Trends, Predictors, and Outcomes of Temporary Mechanical Circulatory Support for Postcardiac Surgery Cardiogenic Shock

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Postcardiac surgery cardiogenic shock (PCCS) is seen in 2% to 6% of patients who undergo cardiac surgery. There are limited large-scale data on the use of mechanical circulatory support (MCS) in these patients. This study sought to evaluate the in-hospital mortality, trends, and resource utilization for PCCS admissions with and without MCS. A retrospective cohort of PCCS between 2005 and 2014 with and without the use of temporary MCS was identified from the National Inpatient Sample. Admissions for permanent MCS and heart transplant were excluded. Propensity-matching for baseline characteristics was performed. The primary outcome was in-hospital mortality and secondary outcomes included trends in use, hospital costs and lengths of stay. In the period between 2005 and 2014, there were 132,485 admissions with PCCS, with 51.3% requiring MCS. The intra-aortic balloon pump was the predominant device used with a steady increase in other devices. MCS use for more frequent in younger patients, males and those with higher co-morbidity. There was a decrease in MCS use across all demographic categories and hospital characteristics over time. Older age, female sex, previous cardiovascular morbidity and MCS use were independently predictive of higher in-hospital mortality. In 6,830 propensity-matched pairs, PCCS admissions that required MCS use, had higher in-hospital mortality (odds ratio 2.4; p < 0.001), higher hospital costs ($98,759 ± 907 vs $81,099 ± 698; p < 0.001) but not a longer length of stay compared with those without MCS use. In conclusion, in patients with PCCS, this study noted a steady decrease in MCS use. Use of MCS identified PCCS patients at higher risk for in-hospital mortality and greater resource utilization.   © 2018 Elsevier Inc. All rights reserved. (Am J Cardiol 2019;123:489−497)

Cardiogenic shock is frequently seen in acute cardiovascular care and continues to have a mortality rate of approximately 40% in the modern era.[1] Postcardiac surgery cardiogenic shock (PCCS) is seen in 2% to 6% of all cardiac surgery patients and is associated with increased morbidity and mortality.[2] With the steady increase in cardiac surgical volumes over the last 2 decades associated with the higher co-morbidity profile of these patients, the number of patients with PCCS expected to increase in the coming years.[3] PCCS is uniformly fatal unless hemodynamic stability is restored to improve vital organ perfusion.[4] Small single-center studies have reported high (60% to 70%) short-term mortality despite early support with temporary mechanical circulatory support (MCS) devices.[5,6] In current practice, advanced percutaneous and nonpercutaneous MCS devices offer an alternative to intra-aortic balloon pump (IABP) in PCCS patients.[7] There is a paucity of data on the outcomes in patients undergoing MCS placement for PCCS.[8,9] The aim of this study was to evaluate utilization trends, hospital costs, lengths of stay, and in-hospital mortality in PCCS admissions with and without the use MCS over a 10-year period. The primary outcome was in-hospital mortality and secondary outcomes included trends, hospital costs, and lengths of stay associated with admissions with and without the use of MCS.

Methods

The Nationwide/National Inpatient Sample (NIS) is the largest all-payer database of hospital inpatient stays in the United States. NIS contains discharge data from a 20% stratified sample of community hospitals and is a part of the

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Healthcare Quality and Utilization Project (HCUP), sponsored by the Agency for Healthcare Research and Quality.[10] Information regarding each discharge includes patient demographics, primary payer, hospital characteristics, principal diagnosis, up to 24 additional secondary diagnoses, and procedural diagnoses.

Using the HCUP-NIS data from 2005 to 2014, a retrospective cohort of admissions with cardiogenic shock after cardiac surgery was identified. Since International Classification of Diseases 9 Clinical Modification (ICD-9CM) codes were redefined in 2005 to distinguish between permanent MCS devices such as left ventricular assist devices (ICD-9CM 37.66) and short-term nonimplantable devices or paracorporeal devices (ICD-9 CM 37.62 and 37.65), procedures performed before 2005 were excluded from this study.[11] Hospital admissions for patients >18 years undergoing cardiac surgery were identified using the ICD-9CM codes—35.10-35.14 (valve repair), 35.20-35.28 (valve replacement), and 36.1-36.2 (coronary artery bypass grafting). PCCS was identified using ICD-9CM code of 785.51, that was defined as shock resulting from diminution of cardiac output in heart disease, shock resulting from primary failure of the heart in its pumping function, as in myocardial infarction, severe cardiomyopathy, or mechanical obstruction or compression of the heart or shock resulting from the failure of the heart to maintain adequate output. Validation studies have shown a specificity of 99%, a sensitivity of 60%, a positive predictive value of 79%, and a negative predictive value of 98% for the ICD-9-CM code 785.51 to identify cardiogenic shock.[12] Admissions for permanent MCS (ICD-9CM 37.66) and orthotopic heart transplants (ICD-9CM 37.5, 37.51 or 33.6) in the primary procedure field were excluded. Short-term MCS use was defined using ICD-9CM codes for IABP (ICD-9CM 37.61), percutaneous MCS (Impella/TandemHeart) (ICD-9CM 37.68), nonpercutaneous MCS (ICD-9CM 37.60, 37.62, 37.65), extracorporeal membrane oxygenation (ECMO) (ICD-9CM 39.65) and percutaneous cardiopulmonary bypass (ICD-9CM 39.66). The procedural days were used include only admissions that received an MCS device after the cardiac surgery.

