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Current status of perioperative temporary mechanical circulatory support during cardiac surgery

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Abstract

Objectives: We sought to determine utilization and outcomes of perioperative temporary mechanical circulatory support (tMCS) in the current practice of cardiac surgery.

Background: tMCS is an evolving adjunct to cardiac surgery not fully characterized in contemporary practice.

Methods: Using the nationwide inpatient sample we retrospectively analyzed hospital discharge data between January 1, 2016 and December 31, 2019. ICD-10-CM procedure codes were used to identify and divide patient hospitalizations into those who had preoperative tMCS (pre-tMCS) versus tMCS instituted the day of surgery or afterwards (sd/post-tMCS).

Results: In all, 1,383,520 hospitalizations met inclusion criteria. 86,445 (6.25%) had tMCS. tMCS was utilized in 8.74% of coronary artery bypass grafting (CABG), 2.58% of isolated valve, and 9.71% of valve/CABG; operations. 29,325 (33.9%) had pre-tMCS while 57,120 (66.1%) had sd/post-tMCS. The use of tMCS was associated with greater inpatient mortality (15.66% vs. 1.53%, $p < .001$), longer length of stay (LOS) (14.4 vs. 8.5 days, $p < .001$), and higher mean inflation-adjusted costs ($93,040 ± 1038 vs. $51,358 ± 296, $p < .001$) compared to no use. Inpatient mortality (5.98% vs. 20.63%, $p < .001$), LOS (13.87 vs. 14.68, $p < .001$), and cost ($82,621 ± 1152 SEM vs. $98,381 ± 1242) were all significantly lower with pre-tMCS compared to sd/post tMCS. When analyzed separately, mortality was higher with later utilization of tMCS (5.98% pre, 17.1% sd, and 49.05% postsurgical date insertion, $p < .001$).

Conclusions: Perioperative tMCS is utilized in 6.25% of modern cardiac surgery, with two-thirds of cases instituted on the day of surgery or afterwards. The use of tMCS is associated with significantly higher mortality, longer LOS, and higher costs. Among patients undergoing tMCS, earlier utilization is associated with better outcomes.

KEYWORDS

cardiac surgery, mechanical circulatory support, perioperative management

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Abdul Mannan Khan Minhas and Dmitry Abramov contributed equally to this study.

1 | INTRODUCTION

Over the past 20 years, patients undergoing cardiac surgery have experienced improved outcomes despite being older and sicker.[1] Although likely multifactorial, putative explanations include the expanding use of temporary mechanical circulatory support (tMCS) both for preoperative optimization and postoperative salvage. Advantages of tMCS include robust circulatory support with concomitant de-escalation of both inotropes (which can be arrhythmogenic and may increase oxygen consumption worsening myocardial ischemia) and vasopressors (which may interfere with tissue perfusion at the level of the microcirculation) allowing for hemodynamic stabilization and potential for end-organ recovery.

tMCS refers to a constellation of devices used for less than 30 days to maintain adequate end-organ perfusion in the setting of cardiogenic shock. The intraaortic balloon pump (IABP) is commonly used, however, over the past decade technology has evolved rapidly and numerous alternative tMCS devices have emerged in the adult setting. Among the most common tMCS devices are the modern, extracorporeal membrane oxygenation (ECMO) systems utilizing centrifugal pumps and polymethylpentene hollow fiber oxygenators and the family of Impella® transvalvular microaxial flow catheters (Abiomed Inc.). Modern tMCS technology offers high levels of output (microaxial devices allow for up to 6.0 L/min of support) combined with facility of insertion and mounting utilization attest to its embrace by the surgical community.

There is limited data available on perioperative use of tMCS in cardiac surgery. Case series have emerged describing institutional experiences with the use of tMCS in the perioperative period of coronary artery bypass grafting (CABG)[2,3] and other adult cardiac operations.[4,5] One previous publication described national trends from 2005 to 2014 with the use of tMCS for management of postoperative cardiogenic shock, but did not examine preoperative tMCS use or differentiate surgery types.[6] We sought to further define the general status of current utilization and outcomes with tMCS in the perioperative period for the spectrum of common adult cardiac surgery in the United States.

