


# Pulmonary artery catheter use in acute myocardial infarction-cardiogenic shock

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## Abstract

**Aims** The aim of this study is to evaluate the contemporary use of a pulmonary artery catheter (PAC) in acute myocardial infarction-cardiogenic shock (AMI-CS).

**Methods and results** A retrospective cohort of AMI-CS admissions using the National Inpatient Sample (2000–2014) was identified. Admissions with concomitant cardiac surgery or non-AMI aetiology for cardiogenic shock were excluded. The outcomes of interest were in-hospital mortality, resource utilization, and temporal trends in cohorts with and without PAC use. In the non-PAC cohort, the use and outcomes of right heart catheterization was evaluated. Multivariable regression and propensity matching was used to adjust for confounding. During 2000–2014, 364 001 admissions with AMI-CS were included. PAC was used in 8.1% with a 75% decrease during over the study period (13.9% to 5.4%). Greater proportion of admissions to urban teaching hospitals received PACs (9.5%) compared with urban non-teaching (7.1%) and rural hospitals (5.4%);  $P < 0.001$ . Younger age, male sex, white race, higher comorbidity, noncardiac organ failure, use of mechanical circulatory support, and noncardiac support were independent predictors of PAC use. The PAC cohort had higher in-hospital mortality (adjusted odds ratio 1.07 [95% confidence interval 1.04–1.10]), longer length of stay ( $10.9 \pm 10.9$  vs.  $8.2 \pm 9.3$  days), higher hospitalization costs ( $\$128\,247 \pm 138\,181$  vs.  $\$96\,509 \pm 116\,060$ ), and lesser discharges to home (36.3% vs. 46.4%) (all  $P < 0.001$ ). In 6200 propensity-matched pairs, in-hospital mortality was comparable between the two cohorts (odds ratio 1.01 [95% confidence interval 0.94–1.08]). Right heart catheterization was used in 12.5% of non-PAC admissions and was a marker of greater severity but did not indicate worse outcomes.

**Conclusions** In AMI-CS, there was a 75% decrease in PAC use between 2000 and 2014. Admissions receiving a PAC were a higher risk cohort with worse clinical outcomes.

**Keywords** Cardiogenic shock; Acute myocardial infarction; Heart failure; Pulmonary artery catheterization; Right heart catheterization; Cardiac intensive care unit; Critical care cardiology

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## Introduction

Acute myocardial infarction with cardiogenic shock (AMI-CS) remains associated with nearly 30–40% mortality in the contemporary era despite early revascularization.<sup>1–9</sup> AMI-CS is associated with pump failure and subsequent vasoplegic shock resulting in a complex haemodynamic picture.<sup>5,10–13</sup>

Given the rapid haemodynamic changes and high vasoactive medication requirements in this population, invasive haemodynamic monitoring with a pulmonary artery catheter (PAC) may have a role in AMI-CS.<sup>10,14</sup> There are limited data on the use and outcomes of PAC in AMI-CS in the contemporary era.<sup>15–17</sup> In 2005, the seminal ESCAPE (Evaluation Study of Congestive Heart Failure and Pulmonary Artery

Catheterization Effectiveness) trial demonstrated no differences in survival and hospitalization outcomes with PAC use in haemodynamically stable patients with heart failure, but this study specifically excluded patients with CS.<sup>18</sup> Similar studies from the sepsis and acute respiratory distress syndrome literature showed no differences in outcomes with PAC use.<sup>19</sup> With dissemination of these neutral results, the use of a PAC in undifferentiated shock and critically ill patients has decreased.<sup>20</sup> However, there are limited epidemiological data on the use of PAC in patients with AMI-CS, a population not included in these studies. Prior studies from large national databases have focused on only ST elevation or non-ST elevation populations or alternately have included undifferentiated CS because of a combination of AMI and end-stage heart failure.<sup>21,22</sup> Using a 15 year nationally representative database, we sought to assess the use of PAC in AMI-CS in USA. We also sought to understand the use of right heart catheterization (RHC) that is independent of PAC use in this population.

## Methods

The Nationwide/National Inpatient Sample (NIS) is the largest all-payer database of hospitalized inpatients in USA. The NIS contains discharge data from a 20% stratified sample of nonfederal hospitals and is a part of the Healthcare Cost and Utilization Project (HCUP), sponsored by the Agency for Healthcare Research and Quality.<sup>23</sup> Information regarding each discharge includes patient demographics, primary payer, hospital characteristics, principal diagnosis, up to 24 secondary diagnoses, and procedural diagnoses. The HCUP-NIS does not capture individual patients but captures all information for a given admission/hospitalization.