Demographic characteristics (age, sex, and race), hospital characteristics (teaching status and location, bed-size, and region) and primary payer associated with each discharge were identified from the HCUP-NIS database. The hospitals were divided into tertiles based on the annual volume of PCCS discharges. The Deyo's modification of Charlson Comorbidity Index was used to identify the burden of co-morbid diseases.[13]

The primary outcome was in-hospital mortality in patients with and without the use of MCS for PCCS. Secondary outcomes included incidence and trends of MCS use in PCCS and the hospital costs and lengths of stay for these admissions.

As recommended by HCUP-NIS, survey procedures using discharge weights provided with HCUP-NIS database were used to generate national estimates.[14] Chi-square and *t* Tests were used to compare categorical and continuous variables, respectively. Linear regression was used to analyze trends over time. The inherent limitations of the HCUP-NIS database were reviewed and addressed during the statistical analysis and interpretation of these data.[15] Univariate analysis for trends and outcomes was performed and were represented as odds ratio with 95% confidence interval or mean ± standard error. Using a multivariate regression incorporating age, gender, race, myocardial infarction, coronary angiography and/or percutaneous coronary intervention, median household income, hospital characteristics and co-morbidities, an analysis was performed for in-hospital mortality using MCS as the dependent variable. As patients with and without MCS differed in their baseline characteristics, we performed propensity-matched analysis for baseline characteristics between the 2 cohorts. We then used 1:1 nearest neighbor matching with 0.01 calipers and without replacement to match patients with MCS use to those without. Two-tailed $p < 0.05$ was considered statistically significant. All statistical analyses were performed using STATA 14.0 (StataCorp, College Station, Texas).

Results

In the 10-year period from 2005 to 2014, there were a total of 132,485 admissions for cardiac surgery that developed PCCS, of which 67,868 (51%) received temporary MCS. The frequency of PCCS increased by 178% during this study period ($p < 0.001$; (Figure 1). In comparison, there was only a modest increase of 17% in the number of MCS devices used, thereby amounting to a 23% decrease in the proportion of PCCS patients treated with MCS (Figures 1 and 2). This was predominantly due to a decrease in the use of IABP, associated with a small increase in non-IABP MCS devices (all $p < 0.001$; (Figure 2). Between 2010 and 2014, there was an increase in the percentage of cases with non-IABP percutaneous MCS and ECMO with a concomitant decrease in nonpercutaneous MCS (Figure 2). Baseline characteristics of patients with and without the use of MCS are detailed in Table 1. Trends of MCS use in PCCS stratified by patient demographic characteristics, that is age, gender, race, Charlson Comorbidity Index and median household income (Figure 3, $p < 0.001$) and hospital volume and regions across the nation (Figure 4, $p < 0.001$). In comparison to the cohort without MCS use, the use of MCS was associated with higher postoperative hemorrhage or hematoma (12.4% vs 10.7%, p <0.001), however, there were no differences in transfusions (4.3% vs 4.6%), strokes (1.9% vs 2%), or vascular trauma (0.1% vs 0.1%).