2 | METHODS

This was a retrospective analysis of discharge data from the National Inpatient Sample (NIS) between January 1, 2016 and December 31, 2019. The NIS is an all-payer database that approximates a 20% stratified sample of discharges from US community hospitals participating in the Healthcare Cost and Utilization Project (HCUP).[7] It contains unweighted data from more than 7 million yearly hospital stays, and once weighted, estimates approximately 35 million stays. It includes deidentified, clinical, and nonclinical elements such as primary and secondary diagnoses, patient demographics, payment source, length of stay (LOS), and severity and comorbidity measures. Our Institutional Review Board waived approval due to lack of private individually identifiable information and direct intervention or interaction; informed consent was not applicable for the same reasons. We acknowledge participation in the Transplant Peer Review Network and complied with the journal's author guidelines and policies.

We identified all hospitalizations in patients aged 18 years and above in the NIS database from January 1, 2016, through December 31, 2019, who underwent CABG or any percutaneous or surgical valvular surgery with International Classification of Diseases, tenth revision, Clinical Modification (ICD-10-CM) procedure code provided in the Supporting Information: table. We excluded patients with history of heart assist device, heart transplantation, those who underwent ventricular assist device or heart transplantation during the current admission, age <18 years or missing information on age and those with missing information on the procedure day. Subsequently, we identified those who recieved tMCS. These hospitalizations were divided in two cohorts. (1) Those who underwent tMCS before the day of CABG/valve surgery (pre-tMCS), (2) those who underwent tMCS on the same day as surgery or subsequent days after the CABG/valve surgery (sd/post-tMCS). For further categorization and data on same day and post-tMCS are also provided separately.

For each hospitalization, baseline patient demographic characteristics, hospital characteristics, and clinically relevant comorbidities were identified. Comorbidities were identified using Elixhauser comorbidities[8] and ICD-10-CM codes provided in Supporting Information: Table 1. Descriptive statistics were used to describe the continuous and categorical variables. The mean and standard error were used for continuous variables, and categorical variables were expressed as frequencies and percentages. Univariate analyses for between-group comparisons used the Rao–Scott χ^2 test for categorical variables and weighted simple linear regression for continuous variables.

Weighted logistic and linear regression was performed to estimate adjusted odds ratios (ORs), adjusted mean differences (MD), and 95% confidence intervals to determine the association of timing of tMCS and various clinical outcomes in hospitalizations undergoing CABG/valvular surgery requiring tMCS. The logistic and linear regression models were adjusted for age, sex, and the following comorbidities: chronic pulmonary disease, atrial fibrillation, hypertension, diabetes mellitus, obesity, dyslipidemia, renal failure, peripheral vascular disease, neurologic disorders, liver disease, hypothyroidism, smoking, drug abuse, alcohol abuse, previous myocardial infarction, previous percutaneous coronary intervention, prior CABG, prior pacemaker or implantable cardioverter defibrillator (ICD), prior cerebrovascular disease, and hospital level characteristics (bed size, region, and location/teaching status).

Hospital total charges were converted to cost estimates using hospital-specific cost-to-charge ratios as provided by HCUP. Total costs were inflated to 2019 US dollars using the Consumer price index inflation calculator provided by the US Bureau of Labor Statistics.[9]

We estimated tMCS percentage as the proportion of hospitalizations of CABG/valve surgery requiring tMCS over a total number of CABG/valve surgery hospitalizations. Trends in tMCS utilization and timing were examined using binary logistic regression, with year as the sole predictor. Primary outcomes were in-hospital mortality, LOS, and in-hospital costs.

Using Stata 16.1 (StataCorp),[10] our analyses took into account survey design complexity by incorporating sampling weights, primary sampling units, and strata. This allowed for the estimation of population proportions, means, and regression coefficients using *svy* commands.[10] Standard errors were computed using Taylor series linearization. $p < .05$ were considered statistically significant.

