Journal of the American Heart Association

ORIGINAL RESEARCH

Right Heart Catheterization in Cardiogenic Shock Is Associated With Improved Outcomes: Insights From the Nationwide Readmissions Database

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BACKGROUND: The usefulness of right heart catherization (RHC) has long been debated, and thus, we aimed to study the real-world impact of the use of RHC in cardiogenic shock.

METHODS AND RESULTS: In the Nationwide Readmissions Database using *International Classification of Diseases, Tenth Revision* (*ICD-10*), we identified 236 156 patient hospitalizations with cardiogenic shock between 2016 and 2017. We sought to evaluate the impact of RHC during index hospitalization on management strategies, complications, and outcomes as well as on 30-day readmission rate. A total 25 840 patients (9.6%) received RHC on index admission. The RHC group had significantly more comorbidities compared with the non-RHC group. During the index admission, the RHC group had lower death (25.8% versus 39.5%, $P<0.001$) and stroke rates (3.1% versus 3.4%, $P<0.001$). Thirty-day readmission rates (18.7% versus 19.7%, $P=0.04$) and death on readmission (7.9% versus 9.3%, $P=0.03$) were also lower in the RHC group. After adjustment, RHC was associated with lower index admission mortality (odds ratio, 0.69; 95% CI, 0.66–0.72), lower stroke rate (odds ratio, 0.81; 95% CI, 0.72–0.90), lower 30-day readmission (odds ratio, 0.83; 95% CI, 0.78–0.88), and higher left ventricular assist device implantations/orthotopic heart transplants (odds ratio, 6.05; 95% CI, 4.43–8.28) during rehospitalization. Results were not meaningfully different after excluding patients with cardiac arrest.

CONCLUSIONS: RHC use in cardiogenic shock is associated with improved outcomes and increased use of downstream advanced heart failure therapies. Further blinded randomized studies are required to confirm our findings.

Key Words: cardiogenic shock ■ catheterization ■ outcome ■ readmission

Despite being in use for 50 years, the role of right heart catherization (RHC) continues to be debated, as illustrated by the recent surge despite a previous downward trend.[1–3] The prior decline in use has been attributed to several factors, including no clear benefit in various clinical settings, its inherently invasive nature, increased resource use, and concurrent improvements in noninvasive diagnostic methods in intensive care.[4–7] A recent report published earlier this year showed a 75% decrease in the use of a pulmonary artery catheter in patients with acute myocardial infarction complicated by cardiogenic shock (CS).[8] In contrast, the American College of Cardiology/American Heart Association guidelines support the use of RHC

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Supplementary Material for this article is available at https://www.ahajournals.org/doi/suppl/10.1161/JAHA.120.019843

For Sources of Funding and Disclosures, see page 8.

JAHA is available at: www.ahajournals.org/journal/jaha

CLINICAL PERSPECTIVE

What Is New?

- This large real-world retrospective study of patients with cardiogenic shock demonstrates that right heart catheterization is associated with improved in-hospital survival and reduced rehospitalizations.
- Moreover, though the use of right heart catheterization across the United States is infrequent, the procedure improves downstream use of life-saving advanced heart failure therapies.

What Are the Clinical Implications?

- In patients with cardiogenic shock, hemodynamic profiling using right heart catheterization should be considered to tailor therapies and optimize outcomes.
- Additional blinded studies are needed to investigate the clinical implications of hemodynamic-driven treatment strategies in these patients.

Nonstandard Abbreviations and Acronyms

CS	cardiogenic shock
MCS	mechanical circulatory support
NRD	Nationwide Readmissions Database
OHT	orthotopic heart transplant
RHC	right heart catheterization

in patients with heart failure with CS or with respiratory failure requiring mechanical ventilation (class IA), albeit routine use of RHC for management of acute heart failure is not recommended (class III).[9] Importantly, no randomized trial in patients with CS exists.

A recent scientific statement from the American Heart Association for the contemporary management of CS suggests the use of RHC in conjunction with other diagnostic tools in cases of diagnostic uncertainty or in patients with initial treatment unresponsiveness.[10] This recommendation for accurate hemodynamic diagnosis and monitoring is increasingly relevant, with the growing complexity of hospitalized patients, the rising use of temporary mechanical circulatory support (MCS), and the need for swift and early evaluation of candidacy for advanced heart failure therapies. To further define the role of RHC in patients with CS, we conducted an analysis from the Nationwide Readmissions Database (NRD) evaluating outcomes, use of advanced heart failure therapies, and readmission rates.