Unadjusted mortality for admissions with and without the use of MCS is presented in Figure 5. In a multivariate model factors such as older age, female sex, previous cardiovascular morbidity and use of MCS were predictive of higher in-hospital mortality in PCCS (Table 2). Using propensity matching for baseline clinical and demographic variables, 6,830 pairs (total 13,660 admissions) were generated for further analysis (Supplementary Table 1). In the propensity matched cohort, the cohort with MCS use had higher hospital mortality − odds ratio 2.4 (95% confidence interval 2.2 to 2.7); $p < 0.001$, higher hospital costs ($98,759 ± 907 vs $81,099 ± 698; $p < 0.001$) but not a longer length of hospital stay (20 ± 0.2 days vs 18 ± 0.2 days; p = 0.05) as compared with the admissions without MCS use.
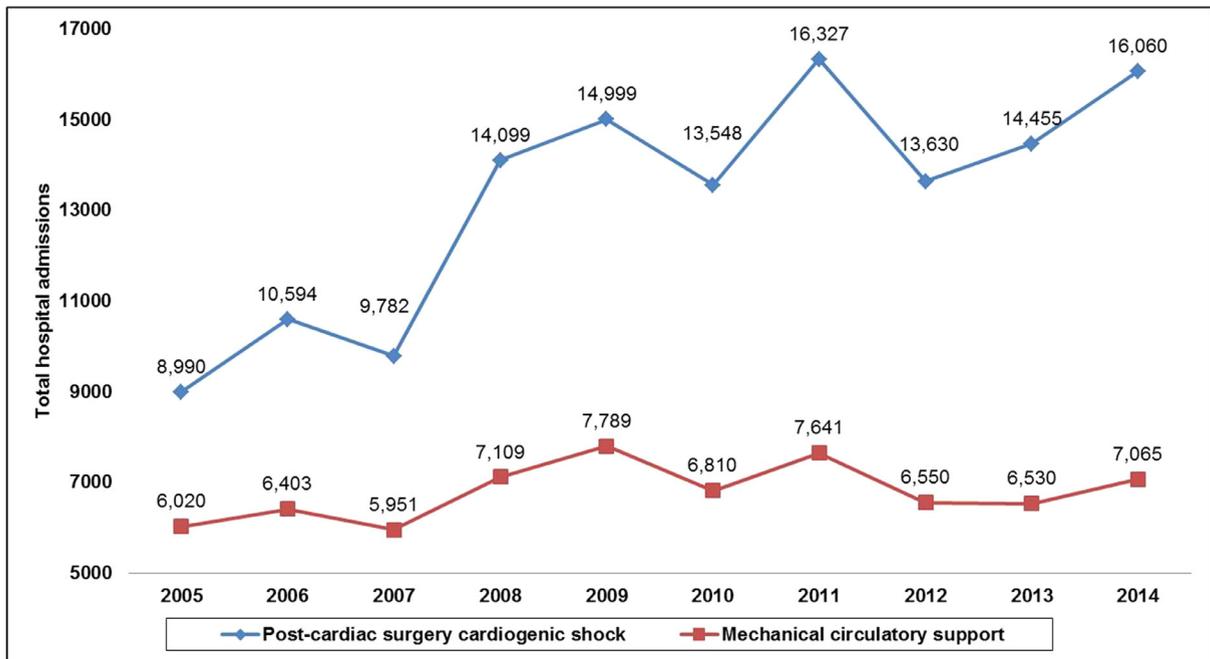
Figure 1. Trends in the frequency of post-cardiac surgery cardiogenic shock and the use of mechanical circulatory support. p Value for trends for all categories p < 0.001.
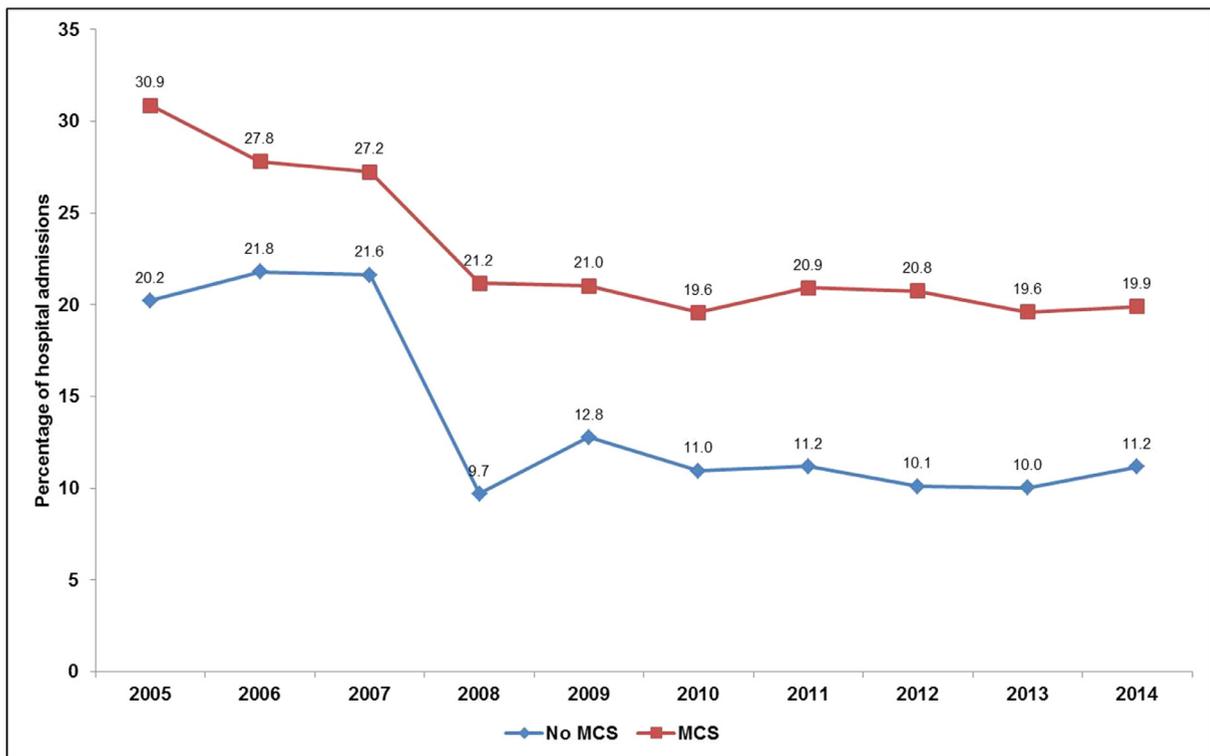