3 | RESULTS

Between January 1, 2016 and December 31, 2019, 1,383,520 weighted hospitalizations met the inclusion criteria (Figure 1). 682,850 (49.4%) underwent isolated CABG, 578,620 (41.8%) underwent isolated valve operations, and 122,050 (8.8%) underwent combined CABG/valve operations. Of the patient hospitalizations that met inclusion criteria 86,445 (6.25%) received tMCS. Isolated CABG accounted for 69%, isolated valve for 17%, and combined CABG/valve for 13% of tMCS cases. Of all patients undergoing CABG, 8.74% had tMCS, while 2.58% of patients undergoing isolated valve operations received tMCS and 9.71% of patients undergoing combined CABG/valve cases used tMCS.

Baseline characteristics of hospitalizations of patients with and without tMCS are presented in Table 1a. Patients with tMCS were younger (65.7 ± 0.1 vs. 67.9 ± 0.05 years, $p < .001$), less likely to be female (28.6% vs. 32.9%, $p < .001$), less likely to be White (73.7% vs. 80.4%, $p < .001$), were more likely to have renal failure, congestive heart failure, liver disease, and neurological disorders, and less likely to have dyslipidemia and hypothyroidism. Baseline characteristics of hospitalizations of patients who had pre-tMCS and sd/post-tMCS are compared in Table 1b. From the cohort, 29,325 weighted patient hospitalizations (33.9%) had pre-tMCS while 57,120 (66.1%) had sd/post-tMCS. Of the latter group, 50,805 patients had tMCS inserted on sd as the surgery while 6315 patients had insertion after surgical date. Patients who received sd/post-tMCS were more likely to be female (29.7% vs. 26.5%, $p < .001$) and were generally sicker with a higher Elixhauser comorbidity index ($p < .001$). Patient characteristics further breaking down patients who received pre-tMCS, sd-tMCS, and post-tMCS are shown in Supporting Information: Table 2. Notably, patients who received post-tMCS had higher Elixhauser comorbidity index compared to patients who received sd-tMCS, pre-tMCS, or no tMCS support.

The trends in overall (both pre and sd/postoperative) tMCS for all classes of operations and as a percentage of each subtype (isolated CABG, isolated valve, combined CABG/valve) are shown in Supporting Information: Figure 1. Neither overall use of tMCS as a percentage of all operations or within each subtype changed significantly over the course of the study, however use of IABP declined overall ($p = .005$) and for isolated valve operations ($p < .001$)

