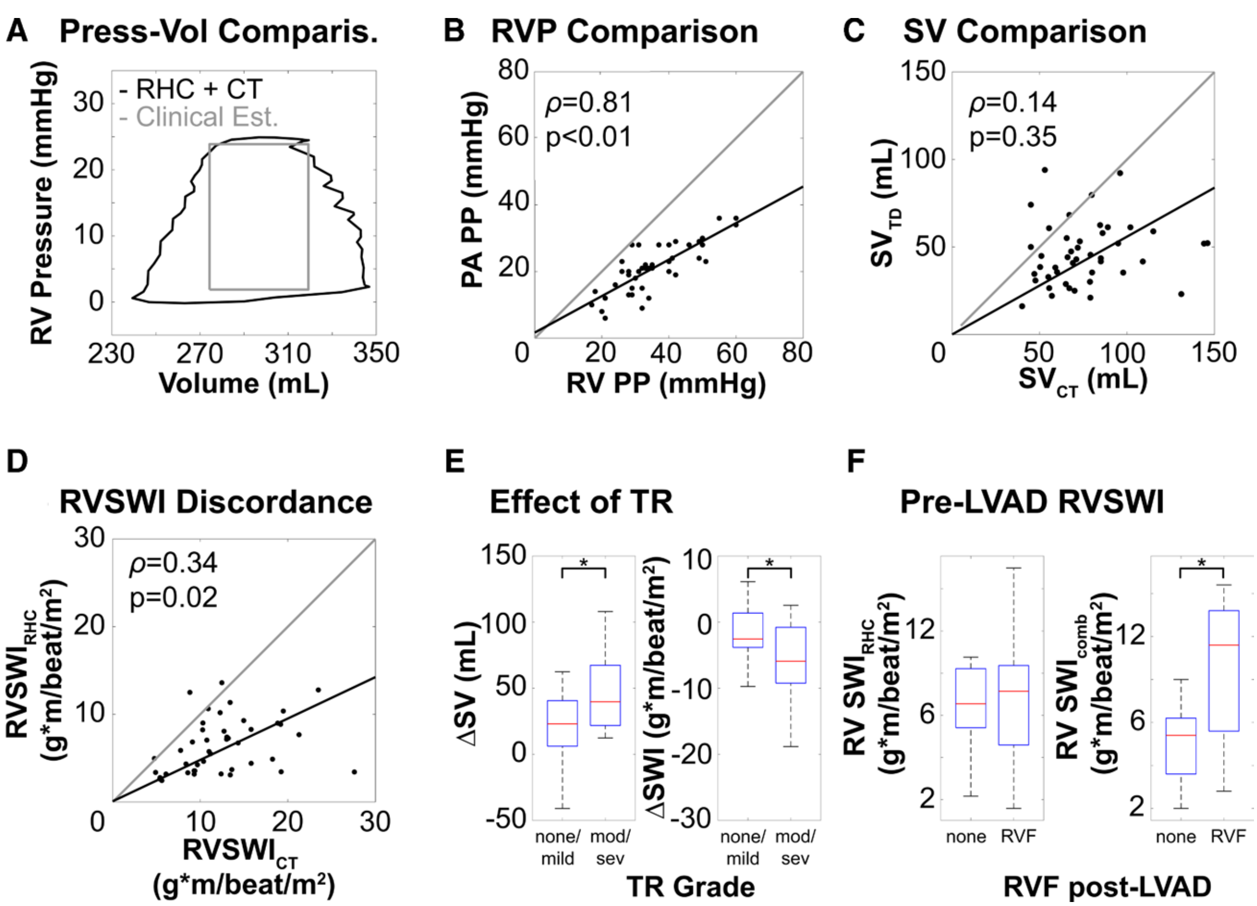

Figure 2. Evaluation of discrepancy between right heart catheterization (RHC)- and pressure–volume (PV) loop-based evaluation of right ventricular stroke work index (RVSWI). Best fit line (black) and unity line (gray) are shown when relevant. **A**: Comparison between the clinical approximation and single-beat approach. **B**: High correlation was observed between mean pulmonary artery pressure (mPAP) minus right atrial pressure (RAP) and right ventricular pulse pressure (RH PP). **C**: RHC- and computed tomography (CT)-derived stroke volume were not significantly correlated. **D**: Mild correlation between RVSWI estimates with clinical underestimation. **E**: Differences between stroke volume (SV) and stroke work index (SWI) were larger in moderate-severe tricuspid regurgitation. **F**: Correcting for underestimation of SV by thermodilution and replacing mPAP with RV PP improved separation between patients that would and would not have post-left ventricular assist device (LVAD) right ventricular failure. *$p < 0.01$.

moderate to severe tricuspid regurgitation had an accuracy of 64% (9/14), specificity of 74%, and sensitivity of 25%.

Advanced Energetic Measures

Our ability to estimate advanced energetic measures of RV performance is shown in Figure 3. Visualizations of these energetic measures are shown in Figure 3A. RV efficiency was strongly correlated with RV ejection fraction ($\rho = 0.77, p < 0.001$, $RVEff = 1.0RVEF + 5$, $R^2 = 0.59$, Figure 3B). PVA had a moderate inverse correlation with RVEF ($\rho = -0.64, p < 0.001$, $PVA = -1.3RVEF + 86$, $R^2 = 0.42$, Figure 3C).

Impact of V_0 Estimate on PVA and RV Efficiency

The method used to estimate V_0 did not have a significant impact on our estimates of PVA and RV efficiency. Estimation of V_0 using the Pmax method succeeded in 38 of the 44 patients. In these 38 patients, the average V_0 was found to be -25 ± 50 ml. This resulted in PVA and efficiency values that underestimated