Figure 2. Trends in the percentage of admissions with mechanical circulatory support for postcardiac surgery cardiogenic shock. p Value for trends for all categories p < 0.001. Trends in the pMCS, npMCS and ECMO/PCPS are magnified in the picture-in-picture figure. ECMO = extracorporeal membrane oxygenation; IABP = intra-aortic balloon pump; MCS = mechanical circulatory support; npMCS = nonpercutaneous mechanical circulatory support; PCCS = postcardiac surgery cardiogenic shock; PCPS = percutaneous cardiopulmonary support; pMCS = percutaneous mechanical circulatory support.

Table 1
Baseline characteristics of postcardiac surgery cardiogenic shock patients with and without mechanical circulatory support

Variable	Mechanical circulatory support		Overall (n = 132,485)	p Value
	Yes (n = 67,868)	No (n = 64,617)		
Age (years)	65.9 ± 0.1	66.5 ± 0.1	66.0 ± 0.1	<0.001
Women	32%	38%	35%	<0.001
White race	64%	66%	65%	<0.001
Non-white race	21%	22%	21%	
Missing race	15%	12%	14%	
Myocardial infarction	68%	35%	52%	<0.001
Coronary angiography/percutaneous coronary intervention	75%	43%	60%	<0.001
Ventricular tachycardia/fibrillation	11%	5%	8%	<0.001
Charlson comorbidity index				<0.001
0	5%	12%	9%	
1	23%	26%	25%	
≥2	72%	62%	67%	
Primary expected payer				<0.001
Nonprivate insurance	62%	67%	65%	
Private insurance	38%	33%	35%	
Median household income for zip code (percentile)				0.06
0−25th	27%	26%	26%	
26th−50th	26%	27%	27%	
51st−75th	25%	25%	25%	
76th−100th	22%	22%	22%	
Hospital bed size				<0.001
Small	6%	5%	5%	
Medium	19%	16%	17%	
Large	75%	79%	77%	
Teaching hospital	62%	75%	69%	<0.001
Hospital region				<0.001
Northeast	17%	17%	17%	
Midwest	24%	21%	23%	
South	38%	38%	38%	
West	21%	24%	23%	
Weekends admission	20%	14%	17%	<0.001
Obesity*	14%	16%	15%	<0.001
Hypertension	54%	60%	57%	<0.001
Diabetes mellitus, type II	33%	33%	33%	0.029
Smoking	15%	13%	14%	<0.001
Coronary artery disease	76%	68%	72%	<0.001
Family history of coronary artery disease	5%	4%	4%	<0.001
Previous myocardial infarction	8%	9%	8%	<0.001
Previous percutaneous coronary intervention	6%	7%	7%	<0.001
Previous coronary artery bypass grafting	2%	2.3%	2%	<0.001
Previous cardiac arrest	0.4%	0.5%	0.4%	<0.001
Atrial fibrillation	34%	40%	37%	<0.001
Congestive heart failure	60%	50%	55%	<0.001
Chronic pulmonary disease	23%	25%	24%	<0.001
Peripheral vascular disease	14%	18%	16%	<0.001
Chronic renal failure	20%	24%	22%	<0.001
Fluid and electrolyte disorders	48%	53%	51%	<0.001
Neurological disorder	6%	7%	6%	<0.001
Anemia[†]	19%	18%	18%	0.007
Coagulopathy	35%	35%	35%	0.40
Hematological/solid malignancy	1.6%	1.9%	1.8%	<0.001

All values represented as percentage or mean ± standard error.

* Body mass index of ≥30 kg/m^2.

