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Mechanical Circulatory Support-Assisted Early Percutaneous Coronary Intervention in Acute Myocardial Infarction with Cardiogenic Shock: 10-Year National Temporal Trends, Predictors and Outcomes

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RUNNING TITLE

MCS-assisted PCI in AMI-CS

CONFLICT OF INTEREST

None

KEY WORDS

ACS/NSTE-ACS; cardiogenic shock; IABP; STEMI; ventricular assist device

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ABSTRACT

Aims: There are limited data on the trends and outcomes of mechanical circulatory support (MCS)-assisted early percutaneous coronary intervention (PCI) in acute myocardial infarction with cardiogenic shock (AMI-CS).

Methods and Results: Using the National Inpatient Sample database from 2005-2014 a retrospective cohort of AMI-CS admissions receiving early PCI (hospital day zero) was identified. MCS use was defined as intra-aortic balloon pump (IABP), percutaneous left ventricular assist device (pLVAD) and extra-corporeal membrane oxygenation (ECMO) support. Outcomes of interest included in-hospital mortality, resource utilization, trends and predictors of MCS-assisted PCI. Of the 110,452 admissions, MCS assistance was used in 55%. IABP, pLVAD and ECMO were used in 94.8%, 4.2% and 1% respectively. During 2009-2014, there was a decrease in MCS-assisted PCI due to a decrease in IABP, despite an increase in pLVAD and ECMO. Younger age, male sex, lower comorbidity, and cardiac arrest independently predicted MCS use. MCS-assisted PCI was predictive of higher in-hospital mortality (31% vs. 26%, adjusted odds ratio 1.23 [1.19-1.27]; $p<0.001$) and greater resource utilization. IABP-assisted PCI had lower in-hospital mortality and lesser resource utilization compared to pLVAD/ECMO.

Conclusions: MCS-assisted PCI identified a sicker AMI-CS cohort. There was a decrease in IABP and an increase in the pLVAD/ECMO.

CONDENSED ABSTRACT

There are limited data on the role of mechanical circulatory support (MCS)-assisted early percutaneous coronary intervention (PCI) in cardiogenic shock complicating acute myocardial infarction (AMI-CS). Using a 10-year nationally-representative cohort of 110,452 admissions with AMI-CS receiving early PCI, concomitant MCS assistance was noted in 55%. There was a temporal decrease in MCS-assisted PCI from 2009-2014 predominantly due to a decrease in intra-aortic balloon pump use. Younger age, male sex, non-white race, lower comorbidity, cardiac arrest, and endotracheal intubation were independent predictors of MCS-assisted PCI. MCS-assisted PCI identified a sicker population with higher in-hospital mortality.

ABBREVIATIONS

AMI: acute myocardial infarction

CI: confidence interval

CS: cardiogenic shock

ECMO: extracorporeal membrane oxygenation

HCUP-NIS: Healthcare Cost and Utilization Project-National Inpatient Sample

IABP: intra-aortic balloon pump

ICD-9CM: International Classification of Diseases-9 Clinical Modification

MCS: mechanical circulatory support

NSTEMI: non-ST-elevation myocardial infarction

OR: odds ratio

PCI: percutaneous coronary intervention

pLVAD: percutaneous left ventricular assist device

STEMI: ST-elevation myocardial infarction

INTRODUCTION

Acute myocardial infarction (AMI) continues to be a leading cause of cardiovascular death and is associated with 30-45% mortality in patients with concomitant cardiogenic shock (CS).[1-5] Contemporary guidelines from United States societies recommend emergent revascularization in all ST-elevation myocardial infarction (STEMI) and non-ST elevation myocardial infarction (NSTEMI) patients with hemodynamic instability.[6, 7] Patients with AMI-CS are at a high-risk for decompensation due to pre-existing left ventricular dysfunction, higher comorbidity, concomitant multi-vessel disease and complex coronary anatomy.[8] Percutaneous left ventricular assist devices (pLVAD) and extracorporeal membrane oxygenation (ECMO) are being increasingly used in the management of CS with a decrease in the intra-aortic balloon pump (IABP).[5, 9-11] There are limited contemporary data on the concomitant use of MCS to support early PCI in AMI-CS.[12-14] Using a 10-year nationally-representative database we sought to assess the use, temporal trends, and outcomes of percutaneous MCS-assisted early PCI (hospital day zero) in AMI-CS.

MATERIAL AND METHODS

Study Population, Variables and Outcomes

The Healthcare Quality and Utilization Project – National Inpatient Sample (HCUP-NIS) is the largest all-payer database of hospital inpatient stays and contains discharge data from a 20% stratified sample of community hospitals in the United States.[15] Similar to prior literature, using previously validated methodology, a retrospective cohort study of admissions with AMI-CS were identified from the HCUP-NIS database from January 1, 2005 through December 31, 2014.[1-4, 9, 10] Since International Classification of Diseases 9 Clinical Modification (ICD-9CM) codes were re-defined in 2005 to distinguish between permanent MCS and short-term non-implantable devices, admissions before 2005 were excluded from this study.[9, 10] AMI in the primary procedure field were identified using ICD-9CM codes 410.1x-410.9x and a secondary diagnosis of CS by ICD-9CM 785.51.[16] Early PCI was defined as PCI performed on hospital day zero. We used the procedure day for IABP (ICD-9CM 37.61), pLVAD (ICD-9CM 37.68), and ECMO (ICD-9CM 39.65) to time the MCS placement on the same day as the PCI procedure.[14] Demographic characteristics, hospital characteristics, primary payer, acute organ failure, organ support and comorbidities (Deyo's modification of Charlson Comorbidity Index) were abstracted (**Supplementary Table 1**).[1-4, 17-22]

The primary outcome was the frequency, utilization trends, and predictors for MCS use in early PCI in AMI-CS. Secondary outcomes included in-hospital mortality, length of stay, and discharge disposition in admissions with AMI-CS that received MCS-assisted PCI in comparison to those that received early PCI alone.

Statistical Analysis

As recommended by HCUP-NIS, survey procedures using discharge weights provided with HCUP-NIS database were used to generate national estimates. Using the trend weights provided by the HCUP-NIS, samples from 2000-2011 were re-weighted to adjust for the 2012 HCUP-NIS re-design.[23] Using trend weights available on the HCUP-NIS database, samples from 2000-2011 were retroactively re-weighted. The new sampling strategy is expected to result in more precise estimates than the previous HCUP-NIS design by reducing sampling error.[15] All analyses were conducted accounting for clustering of admissions within a hospital (HOSP_NIS), weighting (DISCWT), and stratification (NIS_STRATUM) of the NIS consistent with prior data.[24] Chi-square and t-tests were used to compare categorical and continuous variables respectively. Univariable analysis for trends and outcomes was performed and were represented as odds ratio (OR) with 95% confidence interval (CI). Multivariable logistic regression analysis was performed for predictors of MCS use and in-hospital mortality. To confirm the results of the primary findings sub-group analyses stratifying admissions by age, sex, race, type of AMI and presence of cardiac arrest were performed. In the MCS-assisted PCI cohort, *a priori* comparison of the pLVAD and ECMO to the IABP was performed. Two-tailed $p<0.05$ was considered statistically significant. All statistical analyses were performed using SPSS v25.0 (IBM Corp, Armonk NY).