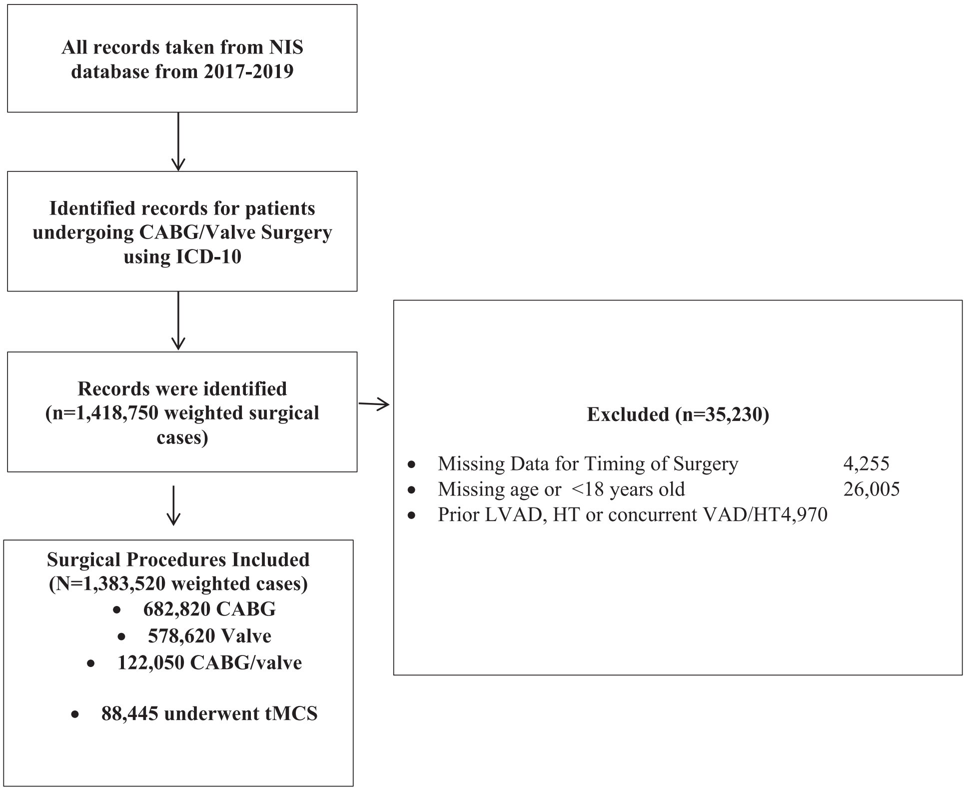

FIGURE 1 Flow diagram of study population. CABG, coronary artery bypass graft; HT, heart transplantation; LVAD, left ventricular assist device; tMCS, temporary mechanical circulatory support.

TABLE 1a Comparison of baseline characteristics of patients with and without tMCS

Baseline characteristics				
Variables	**No MCS (Weighted *n* = 1,297,075)**	**MCS (Weighted *n* = 86,445)**	**Total (Weighted *n* = 1,383,520)**	***p* Value**
Age (mean [SE]) years	67.92 (0.05)	65.74 (0.1)	67.78 (0.05)	<.001
Female	426,405 (32.88)	24,700 (28.57)	451,105 (32.61)	<.001
Race				<.001
White	1,003,815 (80.44)	60,935 (73.68)	1,064,750 (80.02)	
Black	83,575 (6.7)	7040 (8.51)	90,615 (6.81)	
Hispanics	87,220 (6.99)	8060 (9.75)	95,280 (7.16)	
Others	73,305 (5.87)	6670 (8.06)	79,975 (6.01)	
Comorbidities				.977
Chronic pulmonary disease	297,035 (22.9)	19,805 (22.91)	316,840 (22.9)	
Atrial fibrillation	503,555 (38.82)	33,380 (38.61)	536,935 (38.81)	.617
Diabetes mellitus	511,380 (39.43)	36,495 (42.22)	547,875 (39.6)	<.001
Hypertension	1,096,155 (84.51)	70,770 (81.87)	1,166,925 (84.34)	<.001
Obesity	318,660 (24.57)	19,475 (22.53)	338,135 (24.44)	<.001
Peripheral vascular disease	241,370 (18.61)	14,325 (16.57)	255,695 (18.48)	<.001
Renal failure	298,370 (23)	22,775 (26.35)	321,145 (23.21)	<.001
Liver disease	47,350 (3.65)	10,415 (12.05)	57,765 (4.18)	<.001
Neurological disorders	79,705 (6.14)	12,225 (14.14)	91,930 (6.64)	<.001
Dyslipidemia	925,950 (71.39)	54,975 (63.6)	980,925 (70.9)	<.001
Hypothyroidism	174,425 (13.45)	8610 (9.96)	183,035 (13.23)	<.001
Smoking	590,510 (45.53)	38,120 (44.1)	628,630 (45.44)	.001
Alcohol abuse	38,000 (2.93)	3430 (3.97)	41,430 (2.99)	<.001
Drug abuse	34,540 (2.66)	3025 (3.5)	37,565 (2.72)	<.001
Previous myocardial infarction	178,980 (13.8)	11,955 (13.83)	190,935 (13.8)	.911
Previous CABG	82,450 (6.36)	4240 (4.9)	86,690 (6.27)	<.001
Previous PCI	198,285 (15.29)	9880 (11.43)	208,165 (15.05)	<.001
Prior CVD	130,185 (10.04)	6805 (7.87)	136,990 (9.9)	<.001
Prior PPM or ICD	71,360 (5.5)	3160 (3.66)	74,520 (5.39)	<.001
Type of surgery				
CABG alone	623,175 (48.04)	59,665 (69.02)	682,840 (49.36)	<.001
Valvular surgery alone	563,695 (43.46)	14,935 (17.28)	578,630 (41.82)	<.001
CABG and valvular surgery	110,205 (8.5)	11,845 (13.7)	122,050 (8.82)	<.001
All CABG	733,380 (56.54)	71,510 (82.72)	804,890 (58.18)	<.001
All valve surgery	673,900 (51.96)	26,780 (30.98)	700,680 (50.64)	<.001
Hospital location				<.001
Rural	26,305 (2.03)	2175 (2.52)	28,480 (2.06)	
Urban nonteaching	171,965 (13.26)	12,760 (14.76)	184,725 (13.35)	
Urban teaching	1,098,805 (84.71)	71,510 (82.72)	1,170,315 (84.59)	
Bed Size of the hospital				.011
Small	128,420 (9.9)	7900 (9.14)	136,320 (9.85)	
Medium	307,975 (23.74)	21,870 (25.3)	329,845 (23.84)	