[†] ICD-9CM 280.x. ICD-9CM = International Classification of Diseases-9.0 Clinical Modification; MCS = mechanical circulatory support; PCCS = postcardiac surgery cardiogenic shock.

Discussion

In this large nationally-representative cohort of patients, this study noted a serial increase in the incidence of PCCS between 2005 and 2014. Despite the increased use of non-IABP MCS devices during the period, there has been a steady decrease in the use of MCS, due to concomitant decrease in IABP. The IABP still remained the predominant
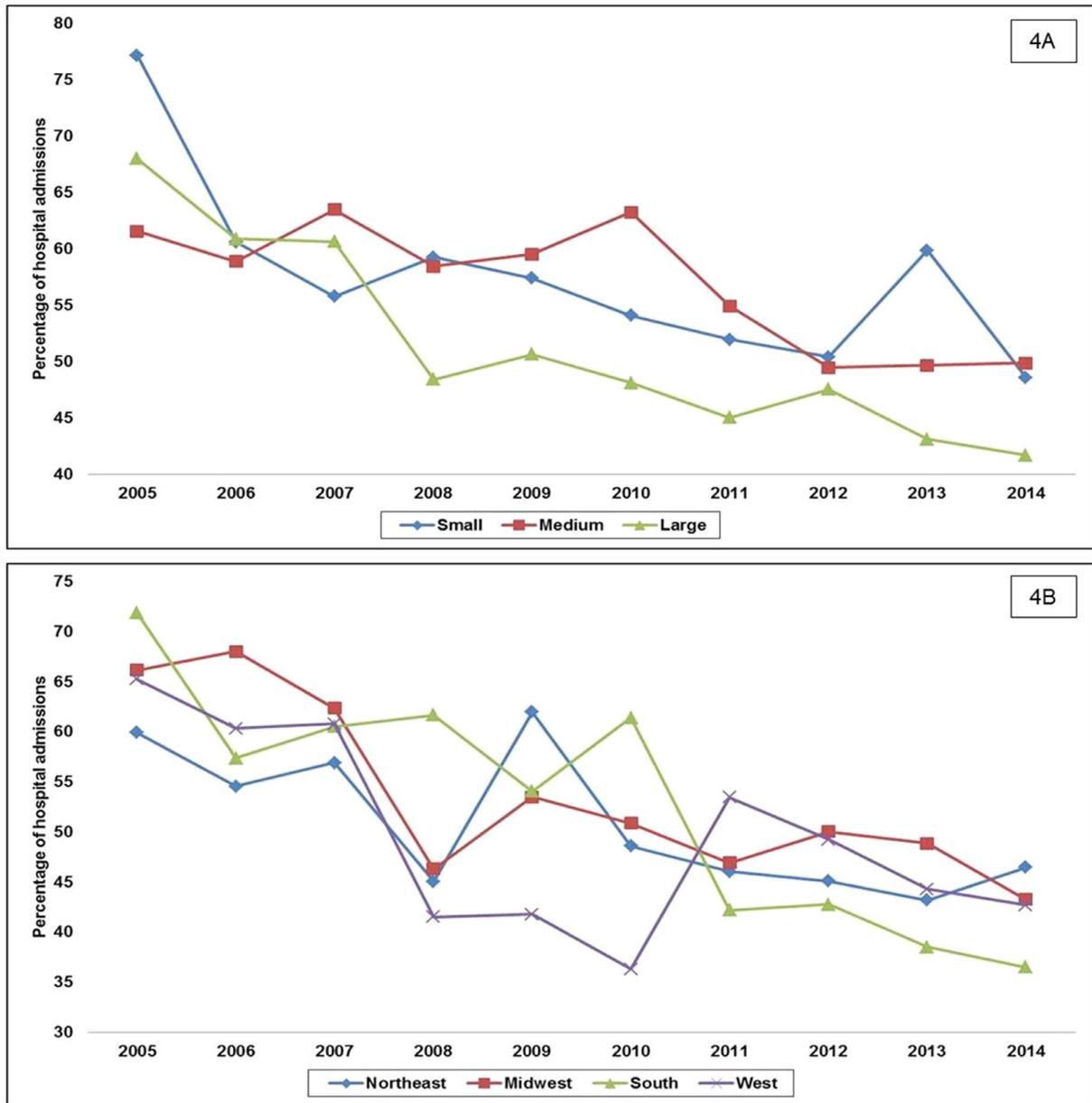
Figure 3. Trends in the use of mechanical circulatory support stratified by age (in years) (*A*), sex (*B*), race (*C*), comorbidity (*D*), and median income for zip code (*E*). p Value for trends for all categories p < 0.001.