RESULTS

There were an estimated 6,111,445 admissions for AMI between January 1, 2005 and December 31, 2014, of which early PCI (hospital day 0) for AMI-CS was performed in 110,452 admissions (**Figures 1A-B**). There was an overall increase in the total admissions for AMI-CS receiving early PCI in this study period, with 86.5% encompassing ST-elevation AMI-CS. Percutaneous MCS were used concomitantly with early PCI in 60,487 (54.8%) admissions, with the IABP in 57,337 (94.8%), pLVAD in 2,568 (4.2%) and ECMO in 582 (1.0%). IABP remained the predominant MCS device of choice, though there was a decrease in use since 2009 (**Figures 2A-B**). MCS-assisted PCI was performed more frequently in admissions that were younger, male and non-white, and with lower comorbidity (**Table 1** and **Supplementary Table 2**). The MCS-assisted PCI cohort had higher rates of cardiac arrest (26% vs. 21%; $p<0.001$) and respiratory failure requiring endotracheal intubation (40% vs. 28%; $p<0.001$) on admission. During the hospital course, the MCS-assisted PCI cohort developed higher rates of non-cardiac organ failure

(**Supplementary Table 2**). Temporal trends of MCS-assisted PCI stratified by patient and hospital characteristics are presented in **Supplementary Figures 1 and 2**. Multivariable logistic regression analysis for predictors of MCS-use for early PCI is presented in **Table 2**. Younger age, male sex, non-white race, lower comorbidity, non-Medicare insurance, concomitant cardiac arrest, endotracheal intubation, and admission to a medium- or large-sized hospital were independent predictors of MCS use for early PCI.

The unadjusted in-hospital mortality (31.0% vs. 25.8%; OR 1.29 [95% CI 1.26-1.33]; p<0.001) was significantly higher in the cohort with MCS-assisted PCI (**Figures 3A and 3B** for temporal trends). Use of MCS assistance for early PCI was independently predictive of higher in-hospital mortality (OR 1.23 [95% CI 1.19-1.27]; p<0.001) (**Supplementary Table 3**). Other significant predictors of in-hospital mortality included older age, earlier year of admission, and acute non-cardiac organ failure. These results remained consistent when admissions were stratified by age, sex, race, type of AMI-CS and presence of cardiac arrest (**Figure 4**). The MCS-assisted PCI cohort had longer length of stay and fewer discharges to home (**Table 3**).

In the MCS-assisted PCI cohort, pLVAD and ECMO were used more commonly in AMI-CS with concomitant cardiac arrest and respiratory failure requiring endotracheal intubation compared to IABP (**Supplementary Table 4**). Unadjusted in-hospital mortality was higher in the groups with pLVAD (49% vs. 30%; OR 2.25 [95% CI 2.08-2.43]; p<0.001) and ECMO (54% vs. 30%; OR 2.75 [95% CI 2.33-3.24; p<0.001) compared to the IABP cohort. In a multivariable analysis incorporating demographics, hospital characteristics, comorbidity, acute organ failure and organ support, use of pLVAD (OR 2.21 [95% CI 2.01-2.43]; p<0.001) and ECMO (OR 3.09 [95% CI 2.53-3.76]; p<0.001) for PCI assistance were associated with higher in-hospital mortality. Compared to pLVAD and ECMO, admissions with IABP were discharged home more frequently (42% vs. 11% vs. 53%; $p<0.001$) and shorter length of stay (9.6 ± 10.4 vs. 16.7 ± 22.5 vs. 9.5 ± 9.4 days; $p<0.001$).

DISCUSSION

In this nationally-representative study of 110,452 patient admissions with AMI-CS who underwent early PCI (day of admission), we noted MCS use in 55% of the admissions. The IABP remained the most commonly used MCS device with a decrease in utilization between 2009 (98.5%) and 2014 (86.6%). Between 2009 and 2014, though there was a concomitant increase in the use of pLVAD (1.1% to 11.3%) and ECMO (0.4% to 2.1%), the overall trend for MCS-assisted PCI showed a decrease since 2009 (59.1% to 49.7%). Younger age, male sex, non-white race, lower comorbidity, concomitant cardiac arrest and endotracheal intubation were significant predictors of MCS use. The MCS-assisted PCI cohort was sicker and had higher in-hospital mortality and greater resource utilization compared to AMI-CS patients receiving early PCI without MCS use. Despite the higher uptake in pLVAD and ECMO devices to support PCI, there has not been a significant decrease in in-hospital mortality in AMI-CS admissions.

Mechanical Circulatory Support in AMI-CS

Prior analyses on AMI-CS and MCS using large databases have focused on unselected MCS use, unselected CS patients and MCS-assisted PCI in all-comers.[14, 25, 26] In contrast to these studies, our data addresses a very specific population of STEMI and NSTEMI patients with CS who were treated with emergent PCI within the first 24 hours. These patients are typically sicker than unselected AMI-CS patients and therefore, may benefit the most from MCS implantation. As noted in this study and by other groups, there has been a steady increase in the use of percutaneous MCS devices in the catheterization laboratory for the management of AMI-CS.[5, 9, 10, 14, 27] The IABP has been the traditional device of choice in AMI-CS, with more recent data demonstrating an increase in the use of pLVAD and ECMO.[27] In AMI-CS patients, compared to the IABP, the Impella® device has not shown a significant outcomes benefit despite improved hemodynamic stabilization.[28] Contrary to these studies we noted higher in-hospital mortality in the pLVAD and ECMO cohorts as compared to the IABP cohort. Potential explanations for this higher mortality include, (i) higher acuity of illness in the pLVAD cohort, that could not be measured holistically due to lack of physiological data; (ii) confounding by indication in this real-world population and (iii) variability in the use of these devices since the study period was before societal guidelines on percutaneous MCS,[13] and (iv) higher number of post cardiac arrest patients in the MCS group who may not benefit from MCS if they have catastrophic neurologic injury. These results are consistent with prior retrospective analyses in patients with unselected CS that have demonstrated higher mortality in patients with pLVAD use and are worthy of further study in carefully designed prospective trials.[5, 9, 10, 14, 27] The widespread adoption of these devices may be associated with 'indication creep', wherein these devices are used in younger and less sick patients who are least likely to benefit from them. These patients may benefit from the adoption of multidisciplinary team approach for careful patient, procedure and treatment selection.[4, 5, 17, 29-31] Further strategies targeting aspects such as multi-disciplinary care, standardized protocols, and prevention of metabolic injury and complications remain priorities in this field.[4, 17, 29, 32]