METHODS

Data Sources

The NRD is part of a family of databases developed for the Healthcare Cost and Utilization Project from the State Inpatient Databases. The NRD is a unique and powerful database designed to support analyses of national readmission rates for all payer types. Readmission rates have been established as an important metric of hospital quality outcomes as defined by the Hospital Readmissions Reduction Program and required as per the Affordable Care Act.[11] It contains data from 27 geographically dispersed states reporting an estimated 36 million discharges nationally. Beginning with the fourth quarter of 2015, the NRD updated its diagnosis and procedure codes using only the *International Classification of Diseases, Tenth Revision, Clinical Modification/Procedure Coding System* (*ICD-10-CM/PCS*) coding system. Institutional review board approval and informed consent was waived for this study because of the deidentified nature of the database. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Study Population

We used the NRD from 2016 and 2017 (January to November for each year) to identify first hospitalization for all patients with a diagnosis of CS (using *ICD-10-CM* code R57.0, T8111XA). The *ICD-10-CM* code used for CS has been reported to have a positive predictive value of 93.5% in validation studies.[12] All patients with CS who had a planned admission were excluded. This most probably includes patients previously diagnosed with CS on inotropes or electively admitted for left ventricular assist device (LVAD) implantation or orthotopic heart transplant (OHT). This was deemed necessary to better gauge the effectiveness of RHC/pulmonary artery catheterization in acute CS. Furthermore, all nonelective readmissions within 30 days of discharge were identified. Index admissions that resulted in LVAD implantation or OHT were excluded because patients exhibit different disease courses. If there were ≥2 readmissions after the index admission, only the first one was included for the analysis. Readmission causes and time to readmission were also evaluated. Apart from a hospital performance metric, readmission rates and time to readmission may constitute an additional measure of impact of RHC on management of CS.

To identify patients who underwent RHC, we used *ICD-10-PCS* codes 4A023N6 (Measurement of Cardiac Sampling and Pressure, Right Heart, Percutaneous Approach), 4A023N8 (Measurement of Cardiac Sampling and Pressure, Bilateral, Percutaneous Approach), 4A133B3 (Monitoring of Arterial Pressure, Pulmonary, Percutaneous Approach), 4A1239Z (Monitoring of Cardiac

Output, Percutaneous Approach), and 02HP32Z (Insertion of Monitoring Device into Pulmonary Trunk, Percutaneous Approach). We used *ICD-10-PCS* codes 5A02210 (Intra-aortic Balloon Pump), 5A0221D (Percutaneous Left Ventricular Assist Device), 5A1522F (Extracorporeal Life Support), 4A023N7 (Left Heart Catheterization), Z98.61/Z95.5 (Percutaneous Coronary Intervention), Z95.811 (Left Ventricular Assist Device), and Z94.1 (Orthotopic Heart Transplant) to investigate therapies during index hospitalizations and readmissions. All baseline and outcome information was compared among the patients who did and did not receive RHC during index hospitalization. Two subgroup analyses were also performed: (1) excluding patients with cardiac arrest; (2) excluding patients receing LVAD/OHT on index admission.

Statistical Analysis

In-hospital outcomes including mortality, acute kidney injury needing hemodialysis, ischemic stroke, and length of stay were compared between the 2 groups. Patient characteristics were presented as mean ±standard deviation for continuous variables or as percentage for categorical variables. Comparisons were performed using the χ^2 test, Student *t* test, and Wilcoxon rank sum test for categorical and continuous variables with normal and nonnormal distribution, respectively. We performed multivariate logistic regression with inpatient mortality as the dependent variable. We then selected variables with a significance level of $P<0.01$ and removed variables without clinically meaningful relevance (eg, peptic ulcer disease, depression). The final model included age, sex, insurance status, hospital size and teaching status, Elixhauser Comorbidity Index score, household income, acute myocardial infarction, heart failure, valvular disease, pulmonary circulation disorder, chronic pulmonary disease, renal failure, liver disease, coagulopathy, obesity, fluid/electrolyte disturbances, use of temporary mechanical support (intra-aortic balloon pump/percutaneous LVAD/ extracorporeal life support and advance heart failure therapies (LVAD/OHT).

We additionally performed 1:1 propensity matching with a caliper width of 0.01 with generation of propensity scores using the psmatch2 command using the Mahalanobis matching method to account for treatment bias. Absolute standardized differences across different variables were <10% (Figure S1). Two-sided *P* values <0.05 were considered significant. All analyses were performed using Stata statistical software (version 16; StataCorp, College Station, TX).

RESULTS

Baseline Characteristics

A total of 236 156 patient hospitalizations with a diagnosis of CS were identified between 2016 and 2017, of which only 25 840 (9.6%) underwent RHC. A flow diagram of our study is shown in Figure 1.

Compared with their counterparts, patients who underwent RHC were more likely to be younger (61.6 years versus 67.3 years, $P<0.001$) and men (68.3% versus 51.2%, $P<0.001$). The RHC cohort had a higher morbidity burden including history of congestive heart failure history (92.8% versus 75.1%), arrhythmias (74.7% versus 66.6%), valvular heart disease (38.3% versus 25.8%), peripheral vascular disease (32.2% versus 20.7%, $P<0.001$), hypertension (75.1% versus 73.7%, $P=0.008$), complicated diabetes mellitus (29.7% versus 26.0%), acute kidney injury (73% versus 60.4%, $P<0.001$), chronic renal failure (49.2% versus 38.7%, $P<0.001$), and obesity (19.6% versus 16.7%, $P<0.001$). They also had a higher Elixhauser Comorbidity Index score (24.0 versus 20.9, $P<0.001$). Baseline characteristics are demonstrated in Table 1. Table S1 illustrates baseline and hospital characteristics after excluding patients with cardiac arrest; the comparison between the groups is largely unchanged.