### Study population, variables, and outcomes

Using the HCUP-NIS data from 2000 to 2014, a retrospective cohort study of admissions with AMI-CS was identified. AMI in the primary procedure field was identified using International Classification of Diseases 9 Clinical Modification (ICD-9CM) codes for ST elevation MI (ICD-9CM 410.1x–410.6x, 410.8x, 410.9x) and non-ST elevation myocardial infarction (ICD-9CM 410.x).<sup>24</sup> CS was identified using ICD-9CM code 785.51 that has a specificity of 99.3%, sensitivity of 59.8%, positive predictive value of 78.8%, and negative predictive value of 98.1%.<sup>25</sup> Patients without in-hospital mortality data and AMI-CS admissions that underwent cardiac surgery (coronary artery bypass grafting, valve repair, valve replacement, durable left ventricular assist device, and orthotopic heart transplant) were excluded. Consistent with prior data, we identified PAC use using the ICD-9CM codes 89.63 (pulmonary artery pressure monitoring), 89.64 (pulmonary artery wedge monitoring), 89.66 (measurement of mixed venous

blood gases), 89.67 [monitoring of cardiac output by oxygen consumption technique (Fick method)], and 89.68 [monitoring of cardiac output by other technique (thermodilution indicator)].<sup>22,26,27</sup> The use of RHC was identified using ICD-9CM 37.21 and 37.23, which reflect as isolated measurement of pulmonary arterial pressures or concomitant use with a left heart catheterization.<sup>15</sup> Though it is possible that the RHC was subsequently converted to PAC monitoring, there is no reliable way to assess in the absence of a concomitant code for PAC placement. An exploratory cohort of admissions receiving invasive haemodynamic monitoring (IHDM), that is, RHC and/or PAC was also evaluated. Therefore, the PAC cohort was restricted conservatively to those with an ICD-9CM for a PAC only. Demographic characteristics, hospital characteristics, acute organ failure, coronary angiography, percutaneous coronary interventions (PCI), and mechanical circulatory support (MCS) use were identified for all admissions using previously used methodologies from our group.<sup>2–5,8,9,28–35</sup> Acute noncardiac organ failure was classified as respiratory (acute respiratory failure, other pulmonary insufficiency, acute respiratory distress syndrome, respiratory arrest, and ventilator management), renal (acute kidney injury), and hepatic (acute hepatic failure, hepatic encephalopathy, hepatic infection, and hepatitis unspecified), hematologic (defibrination syndrome, acquired coagulation factor deficiency, coagulation defect, and thrombocytopenia), and neurologic (anoxic brain injury, acute encephalopathy, coma, altered consciousness, and electroencephalogram).<sup>3–5,9,30,32</sup> Similar to prior literature from the HCUP-NIS, we used the procedure day for RHC/PAC placement to time concomitant coronary angiography, PCI, MCS, and invasive mechanical ventilation.<sup>36</sup> The Deyo's modification of the Charlson comorbidity index was used to identify the burden of co-morbid diseases (Supporting Information, *Table S1*).<sup>37</sup>

The primary outcome was the temporal trends of PAC use during the 15 year study period. Temporal trend analysis was further stratified by patient characteristics, hospital demographics, and in the years before (2000–2006) and after (2007–2014) the ESCAPE trial. Secondary outcomes included timing of PAC placement, use with RHC/PAC with concomitant cardiac procedures, in-hospital mortality, length of stay, hospitalization costs, and discharge disposition in admissions with and without PAC use. In the cohort without PAC use, we compared clinical outcomes between patients that received and did not receive a RHC. A supplementary analysis was performed for unadjusted and adjusted temporal trends in the use and in-hospital mortality for all admissions receiving IHDM.

### Statistical analysis

As recommended by HCUP-NIS, survey procedures using discharge weights provided with HCUP-NIS database were used

**Table 1** Baseline characteristics of acute myocardial infarction-cardiogenic shock with and without pulmonary artery catheter use

Characteristic		PAC (N = 29 609)	No PAC (N = 334 392)	P
AMI type	ST elevation AMI	70.5	70.4	0.84
	Non-ST elevation AMI	29.5	29.6	
Age (years)		68.3 ± 12.5	70.1 ± 13.4	<0.001
Female sex		37.7	41.0	<0.001
Race	White	77.8	78.1	<0.001
	Black	6.8	7.2	
	Others	15.4	14.7	
Weekend admission		27.3	27.6	0.32
Primary payer	Medicare	61.1	63.7	<0.001
	Medicaid	6.6	6.0	
	Private	24.8	22.5	
	Uninsured	5.0	5.5	
Quartile of median household income for zip code	Others	2.5	2.3	<0.001
	0–25th	17.6	23.7	
	26th–50th	24.8	26.8	
	51st–75th	25.8	24.9	
Hospital teaching status and location	75th–100th	31.8	24.6	<0.001
	Rural	5.6	8.8	
	Urban non-teaching	36.4	42.3	
Hospital bed size	Urban teaching	58.0	49.0	<0.001
	Small	6.6	8.5	
	Medium	20.1	23.3	
Hospital region	Large	73.3	68.3	<0.001
	Northeast	22.0	18.5	
	Midwest	21.8	23.1	
Charlson comorbidity index	South	31.0	38.6	<0.001
	West	25.2	19.7	
	0–3	22.8	23.6	
	4–6	59.5	54.4	<0.001
	≥7	17.7	22.0	

Represented as percentage or mean ± standard deviation.

to generate national estimates. Using the trend weights provided by the HCUP-NIS, samples from 2000 to 2011 were re-weighted to adjust for the 2012 HCUP-NIS redesign.<sup>38</sup>  $\chi^2$  and *t*-tests were used to compare categorical and continuous variables, respectively. Logistic regression was used to analyse trends over time (referent year 2000). The inherent restrictions of the HCUP-NIS database related to research design, data interpretation, and data analysis were reviewed and addressed.<sup>38</sup> Univariable analysis for trends and outcomes was performed and was represented as odds ratio (OR) with 95% confidence interval (CI). Multivariable logistic regression analysis incorporating age, sex, race, primary payer status, socio-economic stratum, hospital characteristics, comorbidities, acute organ failure, AMI type, cardiac procedures, and noncardiac procedures was performed for temporal trends of PAC use, temporal trends of in-hospital mortality, predictors of PAC use, and in-hospital mortality. For the multivariable modelling, regression analysis with purposeful selection of statistically (liberal threshold of  $P < 0.20$  in univariate analysis) and clinically relevant variables was conducted.