MCS device of choice in patients with PCCS. There was a decrease in use of MCS across all demographic categories and hospital characteristics. Older age, female sex, previous cardiovascular morbidity and use of MCS were predictive with higher in-hospital mortality in PCCS. The costs associated with MCS use in PCCS remains significantly high likely due to a combination of disease complexity and greater organ failure in this population.

PCCS continues to constitute only a small fraction of patients with cardiogenic shock, however is associated with higher hospital costs, lengths of stay, and mortality as compared with acute myocardial infarction (AMI).[16,17] In a large national cohort of unselected MCS patients from 2007 to 2011, PCCS was noted in about 1.5% of the total patients.[18] In smaller single-center and registry studies,

MCS use was seen in 5% to 7% of cardiac surgical cases, specifically in patients requiring valve surgeries.[5,6,16,19] This study serves to highlight an important gap in the literature examining the role of short-term MCS in PCCS. Previous work from the HCUP-NIS that has looked at non-AMI cardiogenic shock has noted it to have significantly higher mortality than AMI-shock.[20] Importantly, non-AMI shock included a varied etiology of myocarditis, valvular heart disease, and cardiomyopathy. However, PCCS systematically differs from AMI and non-AMI etiologies of cardiogenic shock, therefore needs careful dedicated study.[21] Other international registries such as the Interagency Registry for Mechanically Assisted Circulatory Support and Extracorporeal Life Support Organization registries evaluate long-term MCS and ECMO, respectively without any
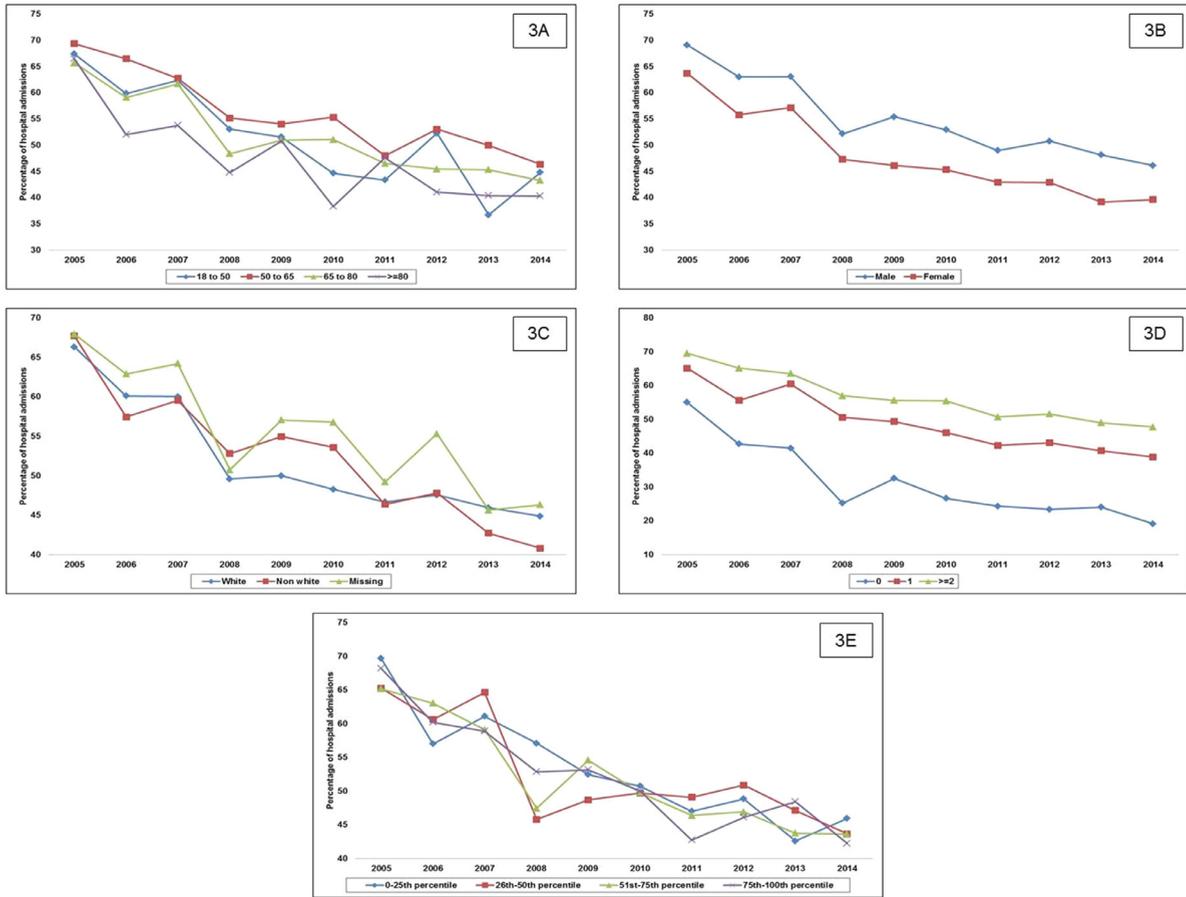
Figure 4. Trends in the use of mechanical circulatory support stratified by hospital size (*A*) and location (*B*). p Value for trends for all categories p < 0.001.
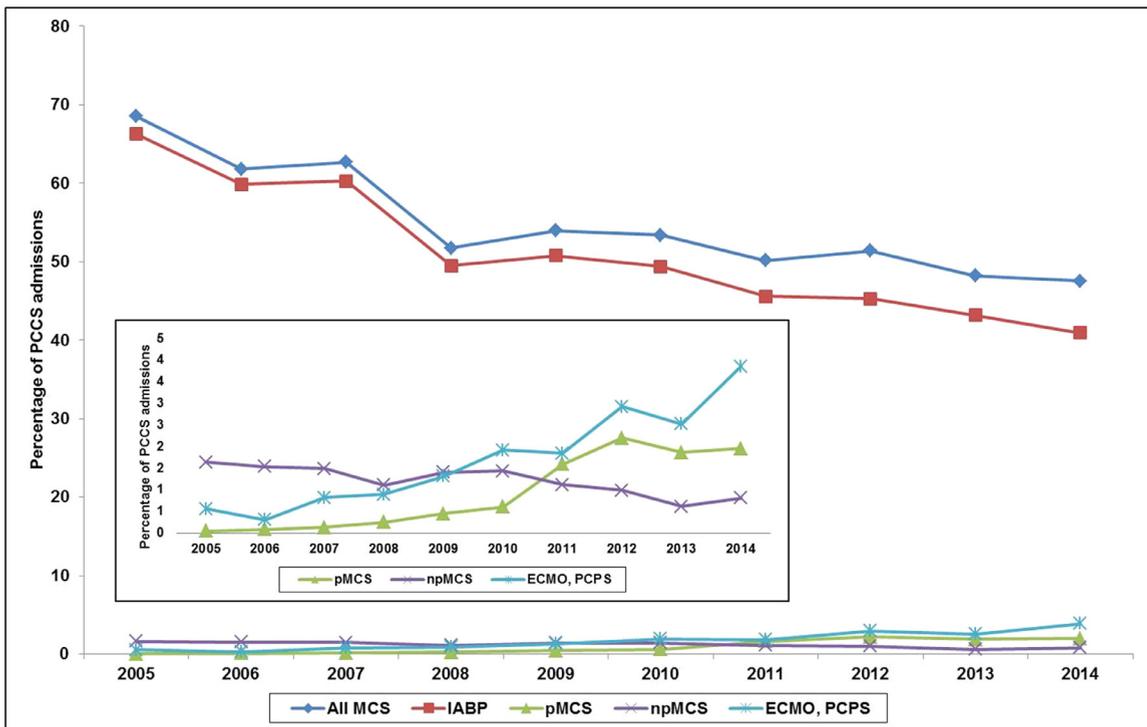