Trends in the Use of Mechanical Circulatory Support

Traditionally, the IABP has been used for left ventricular support during PCI in AMI-CS; however there has been a trend towards decreasing use in recent years.[5, 9, 10, 14, 27] Despite the lack of a demonstrable mortality benefit from the IABP in AMI-CS, >85% of the population in this study received an IABP for MCS-assisted PCI.[11] Around the year 2009, there was an increase in use of pLVAD and ECMO, with a significant increase around 2012. This could be postulated to be due to the influence of two important studies, i.e. the IABP-SHOCK (Intraaortic Balloon Pump in Cardiogenic Shock) and PROTECT II (Prospective, multi-center, randomized controlled trial of the Impella Recover LP 2.5 system versus IABP in patients undergoing non emergent high risk PCI) trials that were published in 2012.[11, 12] Furthermore we demonstrated female sex and non-white race to be associated with lower use of MCS-assisted early PCI and had higher in-hospital mortality. These sex and race disparities have been noted in prior studies in a different population of acute cardiac care patients and is worthy of careful assessment in AMI-CS patients.[17] Hospital-level disparities exist in the outcomes of AMI-CS patients receiving MCS.[1] Prior work from our group has shown larger hospitals to have lower in-hospital mortality in AMI-CS; however the mortality is higher in those receiving MCS.[1, 9, 10] This can be postulated to be due to the higher acuity of this population not fully accounted by various regression analyses. Prior literature has shown a volume-outcome relationship in unselected CS patients that has resulted in an advocacy for multi-disciplinary care in specialized shock centers.[33] Due to the sampling design changes to the HCUP-NIS database in 2012, this study was unable to assess the relationship of hospital volume with outcomes in these patients. However, using hospital location and size as a surrogate for case volume and presence of multi-disciplinary teams, we were unable to demonstrate differences in in-hospital mortality.

Limitations

This study has several limitations, some of which are inherent to the analysis of a large administrative database. The definition of CS was based on discharge diagnoses and not hemodynamic parameters. However, prior validation studies have shown high specificity (99%) and negative predictive value (98%) for this definition.[34] Furthermore, the definitions used for AMI and organ failure have been previously validated, which may decrease the inherent issues associated with the use of administrative codes.[4, 16] Since further granularity in timing beyond day of procedure is unavailable, and AMI-CS evolves dynamically during the first 24-hours, it is possible this study included patients who received MCS for cardiac arrest, worsening CS or post-PCI complications independent of the need for supporting the index PCI. Information on vasoactive medication use and dosing, laboratory parameters (peak serum lactate, serum creatinine, hemoglobin, bicarbonate, acid-base balance, etc.), left ventricular function, and hemodynamic variables known to influence outcomes in this population, were unavailable in the HCUP-NIS database. Therefore the multivariable analyses performed in this study are unable to account for these important parameters. The timing and duration of CS, which are known to influence mortality, could not be reliably measured from this database.[8] However, by restricting our outcomes to early PCI we are optimistic that most patients in either cohort presented with CS at admission. The lack of angiographic data, such target vessel for PCI, classification and the presence of multi-vessel disease with/without chronic total occlusions, that may significantly influence outcomes, were not available in this database. Despite these limitations, this study addresses an important knowledge gap highlighting the national use of MCS to assist PCI in AMI-CS.

CONCLUSIONS

In this study of 110,452 admissions with AMI-CS that underwent early PCI, we noted more than half the population received concomitant MCS. Though the IABP remains the most commonly used device, there has been a steady increase in the pLVAD and ECMO in recent years. The use of MCS identified a sicker cohort of AMI-CS patients. The cohorts with pLVAD and ECMO use had higher in-hospital mortality and resource utilization compared to the IABP cohort, highlighting the need for further careful study in dedicated prospective studies.

IMPACT ON DAILY PRACTICE

Mechanical circulatory support-assisted percutaneous coronary intervention in acute myocardial infarction with cardiogenic shock identified a sicker population with higher in-hospital mortality. Careful selection of patients and procedures is needed to improve outcomes in this critically ill population.

FUNDING

None

APPENDIX

Study Collaborators:

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FIGURE LEGENDS

Figure 1. Study cohort

Legend: Figure 1A: Consort diagram for selection of study cohort from all AMI admissions in the United States; Figure 1B: 10-year temporal trends of total admissions with AMI-CS receiving early PCI (hospital day zero)

Figure 2. Temporal trends in the use of MCS-assistance for early PCI in AMI-CS

Legend: Figure 2A: 10-year temporal trends demonstrating the proportion of cases receiving MCS-assistance for early PCI in AMI-CS; Figure 2B: 10-year temporal trends of individual MCS devices for PCI assistance in in AMI-CS; all $p<0.001$ for trend (picture-in-picture is used to provide greater magnification of pLVAD and ECMO use)

Figure 3. Temporal trends of in-hospital mortality in AMI-CS receiving early PCI

Legend: Figure 3A: Unadjusted temporal trends of in-hospital mortality in AMI-CS receiving early PCI stratified by MCS use ($p<0.001$ for trend over time); Figure 3B: Adjusted temporal trends for in-hospital mortality in AMI-CS receiving early PCI stratified by MCS use with 2000 as referent year; adjusted for age, sex, race, primary payer status, socio-economic stratum, hospital characteristics, comorbidities, AMI type, acute organ failure, cardiac arrest, invasive hemodynamic monitoring, intubation on admission, and hemodialysis use ($p<0.001$).

Figure 4. Multivariate predictors of in-hospital mortality in AMI-CS receiving MCS-assisted early PCI compared to those without MCS-assisted PCI

Caption: Multivariable adjusted odds ratios (95% confidence intervals)* for in-hospital mortality in the admissions receiving early PCI stratified by age, sex, race, type of AMI-CS and presence of cardiac arrest; all $p<0.001$

*Adjusted age, sex, race, year of admission, primary payer, socio-economic status, hospital location/teaching status, hospital bedsize, hospital region, comorbidity, type of AMI, acute organ failure, cardiac arrest, invasive hemodynamic monitoring, mechanical ventilation and hemodialysis

Table 1. Baseline characteristics of cohorts with and without MCS-assisted early PCI

Characteristic		MCS-assisted PCI (N = 60,487)	PCI without MCS (N = 49,965)	*P*
AMI type	**ST-elevation**	87.3	85.6	<0.001
	Non-ST elevation	12.7	14.4	<0.001
Age (years)		64.8 ± 12.7	66.9 ± 13.1	<0.001
Female sex		31.0	40.1	<0.001
Race	**White**	67.9	70.9	<0.001
	Black	6.1	5.5	
	Others*	26.0	23.6	
Inter-hospital transfers		18.3	18.2	0.87
Primary payer	**Medicare**	47.9	54.8	<0.001
	Medicaid	8.4	7.0	
	Others**	43.8	38.1	
Hospital region	**Northeast**	20.8	14.6	<0.001
	Midwest	20.1	22.4	
	South	38.6	40.1	
	West	20.6	22.9	
Charlson Comorbidity Index	**0-3**	36.6	32.2	<0.001
	4-6	49.6	49.3	
	≥ 7	13.9	18.5	
Comorbidities	**Hyperlipidemia**	42.0	45.7	<0.001
	Chronic kidney disease	11.5	13.8	<0.001
	Heart failure	48.0	42.3	<0.001