Multiple confirmatory and subgroup analyses were performed to verify the validity of these findings. We performed a propensity-matched analysis for patient demographics, comorbidities, hospital characteristics, acute organ failure, and acute care interventions between the two cohorts. For the

propensity matching, all variables except race had <1% missing variables. For the race category, missing variables were treated as a separate category. Using 1:1 nearest neighbour matching, 6200 matching pairs (12 400 individual admissions) were developed for further use. The propensity-matched sample had standardized differences <10% for all baseline characteristics. The McNemar  $\chi^2$  test and paired sample *t*-tests were used to compare categorical and continuous variables, respectively, in the propensity-matched sample. An additional analysis of outcomes was performed in the cohort that did not receive PAC between the admissions that received a RHC vs. those who did not. An exploratory supplementary analysis of temporal trends and in-hospital mortality in the cohort receiving IHDM vs. those who did not was performed. Two-tailed  $P < 0.05$  was considered statistically significant. All statistical analyses were performed using SPSS version 25.0 (IBM Corp, Armonk NY).

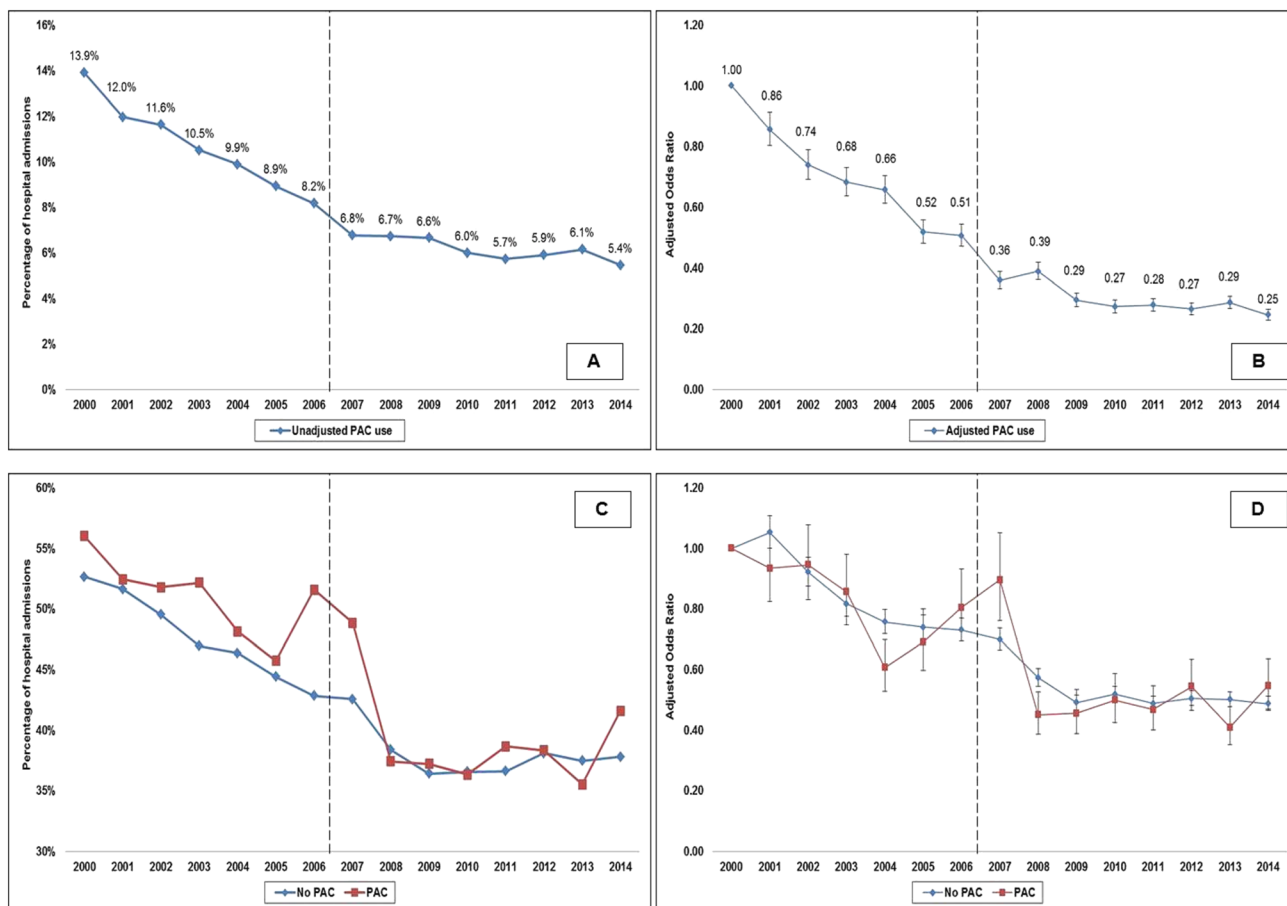
## Results

In the period between 1 January 2000 and 31 December 2014, an estimated 9 747 034 admissions for a primary diagnosis of AMI were identified, of which 444 253 (4.6%) developed CS. Of these admissions with AMI-CS, 80 252 (18.1%)