our initial estimate, though were still highly correlated (*PVA* $\rho = 0.86, p < 0.001$, RV Eff $\rho = 0.91, p < 0.001$). The results from using the nonlinear modeling of V_0 were similar. Modeling succeeded in 36 of the 44 patients. In this group, V_0 was calculated to be 55 ± 26 ml. Again, this led to PVA and efficiency values that were highly correlated to our estimate when $V_0 = 0$ (*PVA* $\rho = 0.92$, $p < 0.001$, RV Eff $\rho = 0.92$, $p < 0.001$). While this assumption led to a consistent absolute error that would affect proposed cutoff values, it did not affect the relative agreement of PVA or RV efficiency.

Discussion

This study aimed to demonstrate the ability of hemodynamics and CT imaging to reconstruct PV loops in heart failure patients and augment hemodynamic or volumetry-alone assessment. In patients with heart failure, clinical $RVSWI_{RHC}$ was significantly different than RVSWI obtained using a single-beat PV loop approach. While the clinical assumption that RV PP is the same as mPAP leads to small errors ($\rho = 0.81$), thermodilution-derived SV_{RHC} was significantly lower than SV_{CT} obtained with CT. The underestimation of SV by thermodilution was more pronounced in patients with moderate-to-severe tricuspid regurgitation, which affected 30% of the study cohort. PV loop-derived $RVSWI_{CT}$ and clinical $RVSWI_{RHC}$ showed stronger agreement if patients with tricuspid regurgitation were excluded from the analysis (all patients: $\rho = 0.36$ vs. patients without TR: $\rho = 0.56$). Correcting for pressure and stroke volume differences (but maintaining a rectangular PV loop shape) led to $RVSWI_{COMB}$ which was similar ($\rho = 0.78$) to the RVSWI estimated by combining RHC and CT data. Lastly, in a subcohort of patients who received an LVAD, correcting RVSWI with CT volumetry showed statistically significant improvement in the ability of RVSWI to differentiate patients that went on to have RV failure from those who did not use AUC of ROC curves.