Legend: Represented as percentage or mean ± standard deviation; *Hispanic, Asian, Native American, Others, Missing; **Private, Uninsured, No Charge, Others

Table 2. Multivariable regression analysis for predictors of MCS-assisted early PCI

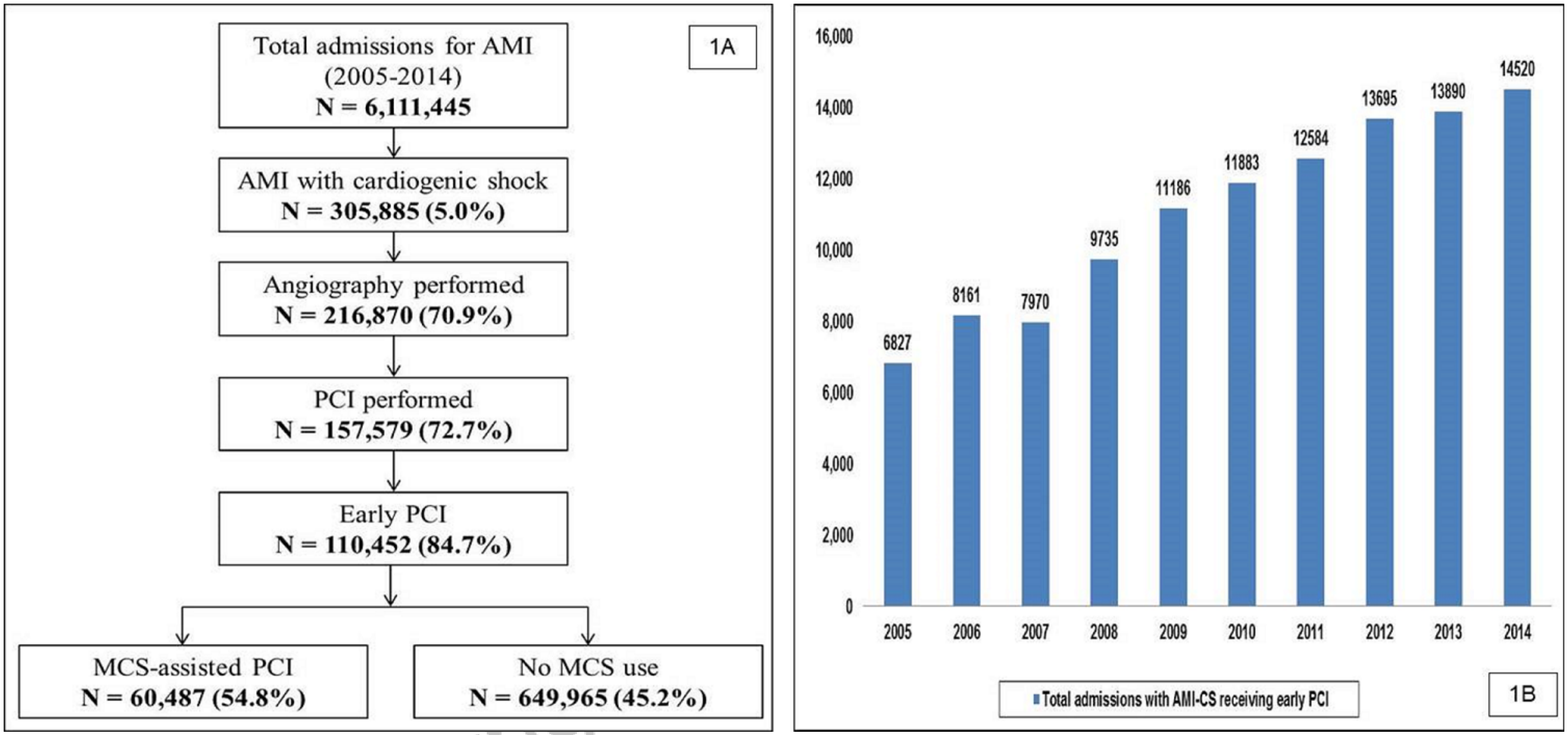
Total cohort (N = 110,452)		Odds ratio	95% confidence interval		*P*
			Lower limit	Upper limit	
Age groups (years)	**19-49**	Reference category			
	50-59	0.98	0.94	1.03	0.52
	60-69	0.92	0.87	0.97	0.004
	70-79	0.90	0.84	0.96	0.001
	≥80	0.76	0.71	0.82	<0.001
Female sex		0.71	0.69	0.73	<0.001
Race	**White**	Reference category			
	Black	1.18	1.11	1.24	<0.001
	Hispanic	1.34	1.27	1.41	<0.001
	Asian	1.15	1.07	1.24	<0.001
	Native American	0.99	0.82	1.19	0.90
	Others	1.20	1.13	1.29	<0.001
Primary payer	**Medicare**	Reference category			
	Medicaid	1.11	1.05	1.18	<0.001
	Private	1.08	1.04	1.13	<0.001
	Uninsured	1.09	1.03	1.15	0.005
	No Charge	0.84	0.71	1.00	0.05
	Others	1.05	0.97	1.14	0.24
Quartile of median household income for zip code	**0-25th**	Reference category			
	26th-50th	1.00	0.97	1.04	0.87
	51st-75th	1.01	0.98	1.05	0.50