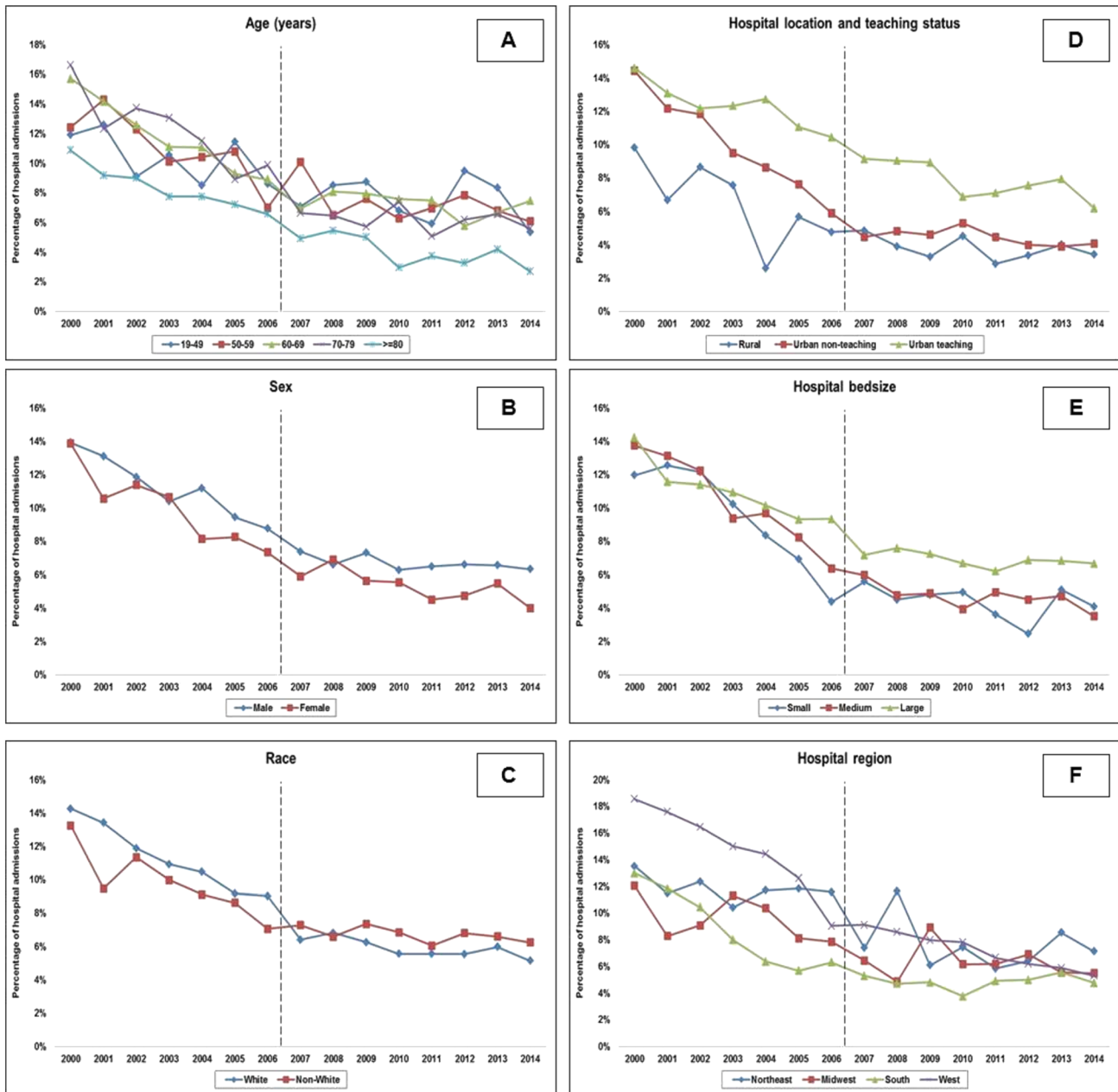
had concomitant cardiac surgery during the hospital admission and were subsequently excluded. In the final cohort of 364 001 admissions, PAC was used in 29 609 (8.1%). Baseline characteristics of the cohorts with and without PAC use are summarized in *Table 1*. Admissions that received a PAC had higher rates of prior heart failure (66.5% vs. 53.9%;  $P < 0.001$ ). During the tertiles of the study period, there was a serial decrease in mean age and increase in comorbidity, proportion of non-ST segment-elevation AMI-CS, and admissions to urban teaching hospitals (*Table S2*). The 15 year unadjusted and adjusted temporal trends of PAC use (*Figure 1*) noted a significant decrease in PAC use in AMI-CS. Temporal trends in the use of PAC stratified by patient and hospital characteristics demonstrated a decrease in

temporal use of PAC in AMI-CS (*Figure 2*). Greater proportion of admissions to urban teaching hospitals received PACs (9.5%) compared with urban non-teaching (7.1%) and rural hospitals (5.4%) with a proportionally consistent temporal decline during the study period (*Figure 2*). Compared with those without PAC use, those with PAC use had a higher prevalence of acute organ failure, pulmonary haemorrhage, and noncardiac organ support (*Table 2*). The PAC cohort received more frequent coronary angiography and MCS support but had lower rates of PCI (*Table 2*). In a multivariable regression analysis, younger age, male sex, white race, higher comorbidity, noncardiac organ failure, and use of MCS and noncardiac organ support were independent predictors of PAC use (*Table 3*).