Our approach also enabled the estimation of advanced energetic measures of RV performance such as pressure–volume area (PVA) and ventricular efficiency using clinically obtained studies. We found these measurements complemented volumetric CT measures of RV function (RVEF). Therefore, combining CT with RHC may provide additional prognostic or diagnostic information for patients than RHC alone. While estimates of V_0 were estimated to be nonzero with different approaches, accounting for V_0 had little effect on how patients would be classified based on PVA and efficiency. Further, the Pmax and nonlinear curve fitting methods failed to yield V_0 estimates in 14% and 18% of the patient population, respectively.

While direct Fick is the gold standard for the estimation of cardiac output, estimated Fick and thermodilution are more commonly used in a clinical setting. Studies comparing these two estimates have found significant differences between thermodilution and estimated Fick, with thermodilution being a stronger predictor of mortality.[20,21] Underestimation of cardiac output in the presence of tricuspid regurgitation is well documented, even using the direct Fick approach.[22–24] In our study, accounting for regurgitant flow ($RVSWI_{COMB}$) strengthened the estimation of PV loop-derived RVSWI (ρ increased from 0.34 to 0.77). This suggests that clinical estimation of RVSWI could more closely match PV loop estimates if RV stroke volume is measured directly and regurgitant volumes are captured. While $RVSWI_{RHC}$ may be more important for patient wellness, we found that incorporating regurgitant flow into RVSWI had

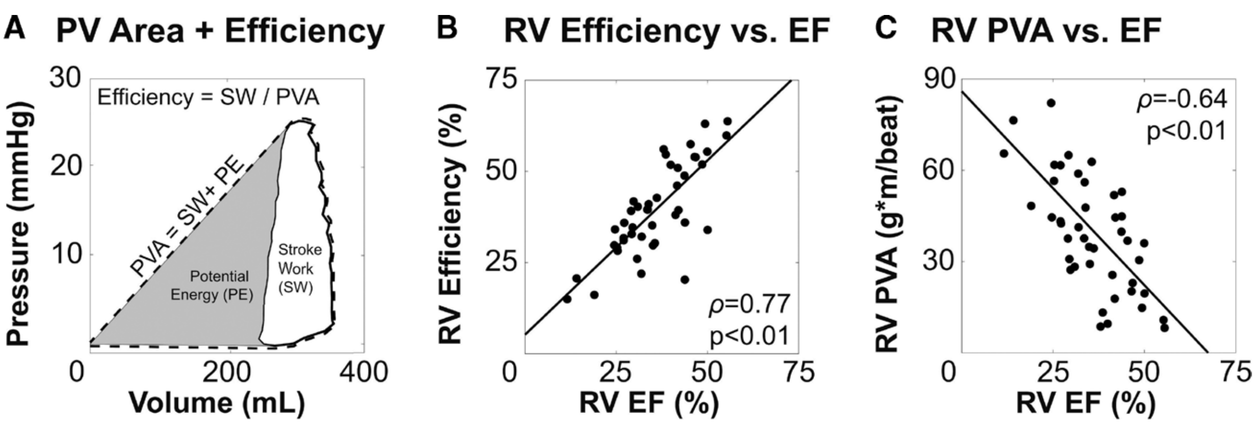

Figure 3. Advanced energetic analysis of right ventricular (RV) performance. Best fit line (black) and unity line (gray) are shown when relevant. **A**: Illustration of pressure–volume area (PVA) as the sum of stroke work and potential energy and efficiency as the ratio of stroke work to pressure–volume area. **B**: Strong positive correlation was observed between RV efficiency and ejection fraction (EF). **C**: Moderate negative correlation was observed between PVA and RV EF.

a significantly higher prognostic value (AUC 0.81) for postoperative right ventricular failure greater than either clinical $RVSWI_{RHC}$ (AUC 0.50) or moderate-severe tricuspid regurgitation alone. This may suggest that including regurgitant flow in RVSWI measures is a better identifier of underlying RV function. This agrees previous data that has found tricuspid regurgitation to be a significant predictor of postoperative RVF on its own. Clinically, this may suggest that CT evaluation of RV volumes, particularly stroke volume, would aid in assessing RV function.