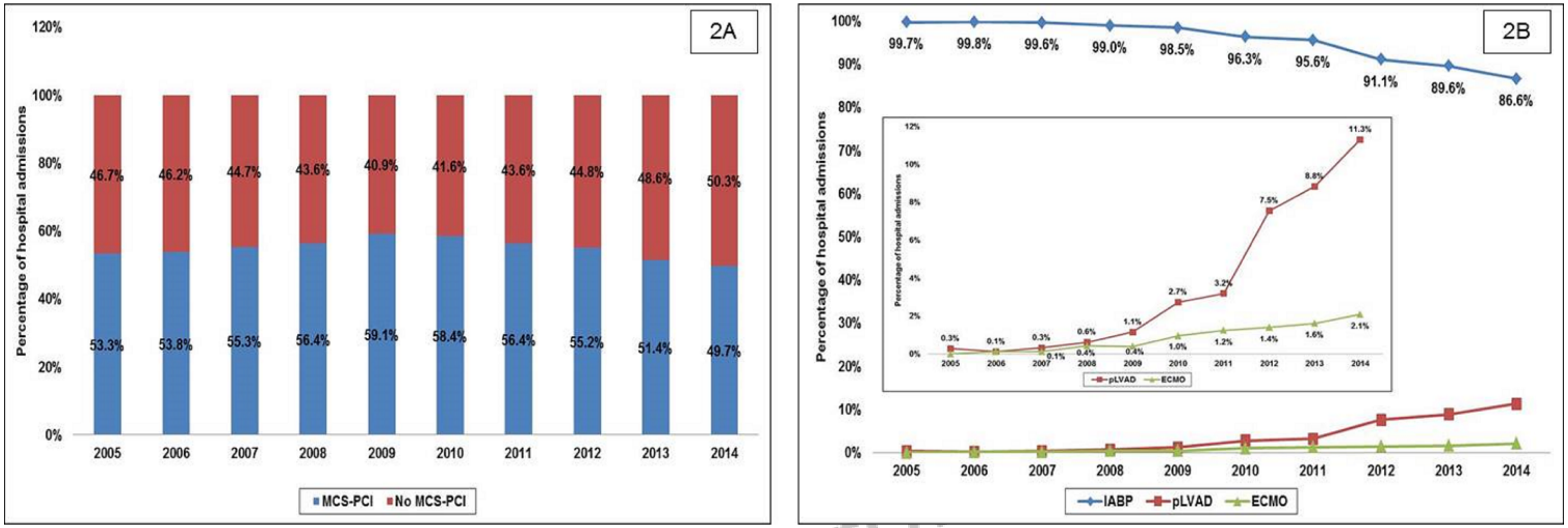
	75th-100th	1.04	0.99	1.08	0.09
Hospital teaching status and location	**Rural**	Reference category			
	Urban non-teaching	0.97	0.91	1.03	0.38
	Urban Teaching	0.99	0.94	1.06	0.87
Hospital bed-size	**Small**	Reference category			
	Medium	1.13	1.07	1.20	<0.001
	Large	1.26	1.20	1.33	<0.001
Hospital region	**Northeast**	Reference category			
	Midwest	0.61	0.58	0.64	<0.001
	South	0.67	0.64	0.70	<0.001
	West	0.60	0.58	0.63	<0.001
Charlson Comorbidity Index	**0-3**	Reference category			
	4-6	1.05	1.01	1.09	0.01
	≥ 7	0.86	0.82	0.91	<0.001
Cardiac arrest		1.14	1.11	1.18	<0.001
Intubated at admission (day 0)		1.72	1.67	1.77	<0.001

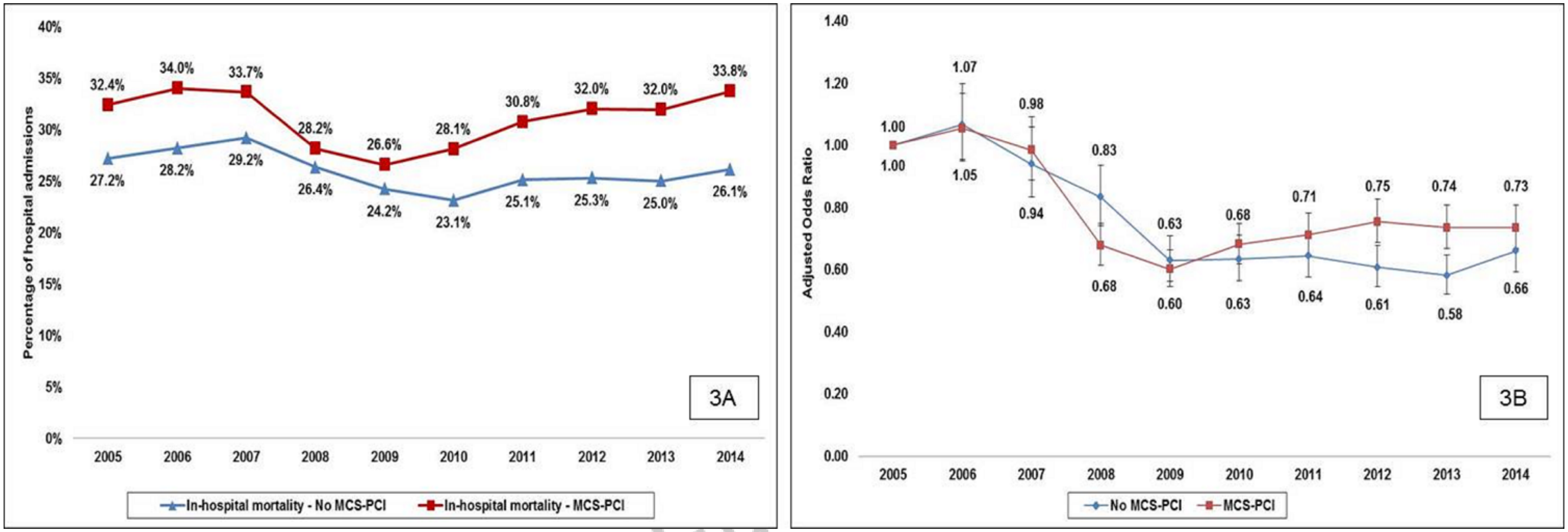
Table 3. Clinical outcomes of cohorts with and without MCS-assisted early PCI

Outcomes		MCS-assisted PCI (N = 60,487)	PCI without MCS (N = 49,965)	*P*
In-hospital mortality		31.0	25.8	<0.001
Length of stay (days)		9.6 ± 9.7	8.1 ± 9.3	<0.001
Discharge disposition	**Home**	52.5	59.2	<0.001
	Transferred to other hospitals	10.1	5.6	
	Skilled nursing facility	21.6	21.2	
	Home with home health care	15.1	13.2	
	Against medical advice	0.5	0.6	