TABLE 1a (Continued)

Baseline characteristics Variables	No MCS (Weighted *n* = 1,297,075)	MCS (Weighted *n* = 86,445)	Total (Weighted *n* = 1,383,520)	*p* Value
Large	860,680 (66.36)	56,675 (65.56)	917,355 (66.31)	
Region				.027
Northeast	243,985 (18.81)	15,890 (18.38)	259,875 (18.78)	
Midwest	304,275 (23.46)	19,060 (22.05)	323,335 (23.37)	
South	511,365 (39.42)	34,660 (40.09)	546,025 (39.47)	
West	237,450 (18.31)	16,835 (19.47)	254,285 (18.38)	
Insurance status				<.001
Medicare	799,615 (61.72)	47,555 (55.11)	847,170 (61.31)	
Medicaid	86,900 (6.71)	8750 (10.14)	95,650 (6.92)	
Private insurance	345,555 (26.67)	23,665 (27.42)	369,220 (26.72)	
Self-pay, no charge, or other	63,400 (4.89)	6325 (7.33)	69,725 (5.05)	
Elixhauser comorbidity index				<.001
0–4	583,675 (45)	28,155 (32.57)	611,830 (44.22)	
5–8	642,965 (49.57)	48,815 (56.47)	691,780 (50)	
≥9	70,435 (5.43)	9475 (10.96)	79,910 (5.78)	

Abbreviations: CABG, coronary artery bypass grafting; CVD, cerebrovascular disease; ICD, implantable cardioverter defibrillator; PCI, percutaneous coronary intervention; PPM, prior pacemake; tMCS, temporary mechanical circulatory support.

TABLE 1b Comparison of baseline characteristics of patients with pre-tMCS and sd/post-tMCS

Variables	Presurgery MCS (Weighted *n* = 29,325)	Postsurgery/same day MCS (Weighted *n* = 57,120)	Total (Weighted *n* = 86,445)	*p* Value
Age (mean [SE]) years	65.9 (0.15)	65.66 (0.12)	65.74 (0.1)	.175
Female	7760 (26.46)	16,940 (29.66)	24,700 (28.57)	<.001
Race				<.001
White	20,320 (72.21)	40,615 (74.43)	60,935 (73.68)	
Black	2025 (7.2)	5015 (9.19)	7040 (8.51)	
Hispanics	3255 (11.57)	4805 (8.81)	8060 (9.75)	
Others	2540 (9.03)	4130 (7.57)	6670 (8.06)	
Comorbidities				
Chronic pulmonary disease	6410 (21.86)	13,395 (23.45)	19,805 (22.91)	.022
Atrial fibrillation	10,520 (35.87)	22,860 (40.02)	33,380 (38.61)	<.001
Diabetes mellitus	13,380 (45.63)	23,115 (40.47)	36,495 (42.22)	<.001
Hypertension	24,535 (83.67)	46,235 (80.94)	70,770 (81.87)	<.001
Obesity	7015 (23.92)	12,460 (21.81)	19,475 (22.53)	.002
Peripheral vascular disease	3985 (13.59)	10,340 (18.1)	14,325 (16.57)	<.001
Renal failure	7190 (24.52)	15,585 (27.28)	22,775 (26.35)	<.001
Liver disease	2380 (8.12)	8035 (14.07)	10,415 (12.05)	<.001
Neurological disorders	3615 (12.33)	8610 (15.07)	12,225 (14.14)	<.001