In addition to cineCT, cardiac magnetic resonance (CMR) imaging and 3D echocardiography can be used to obtain RV volume measures. CT has a strong correlation with CMR for RV volumes. However, CMR is difficult to perform in this patient population due to breath-holding requirements and a high prevalence of implanted cardiac devices. Further, 3D echocardiography is known to underestimate volumes in the setting of RV enlargement[25,26] and has been shown to have high rates of study exclusion[27,28] due to imaging difficulties.

PVA (the sum of stroke work and potential energy, Figure 3A) has been shown to linearly correlate with myocardial oxygen consumption in a load-independent manner.[29,30] However, PVA and RV efficiency have seen limited clinical use due to challenges associated with acquiring contemporaneous pressure and volume data in a clinical setting.[10] We demonstrate an approach to combine RHC with CT to generate single-beat PV loops and measure PVA and ventricular efficiency in patients with heart failure. Our results outline a clinically available means for assessing and testing these advanced metrics. Clinically, PVA and efficiency may help differentiate patients who have similar conventional CT metrics of RV function (RVEF and RVEDVI) during RV evaluation by characterizing contractility as in animal models.[13] This complementary function, however, would need to be evaluated in a dedicated study.

There are several limitations to this study. Right heart catheterization (RHC) and CT imaging were not performed simultaneously. However, 27% of patients had CT scans obtained on the same day as RHC evaluation and 66% of patients had CT scans within 3 days of their RHC evaluation. Second, as a retrospective study, conductance catheter measures were not obtained to compare our PV loops to invasive assessment. Third, our study is a single-center retrospective analysis which limited the size of the patient population. Additionally, only 14 patients had a clinical outcome that was evaluated, As a result, the confidence intervals for the AUC of $RVSWI_{COMB}$ (0.60–1.00) and $RVSWI_{RHC}$ (0.23–0.77) were broad and these results would require further studies to investigate these findings. Lastly, PV-derived measures were created to test the assumptions of RHC-derived measures and test advanced energetic measures for agreement with functional measures that have been correlated to outcomes. However, the individual clinical benefit of using these PV-derived measures, relative to the current clinical approach, requires additional study.

Conclusions

CT evaluation may improve the evaluation of RV function by combining volumetry with right heart catheterization-derived pressure recordings, particularly in the setting of significant tricuspid regurgitation. This approach enabled the valuation of PV loop-derived RVSWI, which estimated the energetic contribution of regurgitant flow and enabled advanced energetic measures such as PVA and RV efficiency to be obtained clinically in the heart failure population.

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Meet the Authors

Dr. Anderson Scott is a researcher in the department of Bioengineering at UC San Diego. He completed his undergraduate degree in Bioengineering at Virginia Commonwealth University and completed his PhD at UC San Diego where he worked with the heart failure team to implement a new CT-based approach to analyze the RV function of patients under consideration for left ventricle assist device implantation.

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Dr. Francisco Contijoch is an assistant professor in the departments of Bioengineering and Radiology at UC San Diego. He completed his undergraduate and master's degrees at Johns Hopkins University and his PhD at the University of Pennsylvania. Prior to his faculty appointment, he completed a postdoctoral fellowship in the division of Cardiology at UC San Diego.

Dr. Contijoch's research laboratory focuses on developing advanced MRI and CT imaging methods to improve assessment of cardiopulmonary function. His team primarily focuses on heart failure, pulmonary hypertension, and congenital heart disease. His group not only develops novel imaging methods and analysis tools, but also applies these techniques to clinical populations to evaluate their effectiveness. Dr Contijoch is a Fellow of the Society for Cardiovascular Magnetic Resonance and is an active member of the Society for Cardiovascular Computed Tomography.