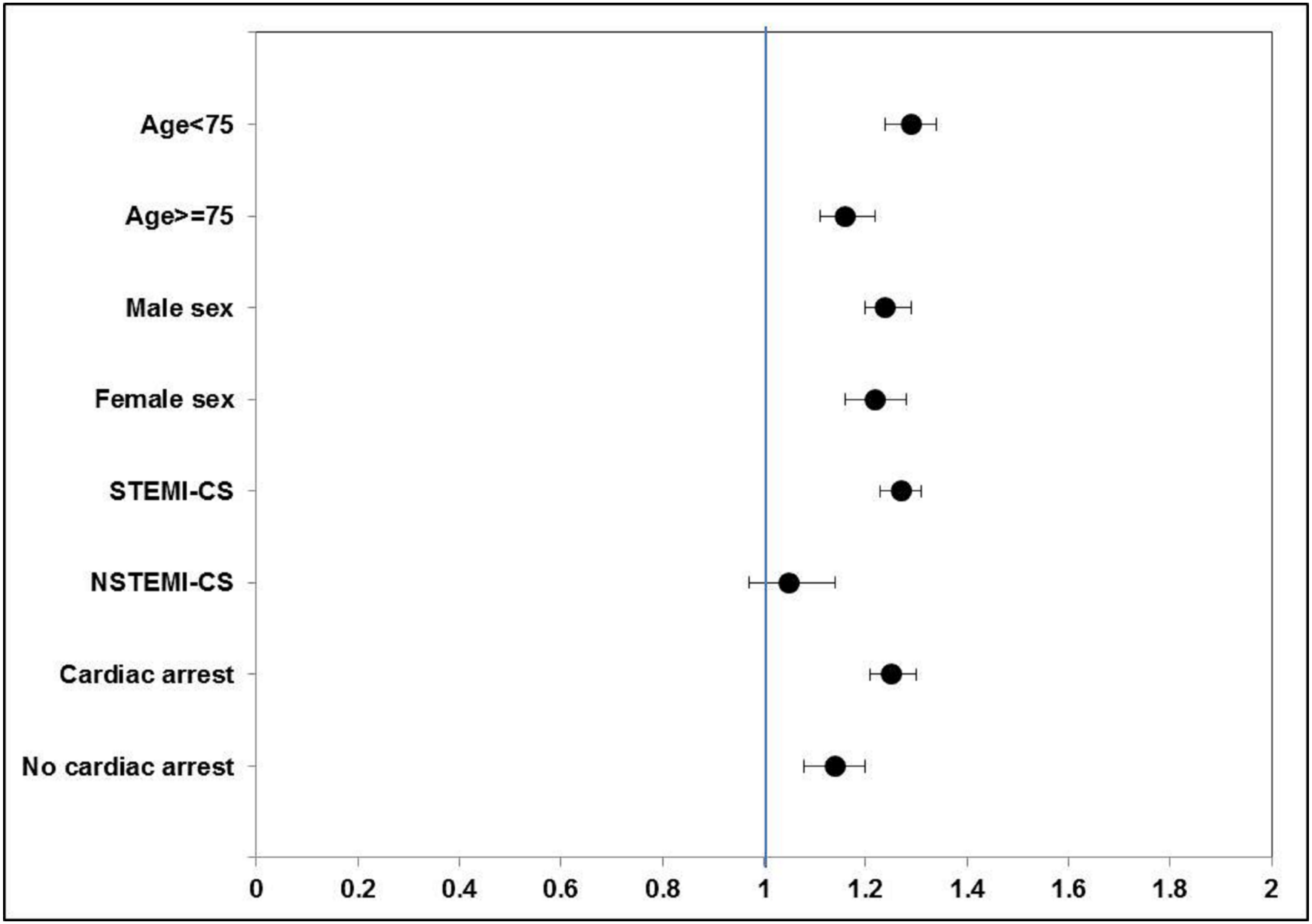
Legend: Represented as percentage or mean ± standard deviation


1A
Total admissions for AMI (2005-2014)
N = 6,111,445
AMI with cardiogenic shock
N = 305,885 (5.0%)
Angiography performed
N = 216,870 (70.9%)
PCI performed
N = 157,579 (72.7%)
Early PCI
N = 110,452 (84.7%)
MCS-assisted PCI
N = 60,487 (54.8%)
No MCS use
N = 649,965 (45.2%)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
6827
8161
7970
9735
11186
11883
12584
13695
13890
14520
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Total admissions with AMI-CS receiving early PCI
1B


2A
120%
100%
80%
60%
40%
20%
0%
Percentage of hospital admissions
46.7% 46.2% 44.7% 43.6% 40.9% 41.6% 43.6% 44.8% 48.6% 50.3%
53.3% 53.8% 55.3% 56.4% 59.1% 58.4% 56.4% 55.2% 51.4% 49.7%
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
MCS-PCI
No MCS-PCI
2B
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of hospital admissions
99.7% 99.8% 99.6% 99.0% 98.5% 96.3% 95.6% 91.1% 89.6% 86.6%
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
IABP
pLVAD
ECMO



40%
35%
30%
25%
20%
15%
10%
5%
0%
Percentage of hospital admissions
32.4%
34.0%
33.7%
28.2%
26.6%
28.1%
30.8%
32.0%
32.0%
33.8%
27.2%
28.2%
29.2%
26.4%
24.2%
23.1%
25.1%
25.3%
25.0%
26.1%
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
In-hospital mortality - No MCS-PCI
In-hospital mortality - MCS-PCI
3A
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Adjusted Odds Ratio
1.00
1.07
0.98
0.83
0.63
0.68
0.71
0.75
0.74
0.73
1.00
1.05
0.94
0.68
0.60
0.63
0.64
0.61
0.58
0.66
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
No MCS-PCI
MCS-PCI
3B


Age<75
Age>=75
Male sex
Female sex
STEMI-CS
NSTEMI-CS
Cardiac arrest
No cardiac arrest
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

SUPPLEMENATARY MATERIAL

Mechanical Circulatory Support-Assisted Early Percutaneous Coronary Intervention in Acute Myocardial Infarction with Cardiogenic Shock: 10-Year National Temporal Trends, Predictors and Outcomes

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SUPPLEMENTARY FIGURE LEGENDS

Supplementary Figure 1. Trends of MCS assistance for early PCI in AMI-CS classified by patient characteristics

Legend: Trends in the MCS-assisted PCI classified by (1A) age, (1B) sex, (1C) race and (1D) Charlson comorbidity index; all $p<0.001$ for trend

Supplementary Figure 2. Trends of MCS assistance for early PCI in AMI-CS classified by hospital characteristics

Legend: Trends in the MCS-assisted PCI classified by (2A) region, (2B) location and teaching status, (2C) and bedsize; all $p<0.001$ for trend

SUPPLEMENTARY TABLES

Supplementary Table 1. Administrative codes used for identification of diagnoses and procedures

Diagnosis/Procedure	International Classification of Diseases 9.0 Clinical Modification Codes
Coronary angiography	36.06, 37.22, 37.23, 88.53-88.56
Percutaneous coronary intervention	00.66, 36.01, 36.02, 36.05, 36.07, 88.57
Cardiac arrest	427.5
Right heart catheterization	37.21, 37.23
Pulmonary artery catheterization	204
Invasive mechanical ventilation	96.7, 96.70, 96.71, 96.72
Hemodialysis	39.95
Acute renal failure	584, 584.5, 584.6, 584.7, 584.8, 584.9
Acute respiratory failure	518.81, 518.85, 786.09, 799.1
Acute hepatic failure	570.x, 572.2, 573.3, 573.4
Acute metabolic failure	276.2
Acute neurologic failure	293, 293.0, 293.1, 293.8, 293.81-293.84, 293.89, 293.9, 348.1, 780.01, 780.09, 89.14, 348.3, 348.30, 348.31, 348.39