Invasive therapies during index admission were invariably more common in patients undergoing RHC including temporary MCS (40% versus 21.6% [intra-aortic balloon pump, 26.5% versus 15.1%; percutaneous left ventricular assist device, 9.4% versus 4.2%; extracorporeal life support, 4.1% versus 2.3%]), and left heart catheterization (35.7% versus 32.3%), albeit percutaneous coronary intervention was less frequent (17.2% versus 20.1%). The utilization of of advance surgical heart failure therapies were significantly higher in the RHC group (LVAD, 8.9% versus 0.9%; and OHT, 4.7% versus 0.4% [Table 1]).

Outcomes During Index Admission

Table 2 illustrates the index admission hospital outcomes. Compared with their counterparts, patients who underwent RHC had a significantly lower mortality rate (25.8% versus 39.5%, $P<0.001$) and ischemic stroke rate (3.4% versus 3.9%, $P=0.018$), although these beneficial outcomes were accompanied by a significantly longer length of stay (22.7 days versus 14.3 days, $P<0.001$). To account for patients who had cardiac arrest before RHC, we performed sensitivity analysis excluding those patients from our cohort. After exclusion, mortality (23.4% versus 35%, $P<0.001$) and stroke (3.2% versus 3.8%, $P=0.04$) rates were still lower in the RHC group, with higher hemodialysis rates (3.2% versus 2.5%, $P=0.015$; Table S2). In a different sensitivity analysis excluding patients not receving LVAD/OHT during index admission, the mortality rate remained lower in patients who underwent RHC (28.7% versus 39.5%, $P<0.001$; Table S3). On multivariate analysis and after adjusting for baseline differences (Figure 2), the use of RHC was associated

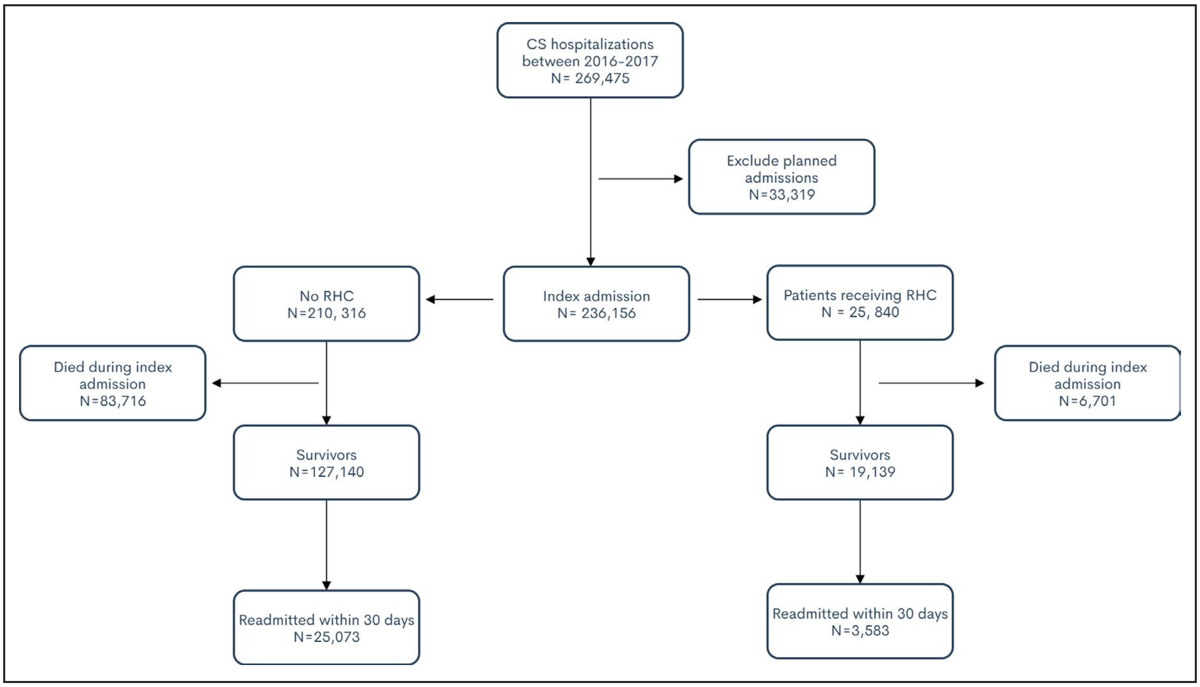

Figure 1. Flowdiagram of selection and comparison of right heart catheterization (RHC) andnon-RHC groups during index admission as well as readmissions.
LVAD indicates left ventricular assist device; and OHT, orthotropic heart transplant.

with a 31% decrease in mortality rate (odds ratio [OR], 0.69; 95% CI, 0.66–0.72) and 19% reduction in stroke rates (OR, 0.81; 95% CI, 0.72–0.90). Similarly, multivariate analysis after excluding patients with cardiac arrest yielded similar findings for mortality (OR, 0.71; 95% CI, 0.68–0.75) and stroke (OR, 0.8; 95% CI, 0.71–0.9), as shown in Figure 3. Finally, outcomes remained largely consistent when stratified by hospital teaching status (Table S4). Out of 25 486 propensity-matched hospitalizations (including 98.6% of the RHC cohort), similar trends of lower mortality were observed in patients undergoing RHC (Table S5). The baseline characteristics of matched populations is shown in Table S6.