**Figure 1** Unadjusted and adjusted 15 year temporal trends of PAC use and in-hospital mortality in cohorts with and without PAC use in AMI-CS. Panel (A): Unadjusted temporal trends of PAC use in AMI-CS ( $P < 0.001$ ). Panel (B): Adjusted multivariable logistic regression for temporal trends of PAC use with 2000 as referent year; adjusted for age, sex, race, primary payer, socio-economic status, hospital location/teaching status, hospital bed size, hospital region, comorbidity, acute organ failure, cardiac arrest, coronary angiography, percutaneous coronary intervention, mechanical circulatory support, invasive mechanical ventilation, haemodialysis ( $P < 0.001$ ); Panel (C): Unadjusted temporal trends of in-hospital mortality in AMI-CS stratified by PAC use ( $P < 0.001$ ); Panel (D): Adjusted multivariable logistic regression for in-hospital mortality temporal trends with 2000 as referent year; adjusted for age, sex, race, primary payer, socio-economic status, hospital location/teaching status, hospital bed size, hospital region, comorbidity, acute organ failure, cardiac arrest, coronary angiography, percutaneous coronary intervention, mechanical circulatory support, invasive mechanical ventilation, haemodialysis ( $P < 0.001$ ). The dotted line demarcates the period before and after the ESCAPE trial. AMI, acute myocardial infarction; CS, cardiogenic shock; PAC, pulmonary artery catheter.



**Figure 2** Temporal trends of PAC use in AMI-CS stratified by patient and hospital characteristics. Fifteen year temporal trends of PAC use in AMI-CS stratified by patient age groups (Panel A), sex (Panel B), race (Panel C), and hospital location and teaching status (Panel D), hospital bed size (Panel E), and hospital region (Panel F); (all  $P < 0.001$ ). The dotted line demarcates the period before and after the ESCAPE trial. AMI, acute myocardial infarction; CS, cardiogenic shock; PAC, pulmonary artery catheter.



Compared with those without PAC use, the cohort with PAC use had higher unadjusted in-hospital all-cause mortality (42% vs. 46.3%; OR 1.19 [95% CI 1.16–1.22];  $P < 0.001$ ). The 15 year unadjusted and adjusted temporal trends of in-hospital mortality are presented in *Figure 1C* and *1D*. Admissions with PAC use had a longer length of stay ( $10.9 \pm 10.9$  vs.  $8.2 \pm 9.3$  days), higher hospitalization costs ( $\$128\,247 \pm 138\,181$  vs.  $\$96\,509 \pm 116\,060$ ), and less frequent discharges to

home (36.3% vs. 46.4%) compared with the cohort that did not receive a PAC (all  $P < 0.001$ ). In a multivariable logistic regression analysis, PAC use (OR 1.07 [95% CI 1.04–1.10];  $P < 0.001$ ) was independently associated with higher in-hospital mortality in AMI-CS (Table S3). Using a 1:1 propensity-matching analysis, 12 400 admissions (6200 pairs) were evaluated (Table S4). In the propensity-matched sample, there were no differences in in-hospital mortality in the

**Table 2** In-hospital course and management of acute myocardial infarction-cardiogenic shock with and without pulmonary artery catheter use

Characteristic		PAC (N = 29 609)	No PAC (N = 334 392)	P
Acute organ dysfunction	Respiratory	57.6	44.1	<0.001
	Renal	43.1	33.6	<0.001
	Hepatic	10.8	7.7	<0.001
Pulmonary haemorrhage		1.7	1.1	<0.001
Cardiac arrest		18.9	19.5	0.02
Coronary angiography		70.2	64.7	<0.001
Percutaneous coronary intervention		48.4	53.4	<0.001
MCS	IABP	52.8	37.6	<0.001
	Percutaneous MCS	2.4	1.3	<0.001
	ECMO	0.6	0.3	<0.001
Invasive mechanical ventilation		61.4	42.1	<0.001
Haemodialysis		5.8	2.9	<0.001

Represented as percentage.

ECMO, extracorporeal membrane oxygenation; IABP, intra-aortic balloon pump; MCS, mechanical circulatory support.

cohorts with and without PAC use (46.4% vs. 46.2%; OR 1.01 [95% CI 0.94–1.08];  $P = 0.84$ ). The propensity-matched cohort receiving PAC was discharged home less frequently (19.5% vs. 23.1%), had longer length of hospital stay ( $10.8 \pm 10.9$  vs.  $10.4 \pm 9.7$  days), and had higher hospitalization costs ( $\$137\,660 \pm 127\,881$  vs.  $131\,546 \pm 113\,261$ ) (all  $P < 0.001$ ).