Figure 5. Trends of in-hospital mortality in patients with and without the use of mechanical circulatory support. p Value for trends for all categories p < 0.001. MCS = mechanical circulatory support.

Table 2

Multivariate analysis of in-hospital mortality in postcardiac surgery cardiogenic shock

Parameter	Odds Ratio	95% Confidence Interval		p Value
		Lower limit	Upper limit	
Age (years)	1.1	1.1	1.1	<0.001
Female sex	1.4	1.3	1.5	<0.001
White race		Reference		—
Non-white race	1.1	0.9	1.1	0.72
Missing race	1.1	0.9	1.3	0.08
Mechanical circulatory support	2.3	2.1	2.5	<0.001
Myocardial infarction	0.9	0.8	0.9	0.001
Coronary angiography/percutaneous coronary intervention	0.7	0.6	0.8	<0.001
Ventricular tachycardia/fibrillation	1.7	1.5	1.9	<0.001
Primary expected payer				
Non-private		Reference		—
Private	0.9	0.8	0.9	0.001
Median household income for patient's zip code (percentile)				
0−25th		Reference		—
26th−50th	1.0	0.9	1.1	0.79
51st−75th	1.0	0.9	1.2	0.46
75th−100th	1.0	0.8	1.1	0.34
Hospital bed size				
Small		Reference		—
Medium	0.9	0.7	1.1	0.44
Large	0.9	0.7	1.1	0.13
Teaching hospital	0.96	0.86	1.07	0.46
Hospital region				
Northeast		Reference		—
Midwest	1.2	1.1	1.5	0.01
South	1.3	1.1	1.5	<0.001
West	1.2	1.1	1.4	0.03
Weekends admission	1.0	0.9	1.1	0.37
Obesity	1.0	0.9	1.2	0.62
Hypertension	0.9	0.9	1.00	0.06
Diabetes mellitus	0.9	0.8	0.9	0.003
Smoking	0.8	0.7	0.9	<0.001
Coronary artery disease	0.8	0.7	0.9	<0.001
Family history of coronary artery disease	0.5	0.4	0.7	<0.001
Previous myocardial infarction	0.9	0.8	1.1	0.29
Previous percutaneous coronary intervention	0.9	0.8	1.1	0.41
Previous coronary artery bypass grafting	1.4	1.1	1.8	0.003
Previous cardiac arrest	0.7	0.3	1.4	0.32
Atrial fibrillation	0.8	0.7	0.8	<0.001
Congestive heart failure	0.9	0.8	0.9	0.002
Chronic pulmonary disease	1.0	0.9	1.0	0.23