Readmission Rates, Outcomes, and Causes

Patients with RHC on index admission had a lower rate of hospital readmission (18.7% versus 19.7%, P=0.04) and death rates during readmission (7.9% versus 9.3%, P=0.03). Table 3 shows additional outcomes during readmission. Except for mortality (P=0.06, not shown), on multivariate adjustment, RHC was found to be associated with 30-day readmission (OR, 0.83; 95% CI, 0.78–0.88) and LVAD/OHT (OR, 6.05; 95% CI, 4.43–8.28) use (Figure 2). Results were not meaningfully affected after exclusion of patients with cardiac arrest as shown in Table S7 and Figure 3. Heart failure exacerbation was the most common cause of readmission (Table S8).

DISCUSSION

Our study evaluated the association of RHC with mortality and in patients admitted with acute CS using data from a large nationwide registry. We found that an RHC strategy was associated with (1) a significant 31% reduction in mortality in index admission, (2) a 17% reduction in 30-day readmission, and (3) a 6-fold increase in use of LVAD/OHT during readmission. Importantly, the above findings did not significantly change after excluding patients with cardiac arrest and/or patients receiving advanced heart failure therapies. We hypothesize that the use of RHC may help to recognize and better characterize the CS patients, leading to increased use of temporary MCS support as well as advanced therapies during the initial encounter. Moreover, among survivors of index hospitalization, the RHC group had more utilization of advanced therapies during readmission.

We found that large academic centers in metropolitan locations more commonly use RHC. This finding has been previously replicated in a study from the National Inpatient Sample showing an increase in RHC use in large academic hospitals after 2005,

Table 1. Baseline Hospital and Patient Characteristics

Demographics	Total, N=236 156	Non-RHC, N=210 316	RHC, N=25 840	*P* value
Demographics				
Mean age, y (SD)	66.6 (14.5)	67.3 (14.3)	61.6 (14.4)	<0.001
Women, %	38.0	38.8	31.7	<0.001
Hospital characteristics				
Hospital size				
Small, %	9.4	10.1	4.2	<0.001
Medium, %	23.1	24.1	14.6	<0.001
Large, %	67.4	65.7	81.1	<0.001
Hospital case volume (mean)	347 (493)	322 (469)	556 (614)	<0.001
Hospital type				
Metropolitan nonteaching, %	18.8	20.3	6.5	<0.001
Metropolitan teaching, %	77.1	75.3	92.0	<0.001
Nonmetropolitan hospital, %	3.9	4.2	1.3	<0.001
Elixhauser Comorbidity Index score (mean)	21.2 (10.1)	20.9 (10.2)	24.0 (9.5)	<0.001
Presentation				
Acute coronary syndrome, %	44.1	45.5	32.9	<0.001
STEMI, %	13.3	13.6	10.9	<0.001
NSTEMI, %	23.9	24.6	18.1	<0.001
Comorbidities				
Congestive heart failure, %	75.1	73.0	92.8	<0.001
Cardiac arrythmias, %	67.5	66.6	74.7	<0.001
Cardiac arrest, %	14.2	14.9	8.1	<0.001
Valvular heart disease, %	26.8	25.3	38.3	<0.001
Pulmonary circulation disorder, %	21.5	19.3	39.5	<0.001
Chronic pulmonary disease, %	28.0	28.2	26.3	<0.001
Peripheral vascular disease, %	21.9	20.7	32.2	<0.001
Hypertension, %	73.8	73.7	75.1	0.008
Acute kidney injury, %	61.8	60.4	73.0	<0.001
Chronic Renal failure, %	39.9	38.7	49.2	<0.001
Diabetes mellitus, uncomplicated, %	15.2	15.3	14.4	0.03
Diabetes mellitus, complicated, %	26.4	26.0	29.7	<0.001
Obesity, %	17.0	16.7	19.6	<0.001
Liver disease, %	21.4	20.9	25.2	<0.001
Neurological disorder, other, %	28.7	30.0	17.8	<0.001
Electrolyte disorder, %	68.8	68.3	73.1	<0.001
Deficiency anemia, %	5.2	4.9	7.7	<0.001
Alcohol abuse, %	6.2	6.2	6.1	0.78
Procedures				
Left heart catheterization, %	32.6	32.3	35.7	<0.001
Percutaneous coronary intervention, %	19.7	20.1	17.2	<0.001
Intra-aortic balloon pump, %	16.3	15.1	26.5	<0.001
Percutaneous ventricular assist device, %	4.8	4.2	9.4	<0.001
Extracorporeal life support, %	2.5	2.3	4.1	<0.001
Utilization of Advance heart failure therapies on index admission				
Left ventricular assist device, %	1.8	0.9	8.9	<0.001
Orthotopic heart transplantation, %	0.9	0.4	4.7	<0.001

NSTEMI indicates non–ST-segment–elevation myocardial infarction; RHC, right heart catheterization; and STEMI, ST-segment–elevation myocardial infarction.