Supplementary Table 2. Baseline, in-hospital course and management

Characteristic		MCS-assisted PCI (N = 60,487)	PCI without MCS (N = 49,965)	*P*
Weekend admission		28.1	28.0	0.27
Quartile of median household income for zip code	**0-25th**	26.5	26.8	<0.001
	26th-50th	26.0	26.8	
	51st-75th	25.0	25.1	
	75th-100th	22.6	21.3	
Hospital teaching status and location	**Rural**	5.2	5.4	<0.001
	Urban non-teaching	40.3	42.2	
	Urban teaching	54.5	52.4	
Hospital bedsize	**Small**	6.3	7.6	<0.001
	Medium	21.7	23.3	
	Large	71.9	69.1	
Acute organ dysfunction	**Respiratory**	51.0	41.5	<0.001
	Renal	34.8	30.3	<0.001
	Hepatic	11.8	8.2	<0.001
	Hematologic	12.8	7.3	<0.001
	Metabolic	20.3	16.4	<0.001
	Neurologic	17.9	15.8	<0.001
Cardiac arrest		25.6	20.7	<0.001
Right heart/pulmonary artery catheterization		22.4	13.2	<0.001
Intubated at admission (day 0)		39.5	27.5	<0.001
Hemodialysis		3.0	2.8	0.10

Supplementary Table 3. Multivariable regression for in-hospital mortality in AMI-CS

Total cohort (N = 110,452)		Odds ratio	95% confidence interval		*P*
			Lower Limit	Upper Limit	
MCS-assisted PCI		1.23	1.19	1.27	<0.001
Age groups (years)	**19-49**	Reference category			
	50-59	1.12	1.04	1.19	0.001
	60-69	1.71	1.59	1.83	<0.001
	70-79	2.85	2.62	3.10	<0.001
	≥80	4.92	4.51	5.37	<0.001
Female sex		1.15	1.12	1.19	<0.001
Race	**White**	Reference category			
	Black	0.99	0.93	1.05	0.72
	Hispanic	1.13	1.06	1.20	<0.001
	Asian	0.88	0.80	0.96	0.005
	Native American	1.38	1.12	1.70	0.003
	Others	1.02	0.94	1.10	0.67
Year of admission	**2005**	Reference category			
	2006	1.09	1.00	1.19	0.05
	2007	0.97	0.89	1.05	0.46
	2008	0.71	0.66	0.78	<0.001
	2009	0.58	0.53	0.63	<0.001
	2010	0.61	0.57	0.67	<0.001
	2011	0.63	0.58	0.68	<0.001
	2012	0.62	0.57	0.67	<0.001

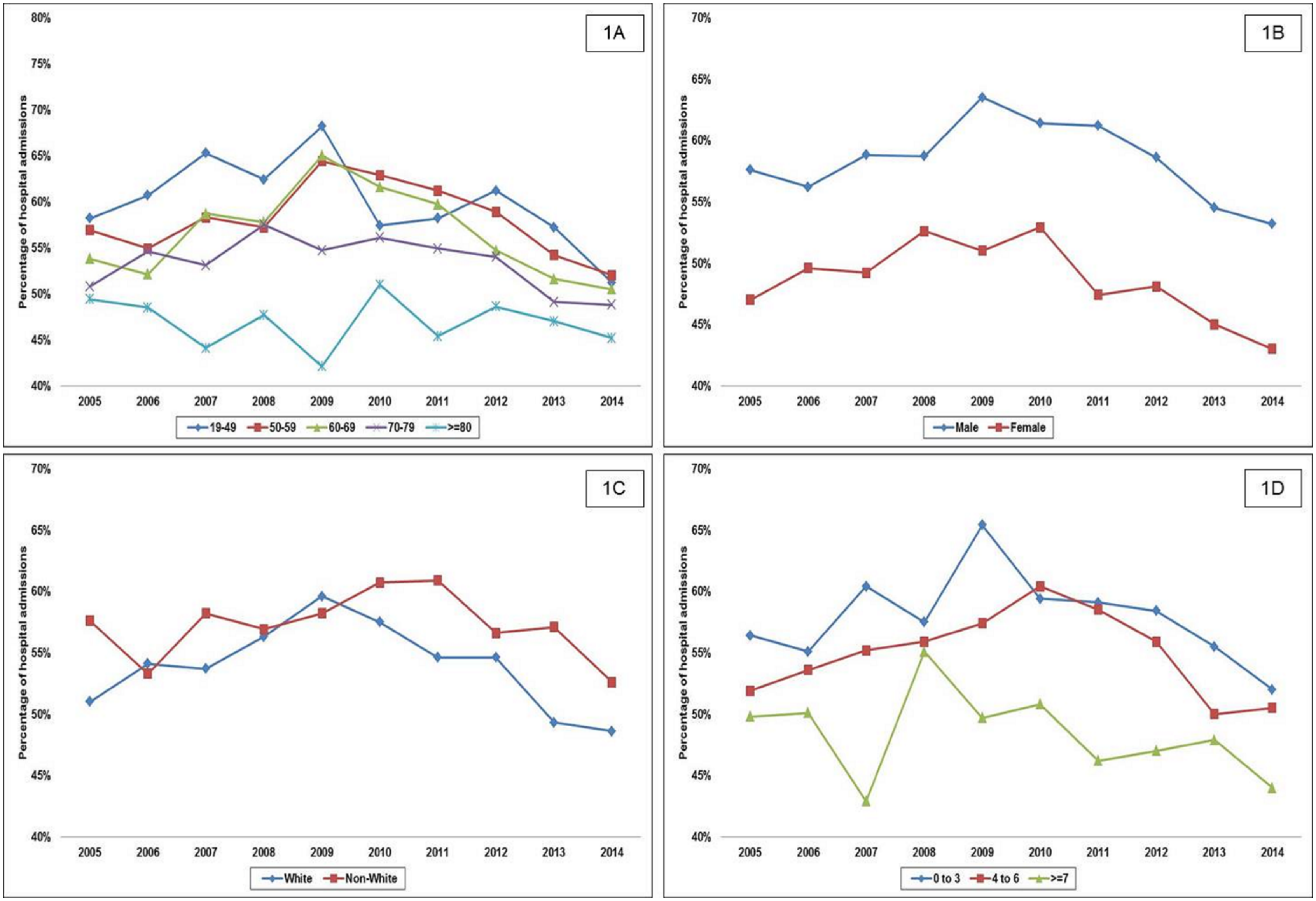
	2013	0.61	0.57	0.66	<0.001
	2014	0.63	0.59	0.68	<0.001
Primary payer	**Medicare**	Reference category			
	Medicaid	0.86	0.80	0.92	<0.001
	Private	0.72	0.68	0.75	<0.001
	Uninsured	1.32	1.24	1.42	<0.001
	No Charge	0.88	0.71	1.08	0.22
	Others	0.80	0.72	0.89	<0.001
Quartile of median household income for zip code	**0-25th**	Reference category			
	26th-50th	0.89	0.85	0.93	<0.001
	51st-75th	0.86	0.83	0.90	<0.001
	75th-100th	0.83	0.80	0.87	<0.001
Inter-hospital transfer		1.03	0.99	1.07	0.13
Hospital teaching status and location	**Rural**	Reference category			
	Urban Non-Teaching	0.89	0.83	0.96	0.002
	Urban Teaching	0.97	0.90	1.04	0.40
Hospital bed-size	**Small**	Reference category			
	Medium	1.03	0.96	1.10	0.39
	Large	1.07	1.00	1.14	0.04
Hospital region	**Northeast**	Reference category			
	Midwest	1.01	0.95	1.06	0.84
	South	1.15	1.10	1.20	<0.001
	West	1.04	0.98	1.09	0.18
Charlson Comorbidity Index	**0-3**	Reference category			
	4-6	0.73	0.70	0.77	<0.001