data on temporary MCS. There has been a decrease in the use of IABP in these patients with a concomitant increase in non-IABP MCS devices.[22,23] In contrast to patients with AMI complicated by cardiogenic shock, this study noted a greater use of ECMO as compared with other percutaneous devices such as the Impella or the TandemHeart.[22] This can be postulated to be due to greater operator comfort with ECMO technique in cardiac surgery, inability to separate from cardiopulmonary bypass necessitating central ECMO cannulation and higher incidence of biventricular failure in patients with PCCS. Despite the limitations of the IABP to influence outcomes in cardiogenic shock, it still remains the most widely used MCS device.[23,24] This is likely be due to the relative ease with insertion at the bedside, lack of compelling data from other MCS devices and the decreased risk of hematological and vascular complications with the IABP.[8,9]

This study is consistent with similar literature on cardiogenic shock in AMI patients that demonstrates an increase in the overall incidence of cardiogenic shock and greater use of MCS devices in younger and male patients.[1,22] Despite a higher overall proportion of nonprivate insurance patients, this study noted greater use of MCS in patients with private insurance compared with those on nonprivate insurance. Previous literature from the HCUP-NIS database has alluded to the role of insurance in patient outcomes.[25] Given the high costs associated with care for both cardiac surgery and MCS patients, these considerations are worthy of careful evaluation in subsequent studies to ensure equitable healthcare in the United States.

This study did not show any correlation between hospital volumes and MCS use in contrast to previous data that showed hospital size to be a marker of greater MCS use in cardiogenic shock associated with AMI.[22,26] There was

differential use of MCS across the various regions in the United States, with the highest use noted in the South and the least in the Northeast. As noted in Figure 4, there was a prominent decrease in the use of MCS in the large-sized hospitals in contrast to similar data from cardiogenic shock from AMI.[22] It is pertinent to note that this study's duration preceded the recent guidelines on MCS use; hence the practice variability could potentially be explained by the lack of uniform consensus on the indication, duration and type of MCS device use.[7]

This study has several limitations, some of which are inherent to the analysis of a large administrative database. Coding errors, misrepresentation of procedural volumes, and under-reporting of co-morbidities are potential limitations of using ICD-9CM codes.[27] The lack of follow-up data and subsequent procedures remains a limitation of this hospital admission database. Although we adjusted for differences in cohort characteristics using propensity matching and multivariable analysis, it is possible that the observed outcomes could have been influenced, to some extent, by other unidentified confounders because of the inherent limitations of using administrative databases. Vasoactive medication dosing, presurgical left ventricular function, peak lactate, duration of cardiopulmonary bypass and hemodynamic variables are known to influence outcomes in this population that was unavailable in the HCUP-NIS database.[4−6] Importantly, the timing of cardiogenic shock with relation to the cardiac surgery could not be reliable assessed. This was partially mitigated by timing the MCS placement postcardiac surgery. Additionally, the incorporating of newer MCS devices in clinical care could potentially have resulted in greater use in patients over more recent years due to greater availability. Finally, this study was limited to in-hospital costs and was unable to account for long-term costs of care for these patients.

In conclusion, use of MCS is seen in nearly 50% of all PCCS patients, with the IABP being the most commonly used device. Despite an increase in the use of non-IABP MCS devices, there has been an overall decrease in the use of MCS in these patients over this 10-year study duration. Use of MCS is an independent predictor of higher in-hospital mortality and hospital costs, likely alluding to higher overall severity of illness in this population. Given the lack of randomized trials on non-IABP MCS devices, careful prospective study is needed before widespread adoption of these devices in clinical practice.

Supplementary Materials

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.1016/j.amjcard.2018.10.029.

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