despite the findings of the ESCAPE (Evaluation Study of Congestive Heart Failure and Pulmonary Artery Catheterization Effectiveness) randomized trial.[13,14] These persistent differences in the invasive hemodynamic use among medical centers point to the lack of standardization of care in patients with CS. Whether this is because of differences in resources available among hospitals, variable degrees of familiarity in the use of invasive hemodynamics, or lack of appropriate use, guidelines need to be further elucidated. To that extent, there has lately been considerable effort in the standardization of CS definition and treatment approach by consensus documents endorsed by the American Heart Association and the Society for Cardiovascular Angiography and Intervention.[10,15]

In addition, patients in the RHC group received more aggressive treatment with temporary MCS that resulted in lower mortality rates, even after adjusting for baseline differences. We believe that these findings should be interpreted in conjunction and are reflective of the higher level of care that patients receive in these centers. This higher use of RHC in large academic and advanced heart failure centers may have led to early, accurate, and appropriate interpretation of hemodynamic data from experienced heart failure specialists and multidisciplinary teams, resulting in a mortality benefit.[13] In addition, RHC likely provided an early objective assessment of the patients' clinical state. As such, temporary MCS use may have been reflective of the early and objective recognition of severe CS, and our findings have been congruent with the Cardshock Study, an observational, prospective multicenter registry.[16] However, the association of RHC and mortality further underscores the benefits of RHC use in the identification and treatment of CS. Importantly, lower mortality rates were seen in the RHC group despite worse Elixhauser Comorbidity Index scores and baseline comorbidities, implying that RHC was not selectively used in patients who were deemed better candidates and would be expected to have favorable outcomes.

In addition, our findings show that the favorable outcomes of RHC use were extended beyond index admission statistics and led to an overall reduction in 30-day readmission rate, longer time out of hospital for those who got readmitted, and eventually a 1.4% reduction in readmission mortality for those who received an RHC. Although the ESCAPE trial did not find that RHC-directed volume optimization was superior with regard to days alive and out of hospital (primary outcome), it did not specifically evaluate patients with CS.[14] However, in a different prospective study by Rossello et al in patients with CS only, the use of RHC was independently associated with a 30-day (hazard ratio, 0.55; 95% CI, 0.35–0.86; P=0.008) and long-term mortality benefit (hazard ratio, 0.63; 95% CI, 0.41–0.97; P=0.035).[17] These latter findings support our conclusions, suggesting that RHC-guided management in CS may result in favorable end points.

Furthermore, we demonstrated that the use of RHC is associated with a >6-fold increase in LVAD and OHT use during rehospitalization. This finding further substantiates the implications of early and accurate characterization of shock, stratification of patient condition severity, and candidacy for these advanced therapies, all impossible without RHC. Another recent study using National Inpatient Sample data by Hernandez et al found similar associations of increased advanced therapies used in patients with heart failure with CS (LVAD: OR, 3.42; 95% CI, 3.11–3.78; P<0.001 or OHT: 2.0% versus 0.5%; OR, 1.12; 95% CI, 1.06–1.18; P<0.001).[18] The increased numbers of LVAD/OHT on readmission are expected given the prior completed profiling of patients.

The use of RHC in patients who are sicker and have significant baseline comorbidities comes as no surprise. Patients with preexisting conditions, such as heart failure, arrhythmias, valvular abnormalities, and renal failure, frequently represent a diagnostic challenge in the acute setting of undifferentiated shock. In these instances, and given the residual limitations of noninvasive hemodynamic methods, RHC provides clinicians with timely and accurate diagnostic results and reliable hemodynamics that affect a patient's outcomes and length of stay.

Interestingly, patients who presented with acute coronary syndrome, including ST-segment–elevation myocardial infarction, were less likely to receive RHC. A previous Medicare beneficiaries' study found that RHC use in myocardial infarction has been steadily declining since 1999,[19] as prior studies suggested increased

Table 2. Index Admission In-Hospital Outcomes and Therapies

Outcomes	Total, N=236 156	Non-RHC, N=210 316	RHC, N=25 840	P value
Death, %	38.0	39.5	25.8	<0.001
Stroke, %	3.9	3.9	3.4	0.018
Need for hemodialysis, %	3.2	2.8	3.6	0.009
Mechanical ventilation, %	48.9	20.0	39.5	<0.001
Length of stay, d	15.3 (16.3)	14.3 (15.1)	22.7 (20.9)	<0.001

RHC indicates right heart catheterization.