In the cohort that did not receive a PAC ( $N = 334\,392$ ), a RHC was performed in 41 719 (12.5%) admissions. Compared with those without a RHC, those who received a RHC were younger, more often male sex, of non-white race, with lower comorbidity, and higher acuity of illness (Table S5). Admissions receiving a RHC had higher use of PCI, MCS, and noncardiac organ support. The RHC cohort had lower unadjusted (35.5% vs. 43%; OR 0.73 [95% CI 0.72–0.75];  $P < 0.001$ ) in-hospital mortality but not adjusted in-hospital mortality (OR 1.01 [95% CI 0.99–1.04];  $P = 0.38$ ). The cohort with RHC use had longer hospital stay and higher hospitalization costs compared with those without a RHC (Table S6). Temporal trends in the use and in-hospital mortality in the cohorts with and without IHDM (RHC and/or PAC) showed trends similar to those with PAC use (Figure S1). The cohort that received IHDM had lower in-hospital mortality than those without IHDM on unadjusted analyses but not on adjusted analyses (40% vs. 43%; unadjusted OR 0.88 [95% CI 0.87–0.90];  $P < 0.001$ ; adjusted OR 1.01 [95% CI 0.98–1.05];  $P = 0.73$ ) (adjusted for covariates listed in Table S3).

The timing of PAC/RHC placement was available for 53 247 (74.7%) of the total cohort. RHC/PAC was performed at a median of 0 (interquartile range 0–1) days after admission, with 63% performed the day of admission (Figure 3A). RHC/PAC was performed concomitantly with coronary angiography, PCI, MCS, and invasive mechanical ventilation in 11.2%, 7.1%, 7.7%, and 5.3% admissions, respectively. In the total cohort, 5.3% of the admissions received coronary angiography (with/without PCI), MCS, and PAC on the same day (Figure 3B).

## Discussion

In this nationally representative population of AMI-CS, we noted a 75% decrease in PAC use between 2000 and 2014 despite a concomitant increase in patient acuity. Younger age, male sex, white race, higher baseline comorbidity, presence of noncardiac organ failure, and use of MCS were independent predictors of PAC use. Admissions receiving a PAC were a higher risk cohort that had higher unadjusted and adjusted in-hospital mortality, though these differences were not noted in the propensity-matched sample. The use of a RHC in admissions that did not receive a PAC was a marker of greater acuity and associated with higher resource utilization but no differences in in-hospital mortality. About 63% of the RHC/PACs were performed on the admission day with nearly 13% performed on the same day as coronary angiography, PCI, MCS, or invasive mechanical ventilation.

This study provides novel insight into management and outcome of a population not previously evaluated. In patients with ST elevation AMI-CS, Kolte et al.<sup>39</sup> noted a declining trend in the use of PAC during 2003–2010. Consistent with these data, we note a similar trend in all AMI-CS patients over a longer study period (2000–2014). Furthermore, this current study evaluates the use of RHC, either concomitantly with coronary angiography and MCS or in isolation, providing further insights into management of this complex population. The RHC provides similar information without the need for prolonged monitoring; however, the relative role both modalities needs further evaluation. Hernandez et al.<sup>22</sup> noted decreased mortality in the CS admissions because of end-stage heart failure receiving a PAC. In contrast to their data, our study did not observe a similar signal.<sup>7,40</sup> Patients with end-stage heart failure typically have higher filling pressures, lower ejection fractions, but with lesser end-organ hypoperfusion that is likely related to the chronicity of the process.<sup>40</sup> These differences may justify the greater benefit of PAC in

**Table 3** Multivariable regression for predictors of pulmonary artery catheter use in acute myocardial infarction-cardiogenic shock

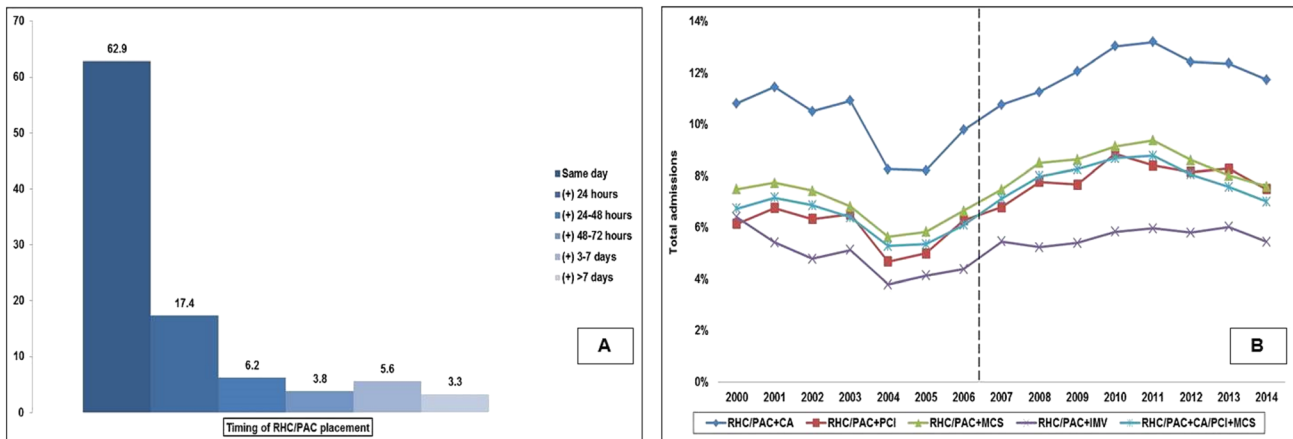
Total cohort (N = 364 001)	Odds ratio	95% confidence interval		P	
		Lower limit	Upper limit		
Age groups (years)	19–49	Reference category			
	50–59	0.93	0.88	0.99	0.02
	60–69	0.88	0.83	0.94	<0.001
	70–79	0.87	0.82	0.93	<0.001
	≥80	0.64	0.60	0.69	<0.001
Female sex		0.97	0.94	0.99	0.009
Race	White	Reference category			
	Non-white	0.96	0.93	0.99	0.002
Primary payer	Medicare	Reference category			
	Medicaid	0.94	0.89	0.99	0.03
	Private	0.98	0.94	1.02	0.26
	Uninsured	0.86	0.80	0.91	<0.001
	No charge	1.10	0.91	1.34	0.32
	Others	1.04	0.96	1.12	0.39
Quartile of median household income for zip code	0–25th	Reference category			
	26th–50th	1.25	1.20	1.29	<0.001
	51st–75th	1.35	1.29	1.40	<0.001
	75th–100th	1.60	1.54	1.67	<0.001
Weekend admission		1.00	0.98	1.02	0.85
Hospital teaching status and location	Rural	Reference category			
	Urban non-teaching	0.97	0.92	1.03	0.34
	Urban teaching	1.32	1.25	1.40	<0.001
Hospital bed size	Small	Reference category			
	Medium	1.09	1.03	1.15	0.001
	Large	1.36	1.29	1.43	<0.001
Hospital region	Northeast	Reference category			
	Midwest	0.88	0.85	0.92	<0.001
	South	0.82	0.79	0.85	<0.001
	West	1.25	1.20	1.30	<0.001
Charlson comorbidity index	0–3	Reference category			
	4–6	1.17	1.12	1.22	<0.001
	≥7	0.95	0.90	1.00	0.04
Acute organ failure	Respiratory	1.18	1.15	1.22	<0.001
	Renal	1.29	1.26	1.33	<0.001
	Hepatic	1.02	0.97	1.06	0.50
	Hematologic	1.39	1.33	1.44	<0.001
	Neurologic	0.71	0.69	0.74	<0.001
Cardiac arrest		0.80	0.77	0.83	<0.001
Coronary angiography		1.24	1.19	1.28	<0.001
Percutaneous coronary intervention		0.54	0.52	0.56	<0.001
Mechanical circulatory support		1.94	1.88	1.99	<0.001
Invasive mechanical ventilation		1.84	1.79	1.90	<0.001
Haemodialysis		1.28	1.20	1.35	<0.001