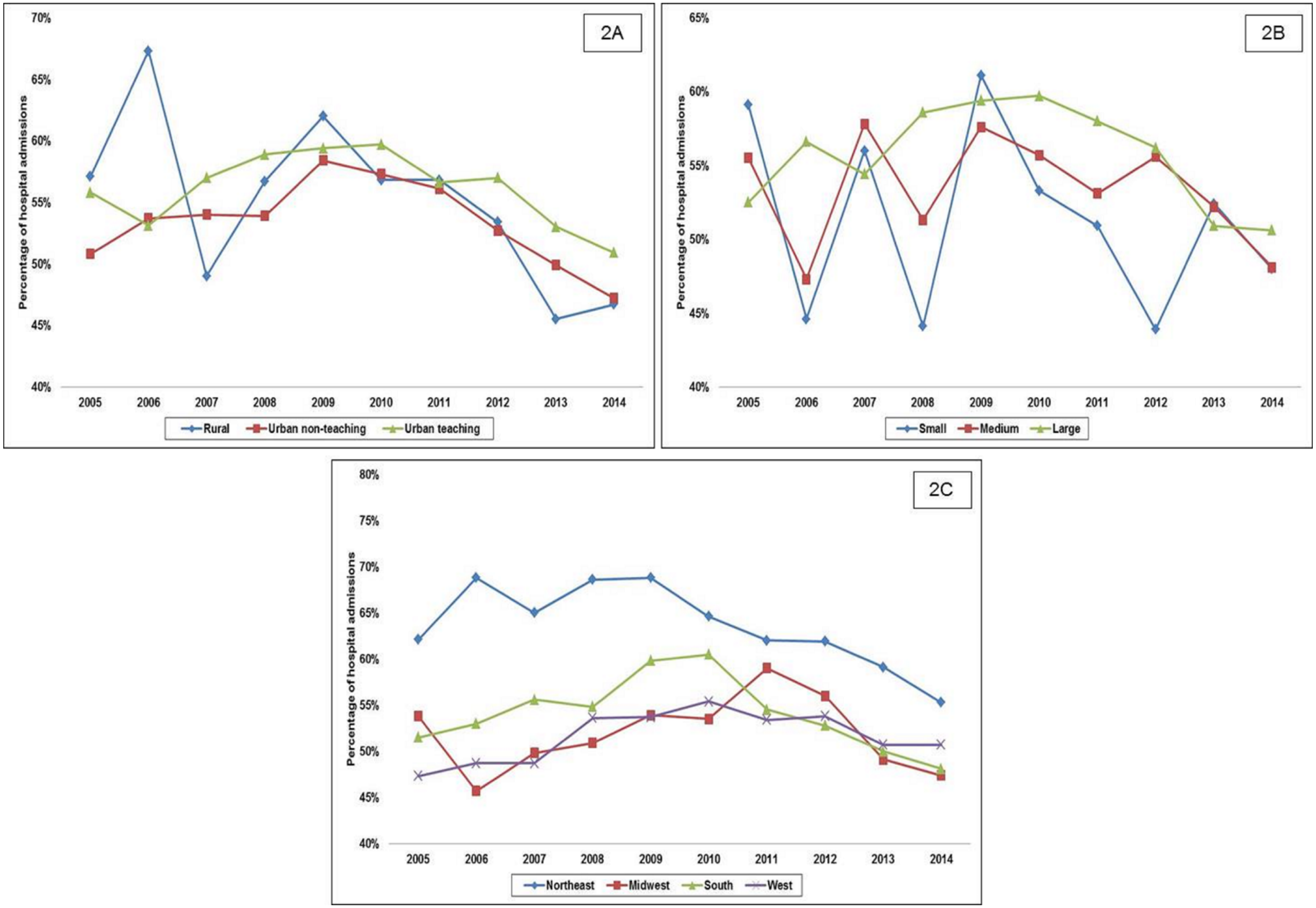
	≥ 7	0.62	0.58	0.66	<0.001
Acute organ dysfunction	**Respiratory**	1.28	1.24	1.33	<0.001
	Renal	1.48	1.43	1.54	<0.001
	Hepatic	1.33	1.27	1.40	<0.001
	Hematological	0.82	0.78	0.86	<0.001
	Metabolic	2.09	2.01	2.17	<0.001
	Neurological	1.68	1.61	1.75	<0.001
Cardiac arrest		2.23	2.15	2.31	<0.001
Right heart/pulmonary artery catheterization		1.09	1.05	1.14	<0.001
Intubated at admission (day 0)		1.58	1.52	1.63	<0.001
Hemodialysis		1.70	1.56	1.85	<0.001

Supplementary Table 4. Baseline characteristics of IABP-PCI vs. pLVAD/ECMO-PCI

Characteristic		IABP-assisted PCI (N = 57,337)	pLVAD/ECMO assisted PCI (N = 3,150)	*P*
AMI type	**STEMI**	87.4	85.7	0.004
	NSTEMI	12.6	14.3	
Age (years)		64.9 ± 12.7	62.0 ± 11.9	<0.001
Female sex		31.4	23.3	<0.001
Race	**White**	68.2	62.4	<0.001
	Black	5.9	9.6	
	Hispanic	8.1	8.2	
	Asian	3.0	3.9	
	Native American	0.5	0.6	
	Others	4.1	5.9	
	Missing	10.2	9.4	
Weekend admission		28.3	24.5	<0.001
Primary payer	**Medicare**	48.3	40.7	<0.001
	Medicaid	8.3	10.0	
	Private	31.5	38.3	
	Uninsured	8.1	7.2	
	No charge	0.6	0.2	
	Others	3.2	3.6	
Quartile of median household income for zip code	**0-25th**	26.3	28.9	<0.001
	26th-50th	25.9	26.8	
	51st-75th	25.2	21.6	

	75th-100th	22.5	22.7	
Charlson Comorbidity Index	**0-3**	36.4	39.5	0.002
	4-6	49.7	47.0	
	≥ 7	13.9	13.5	
Cardiac arrest		24.8	39.9	<0.001
Intubated on admission (day 0)		39.3	42.7	<0.001


1A
Percentage of hospital admissions
80%
75%
70%
65%
60%
55%
50%
45%
40%
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
19-49 50-59 60-69 70-79 >=80
1B
70%
65%
60%
55%
50%
45%
40%
Male Female
1C
White Non-White
1D
0 to 3 4 to 6 >=7


2A
Percentage of hospital admissions
70%
65%
60%
55%
50%
45%
40%
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Rural
Urban non-teaching
Urban teaching
2B
65%
60%
55%
50%
45%
40%
Small
Medium
Large
2C
80%
75%
70%
Northeast
Midwest
South
West