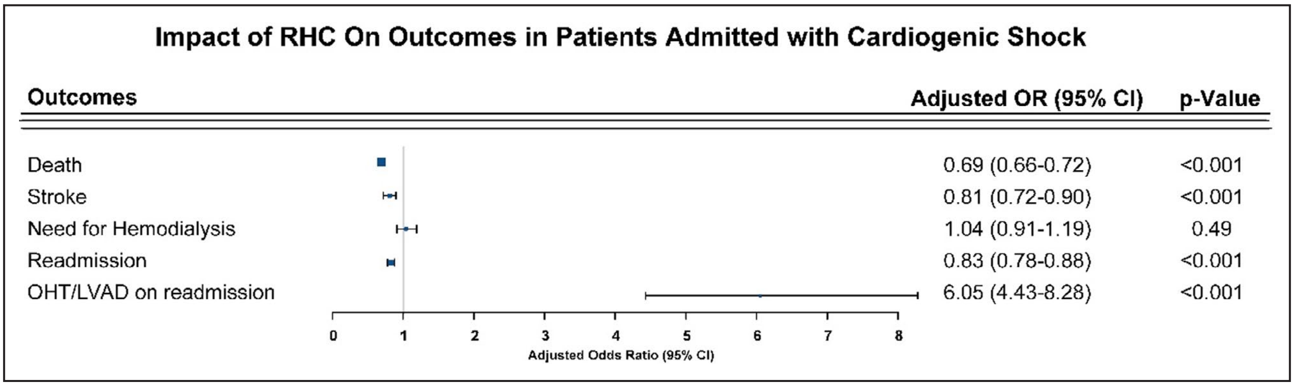

Figure 2. Forest plot of the impact of right heart catheterization (RHC) on the cardiovascular outcomes for patients admitted with cardiogenic shock.
LVAD indicates left ventricular assist device; OHT, orthotropic heart transplant; and OR, odds ratio.

mortality in this population.[20–22] Nonetheless, even after adjustment for acute myocardial infarction, our study suggests RHC is associated with survival benefit, contrary to prior studies.

Based upon our results, patients in the RHC group appear to have higher rates of acute kidney injury and hemodialysis during index hospitalization. Although the nature of the data set precludes understanding the underlying mechanisms, a few plausible explanations exist. First, the higher rates of acute kidney injury could just represent the severity of CS and cardiorenal syndrome in this group. Second, acute kidney injury may have been the byproduct of increased use of temporary MCS or occur as a result of contrast-induced nephrotoxicity. Thus, renal dysfunction may trigger further hemodynamic evaluation using RHC. Thus after multivariate adjustment, RHC does not change the need for hemodialysis in CS patients.

Limitations

The findings of our study must be interpreted within the context of their limitations. First, the use of an administrative data set for this study makes it prone to errors of coding of diagnosis and procedures. Second, the data set also lacks the severity of CS, hemodynamic data, echocardiographic variables, as well as the temporality of interventions that are important clinical parameters in these patients and could affect interpretation of our conclusions. Moreover, the non-RHC group may include patients who could have expired before RHC was performed, which was partially addressed by excluding patients with cardiac arrest. Third, given the observational nature of the study, direct causality cannot be inferred toward the reported outcomes, although the findings of our analysis provide solid evidence for the strong association of the benefit of RHC in patients with CS. Fourth, the NRD database does not capture deaths or other end points that occurred out of the hospital and thus may underestimate overall risk during follow-up. However, we believe that despite these limitations, the NRD captures relevant clinical data to provide scientific rigor and validity that make our findings relevant and meaningful.

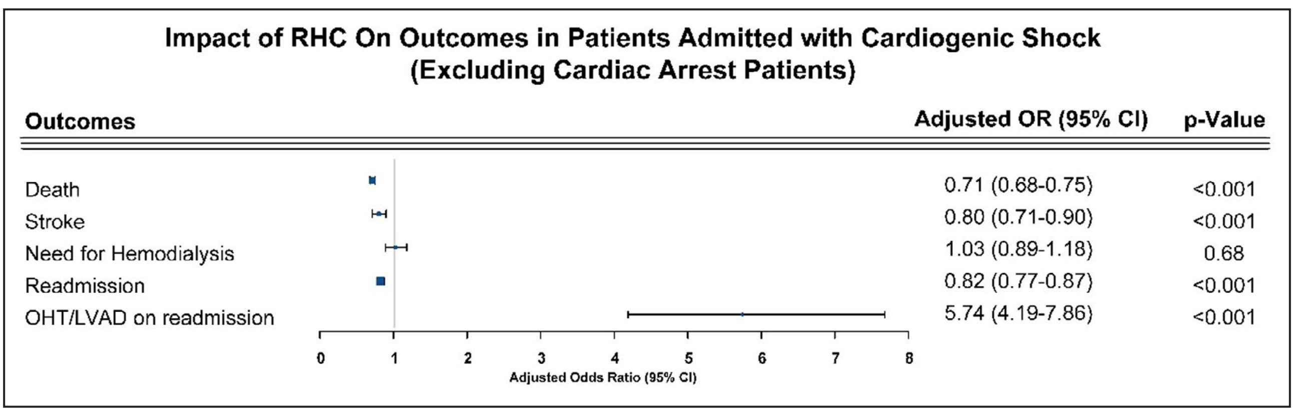

Figure 3. Forest plot of the impact of right heart catheterization (RHC) on the cardiovascular outcomes for patients admitted with cardiogenic shock, excluding patients with cardiac arrest.
LVAD indicates left ventricular assist device; and OHT, orthotropic heart transplant; and OR, odds ratio.