the end-stage heart failure population to aid in close optimization of filling pressures and fluid status. The results of our study can be readily compared with the substudy from GUSTO IIb and III (Global Use of Strategies To Open occluded coronary arteries in acute coronary syndromes) trials.<sup>41</sup> In this study, the cohort with PACs more frequently received coronary revascularization, mechanical circulatory support, and mechanical ventilation consistent with our data. These patients had higher resource utilization and short-term mortality in the unmatched cohort and higher resource utilization in the propensity-matched cohort, suggesting that PAC use is a marker for greater illness severity.<sup>41,42</sup> As noted in our study, in admissions within the non-PAC cohort, RHC was used in those with greater severity, without any differences in outcomes. Smaller studies have shown the use of a PAC

to be associated with improved survival in CS because of any aetiology.<sup>43,44</sup> Rossello *et al.*<sup>16</sup> showed the use of PAC to be associated with lower mortality in CS from non-AMI aetiology, but no differences in those with AMI-CS. In a subgroup analysis of the CardShock study, Sionis *et al.*<sup>17</sup> noted the use of a PAC to be associated with greater use of aggressive therapies (including inotropes) but without any differences in in-hospital mortality.

This study noted a declining trend in the use of PAC in AMI-CS, which is in contrast to similar studies from patients with heart failure.<sup>26,45</sup> These rates of decline started before the ESCAPE trial and continued to show a steady downward trend. These trends of declining PAC use were consistent across all patient and hospital characteristics as noted in a prior study in Medicare beneficiaries with AMI.<sup>46</sup> The use of

**Figure 3** Timing of PAC placement and concomitant cardiac procedures in AMI-CS. Panel (A): Timing of RHC/PAC during hospital stay (percentage); Panel (B): Fifteen year temporal trends of PAC with concomitant cardiac and noncardiac procedures. The dotted line demarcates the period before and after the ESCAPE trial. AMI, acute myocardial infarction; CA, coronary angiography; CS, cardiogenic shock; IMV, invasive mechanical ventilation; MCS, mechanical circulatory support; PAC, pulmonary artery catheter; PCI, percutaneous coronary intervention; RHC, right heart catheterization.



PAC in this study is lower than that noted in prospective registries of patients with AMI-CS.<sup>17,43</sup> This may be postulated to be because of lesser severity of CS in this nationally representative population, multiple neutral trials in both cardiac and noncardiac patients, the ubiquitous use of echocardiography, and advances in non-invasive/minimally invasive haemodynamic monitoring.<sup>20,41</sup> This study also identified unique predictors of PAC use. Presence of noncardiac organ failure and use of invasive mechanical ventilation and haemodialysis were strong predictors of PAC use in AMI-CS. This can be hypothesized to be because of the development of complex haemodynamics in this population with superimposed distributive shock, which needs careful understanding of cardiac haemodynamics and titration of vasoactive medications.<sup>10,12,13</sup> This study noted significant disparities in the use of PAC in this nationally representative population. We noted greater use of PAC in admissions with higher socio-economic status and bearing insurance coverage, which may allude to social disparities noted in other AMI populations.<sup>47,48</sup> Furthermore, the use of PAC in large urban hospitals and in patients with MCS demonstrates the paradigm shift in the management of AMI-CS with the advent of newer percutaneous MCS devices.<sup>15,43,49,50</sup> Second, with advanced MCS being available in the contemporary era,<sup>6,7,28,29,51-53</sup> PAC is being increasingly used to treat patients with higher severity of illness.<sup>15,45</sup> Preliminary data have shown improvements in clinical outcomes with a protocolized approach to AMI-CS including the use of PAC.<sup>54,55</sup> This is substantiated by the use of greater cardiac and noncardiac organ support in our study and the higher use of MCS and PACs in large, urban teaching hospitals.<sup>28,29</sup> There exist significant disparities in the hospital-level management and outcomes of AMI-CS.<sup>2</sup> It is possible that these disparities may contribute to the higher use of PAC at large, urban teaching hospitals, or