Table 3. 30-Day Readmission Rate, Death, and Mechanical Circulatory Support Use

End points	Total, N=146 279	Non-RHC, N=127 140	RHC, N=19 139	*P* value
30-day readmission rate, %*	19.5	19.7	18.7	0.045
Time to readmission, d, mean (SD)*	11.6 (8.4)	11.4 (8.4)	12.5 (8.3)	<0.001
Death on readmission hospitalization, %	9.2	9.3	7.9	0.03
Intra-aortic balloon pump, %*	1.32	1.0%	2.9%	<0.001
Percutaneous ventricular assist device, %*	0.44	0.40	0.68	0.11
Extracorporeal life support, %*	0.38	0.27	1.0	0.004
OHT, %*	0.30	0.14	1.27	<0.001
LVAD, %*	1.09	0.53	4.3	<0.001

LVAD indicates left ventricular assist device; OHT, orthotropic heart transplant; and RHC, right heart catheterization.
*Only unplanned readmissions included.

CONCLUSIONS

Our findings provide insights into the impact of RHC in patients with CS. Our findings merit consideration of RHC in patients with CS to improve mortality, either through recovery or the use of advanced heart failure therapies. Further blinded randomized studies are required to confirm our findings.

ARTICLE INFORMATION

Received October 19, 2020; accepted June 10, 2021.

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Sources of Funding

None.

Disclosures

None.

Supplementary Material

Tables S1–S8
Figure S1

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SUPPLEMENTAL MATERIAL

Table S1. Baseline hospital and patient characteristics excluding cardiac arrest.

Demographics	Total N= 202593	Non-RHC N=178852	RHC N=23740	P value
Demographics				
Mean age [y (SD)]	66.9 (14.4)	67.6 (14.2)	61.5 (14.5)	<0.001
Women (%)	38.1	38.9	31.8	<0.001
Elixhauser score (mean)	20.9 (10.1)	20.6(10.2)	23.9(9.5)	<0.001
Presentation				
Acute Coronary Syndrome (%)	44.0	45.7	31.4	<0.001
STEMI (%)	12.8	13.2	10.0	<0.001
NSTEMI (%)	24.3	25.2	17.6	<0.001
Comorbidities				
Congestive heart failure (%)	76.8	74.6	93.4	<0.001
Cardiac arrythmias (%)	66.7	65.8	73.9	<0.001
Valvular heart disease (%)	28.2	26.7	39.1	<0.001
Pulmonary circulation disorder (%)	22.2	19.7	40.4	<0.001
Chronic Pulmonary disease (%)	28.5	28.7	26.4	<0.001
Peripheral vascular disease (%)	22.8	21.4	32.9	<0.001
Hypertension (%)	74.6	74.4	75.5	0.09
Renal failure (%)	40.5	39.3	50.0	<0.001
Diabetes, uncomplicated (%)	15.0	15.1	14.4	0.08
Diabetes, complicated (%)	26.4	26.0	29.5	<0.001
Obesity (%)	17.0	16.7	19.4	<0.001
Liver Disease (%)	20.2	19.6	24.3	<0.001
Electrolyte disorder (%)	67.4	66.7	72.4	<0.001
Deficiency anemia (%)	5.4	5.0	7.9	<0.001
Alcohol abuse (%)	6.1	6.1	6.0	0.94
Length of stay (days)	14.9 (15.9)	13.7(14.6)	22.5(20.8)	<0.001
Mechanical ventilation (%)	43.3	44.2	36.2	<0.001
Acute kidney injury (%)	63.5	62.1	73.6	<0.001
Left heart catheterization (%)	32.9	32.7	34.7	0.02

Percutaneous coronary intervention (%)	19.6	20.0	16.0	<0.001
Intra-aortic Balloon pump (%)	16.5	15.3	25.8	<0.001
Percutaneous ventricular assist device (%)	4.6	4.0	8.6	<0.001
Extracorporeal life support (%)	2.3	2.2	3.6	<0.001
Orthotopic heart transplantation (%)	1.0	0.4	5.0	<0.001
Left ventricular assist device (%)	2.0	1.0	9.4	<0.001
Primary insurance				
Medicare (%)	64.6	65.7	56.8	<0.001
Medicaid (%)	11.1	10.7	14.3	<0.001
Private insurance (%)	18.1	17.3	23.6	<0.001
Self-pay (%)	2.7	2.8	2.1	<0.001
No Charge (%)	0.2	0.2	0.2	0.50
Other (%)	2.9	2.9	2.6	0.16
Hospital Characteristics				
Hospital Size				
Small (%)	9.2	9.9	4.2	<0.001
Medium (%)	22.7	23.9	13.9	<0.001
Large (%)	67.9	66.1	81.7	<0.001
Hospital case volume (mean)(SD)	352.5 (500.3)	325(475)	558(617)	<0.001
Hospital type				
Metropolitan non-teaching (%)	18.5	20.1	6.4	<0.001
Metropolitan teaching (%)	77.3	75.3	92.2	<0.001
Non-metropolitan hospital (%)	4.1	4.5	1.3	<0.001

NSTEMI=Non-ST elevation myocardial infarction, RHC=Right Heart Catheterization, STEMI= ST elevation myocardial infarction

Table S2. Index admission in-hospital outcomes and therapies for patients without cardiac arrest.

Outcomes	Total N= 202592	Non-RHC N=178852	RHC N=23740	P value
Death (%)	33.6	35.0	23.4	<0.001
Stroke (%)	3.7	3.8	3.2	0.004
Hemodialysis (%)	2.6	2.5	3.2	0.015

RHC =Right Heart Catheterization

Table S3. In hospital comparison of outcomes in patients who did not receive LVAD/OHT.

Outcomes	Non-RHC N=207406	RHC N=22319	P value
Death (%)	39.7%	28.7%	<0.001
Hemodialysis (%)	3.1%	4.1%	0.01
Length of Stay (days)	13.7(6.85)	18.3(7.45)	<0.001

RHC= right heart catheterization, LVAD/OHT= Left ventricular assist device/Orthotopic heart transplant

Table S4. Index admission in-hospital outcomes and therapies.

	Teaching hospital (N=182211)			Non-teaching hospital (N=44580)		
Outcomes	**Non-RHC (N= 158420)**	**RHC (N=23791)**		**Non-RHC (N=42878)**	**RHC (N=1702)**	**P value**
Death (%)	39.0%	25.3%	<0.001	40.9%	31.7%	<0.001
Stroke (%)	4.2%	3.4%	0.001	3.1%	3.2%	<0.001
Hemodialysis (%)	3.2%	3.8%	0.07	2.8%	3.2%	0.53
Mechanical ventilation (%)	49.9%	38.6%	<0.001	51.8%	51.0%	0.69
Length of stay (days)	15.2 (16.0)	23.2 (21.3)	<0.001	11.6 (11.5)	16.1(16.3)	<0.001

RHC= right heart catheterization

Table S5. Comparison of index hospital outcomes of propensity matched patients.

Outcomes	Non-RHC N=25787	RHC N=25486	Odds Ratio	P value
Death (%)	33.1%	25.8%	0.69 (0.65-0.72)	<0.001

RHC= right heart catheterization

Table S6. Baseline comparison and outcomes of propensity matched patients.

Demographics	Non-RHC N=25787	RHC N=25486
Mean age [y (SD)]	61.5	61.5
Women (%)	31.4%	31.7%
Hospital Characteristics		
Hospital Size		
Small (%)	3.4%	4.2%
Medium (%)	14.5%	14.6%
Large (%)	81.9%	81.0%
Hospital case volume (mean)		
Hospital type		
Metropolitan non-teaching (%)	10.1%	6.5%
Metropolitan teaching (%)	82.8%	92.1%
Non-metropolitan hospital (%)	6.9%	1.3%
Elixhauser score (mean)	23.7(9.8)	24.0(9.5)
Presentation		
Acute Coronary Syndrome (%)	34.0%	33.0%
STEMI (%)	9.8%	11.0%
NSTEMI (%)	20.4%	18.1%
Comorbidities		
Congestive heart failure (%)	91.6%	92.8%
Cardiac arrythmias (%)	67.4%	74.7%
Valvular heart disease (%)	37.3%	38.2%
Pulmonary circulation disorder (%)	38.7%	39.4%
Chronic Pulmonary disease (%)	25.6%	26.3%
Peripheral vascular disease (%)	22.9%	32.2%
Hypertension (%)	74.9%	75.2%
Renal failure (%)	48.2%	49.1%
Diabetes, uncomplicated (%)	14.2%	14.4%
Diabetes, complicated (%)	29.6%	29.7%

Obesity (%)		
Liver Disease (%)	25.4%	25.3%
Electrolyte disorder (%)		
Coagulopathy (%)	31.4%	31.9%
Deficiency anemia (%)	19.4%	19.6%
Alcohol abuse (%)	72.1%	73.1%
Depression (%)	11.3%	13.4%

NSTEMI=Non-ST elevation myocardial infarction, RHC=Right Heart Catheterization, STEMI= ST elevation myocardial infarction

Table S7. Outcomes and therapies for patient without cardiac arrest during readmission.

Outcomes	Total N= 134279	Non-RHC N=116113	RHC N=18166	P value
30-day readmission rate (%)*	19.7	19.9	18.7	0.03
Time to readmission [d, mean (SD)]	11.7(8.4)	11.5(8.4)	12.7(8.3)	<0.001
Death on readmission hospitalization (%)	9.3	9.6	8.0	0.03
Intra-aortic Balloon pump (%)	1.3	1.1	3.0	<0.001
Percutaneous ventricular assist device (%)	0.4	0.40	0.10	0.09
Extracorporeal life support (%)	0.3	0.2	0.9	0.01
OHT (%)	0.3	0.15	1.3	0.001
LVAD (%)	1.1	0.5	4.4	<0.001

RHC =Right Heart Catheterization, d=days, MCS=Mechanical circulatory support, RHC=Right Heart Catheterization, SD=standard deviation. *Only unplanned readmissions included.

Table S8. Causes of readmission.

Primary cause of readmission	Total N=160,547	Non-RHC N=124,727	RHC N=17,910	P value
Cardiogenic shock	0.32%	0.32%	0.34%	0.87
Heart failure	13.4%	12.6%	17.8%	<0.001
Acute Kidney Injury	3.01%	3.1%	2.5%	0.09

RHC=Right heart catheterization

Figure S1. Graphical representation of absolute standardized differences across different covariates used for propensity matching cohort.