alternately this is representative of the higher acuity of illness in these centres. This crucial selection bias has been previously validated in the ESCAPE registry that noted greater PAC use in heart failure patients with higher severity of illness.<sup>56</sup>

In this study, we noted nearly 63% of RHC/PAC performed on admission with 13% performed concomitantly with other cardiac and noncardiac procedures. Nalluri et al.<sup>15</sup> noted the use of a RHC in AMI-CS admissions receiving percutaneous MCS to be associated with lower in-hospital mortality. It is important to note that this study specifically studied RHC with/without concomitant PAC use, because it sought to capture the use of RHC simultaneously with MCS placement. In contrast to their work, this study did not demonstrate any survival benefit from RHC use in the non-PAC population. The use of RHC/PAC-derived variables such as cardiac power output (mean arterial pressure X cardiac output/451) has shown significant survival correlations and remains worthy of further dedicated study.<sup>43,57</sup>

## Limitations

This study has several limitations, despite the HCUP-NIS database's attempts to mitigate potential errors by using internal and external quality control measures. The ICD-9CM codes for AMI and CS have been previously validated, reducing the inherent errors in ascertainment in this study.<sup>24,25,27</sup> However, as noted in the Methods section, the validation study for CS shows moderate sensitivity, and therefore, this study may have missed some admissions with CS. Although we used a strategy consistent with prior work from administrative databases,<sup>22,26,27</sup> the ICD-9CM codes for PAC have not been formally validated previously. The clinical consequences



of using a haemodynamic tool such as the PAC could not be accurately measured, including data interpretation and treatment changes. Because of the administrative nature of this cohort, we do not have haemodynamic data, biventricular function, pulmonary hypertension, and quantification of vasoactive medications; all of which are known to influence outcomes in patients with shock.<sup>12,58–63</sup> The declining use of the PAC may have resulted in consequent hesitation in using and/or challenges with interpretation of information.<sup>20</sup> The ICD-9CM codes for a RHC are not validated, and it is possible that those receiving a RHC had a PAC left *in situ* for continuous monitoring. Admissions receiving durable cardiac replacement therapy such as left ventricular assist devices and cardiac transplantation were excluded from this study, and therefore, our data cannot be extrapolated to this population. The HCUP-NIS does not provide information on level of care (intensive care unit, step-down unit, or floor level), so we cannot evaluate the influence of specialized care on the outcomes in this population. Despite these limitations, this study addresses an important knowledge gap highlighting the epidemiology of PAC use in AMI-CS in a contemporary 15 year period.

## Conclusions

In this large study of 364 001 AMI-CS admissions, these observational data suggest a 75% decrease in PAC use between 2000 and 2014. Use of a PAC identified a higher risk cohort with greater organ failure and higher in-hospital mortality and resource utilization. Further research is needed on the role of PAC use in the acute management of AMI-CS in light to aid in appropriate haemodynamic optimization in this acutely ill cohort.<sup>7,49</sup>

## Conflict of interest

A.S.J. has been a consultant for Beckman, Abbott, Siemens, ET Healthcare, Sping6toec, Quidel, Brava, and Novartis. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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## Author contributions

The study design, literature review, data analysis, and statistical analysis were carried out by S.V., A.S., S.H.P., S.A., and S.V. The data management, data analysis, and drafting of the manuscript were performed by S.V., A.S., S.H.P., S.A., and S.V. S.V., A.S., S.H.P., A.P., M.R.B., J.C.J., S.A., S.V., B.J.G., A.S.J., D.R.H., S.M.D., and G.W.B. have access to the data. The manuscript revision, intellectual revisions, and mentorship were performed by A.P., M.R.B., J.C.J., B.J.G., A.S.J., D.R.H., S.M.D., and G.W.B. The final approval were carried out by S.V., A.S., S.H.P., A.P., M.R.B., J.C.J., S.A., S.V., B.J.G., A.S.J., D.R.H., S.M.D., and G.W.B.

## Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**Table S1.** Identification of diagnoses and procedures.

**Table S2.** Characteristics of AMI-CS with PAC use stratified by time period.

**Table S3.** Multivariable regression for in-hospital mortality in AMI-CS.

**Table S4.** Propensity-matched cohorts of AMI-CS with and without PAC.

**Table S5.** Baseline characteristics of cohorts with and without RHC use.

**Table S6.** Clinical outcomes of cohorts with and without RHC use.

**Figure S1.** Unadjusted and adjusted 15-year temporal trends of IHDM use and in-hospital mortality in cohorts with and without IHDM use in AMI-CS.

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