(Continues)

TABLE 1b (Continued)

Variables	Presurgery MCS (Weighted *n* = 29,325)	Postsurgery/same day MCS (Weighted *n* = 57,120)	Total (Weighted *n* = 86,445)	*p* Value
Dyslipidemia	20,100 (68.54)	34,875 (61.06)	54,975 (63.6)	<.001
Hypothyroidism	2955 (10.08)	5655 (9.9)	8610 (9.96)	.71
Smoking	13,595 (46.36)	24,525 (42.94)	38,120 (44.1)	<.001
Alcohol abuse	1265 (4.31)	2165 (3.79)	3430 (3.97)	.107
Drug abuse	1015 (3.46)	2010 (3.52)	3025 (3.5)	.849
Previous myocardial infarction	4110 (14.02)	7845 (13.73)	11,955 (13.83)	.607
Previous CABG	985 (3.36)	3255 (5.7)	4240 (4.9)	<.001
Previous PCI	3375 (11.51)	6505 (11.39)	9880 (11.43)	.815
Prior CVD	2265 (7.72)	4540 (7.95)	6805 (7.87)	.601
Prior PPM or ICD	760 (2.59)	2400 (4.2)	3160 (3.66)	<.001
Type of surgery				
CABG alone	24,270 (82.76)	35,395 (61.97)	59,665 (69.02)	<.001
Valvular surgery alone	2570 (8.76)	12,365 (21.65)	14,935 (17.28)	<.001
CABG and valvular surgery	2485 (8.47)	9360 (16.39)	11,845 (13.7)	<.001
All CABG	26,755 (91.24)	44,755 (78.35)	71,510 (82.72)	<.001
All valve surgery	5055 (17.24)	21,725 (38.03)	26,780 (30.98)	<.001
Hospital location				.006
Rural	820 (2.8)	1355 (2.37)	2175 (2.52)	
Urban nonteaching	4685 (15.98)	8075 (14.14)	12,760 (14.76)	
Urban teaching	23,820 (81.23)	47,690 (83.49)	71,510 (82.72)	
Bed size of the hospital				.037
Small	2755 (9.39)	5145 (9.01)	7900 (9.14)	
Medium	7795 (26.58)	14,075 (24.64)	21,870 (25.3)	
Large	18,775 (64.02)	37,900 (66.35)	56,675 (65.56)	
Region				<.001
Northeast	5810 (19.81)	10,080 (17.65)	15,890 (18.38)	
Midwest	6410 (21.86)	12,650 (22.15)	19,060 (22.05)	
South	10,975 (37.43)	23,685 (41.47)	34,660 (40.09)	
West	6130 (20.9)	10,705 (18.74)	16,835 (19.47)	
Insurance status				.095
Medicare	15,785 (53.93)	31,770 (55.71)	47,555 (55.11)	
Medicaid	3005 (10.27)	5745 (10.07)	8750 (10.14)	
Private insurance	8185 (27.96)	15,480 (27.15)	23,665 (27.42)	
Self-pay, no charge, or other	2295 (7.84)	4030 (7.07)	6325 (7.33)	
Elixhauser comorbidity index				<.001
0–4	11,435 (38.99)	16,720 (29.27)	28,155 (32.57)	
5–8	15,500 (52.86)	33,315 (58.32)	48,815 (56.47)	
≥9	2390 (8.15)	7085 (12.4)	9475 (10.96)	

Abbreviations: CABG, coronary artery bypass grafting; CVD, cerebrovascular disease; ICD, implantable cardioverter defibrillator; PCI, percutaneous coronary intervention; PPM, prior pacemake; tMCS, temporary mechanical circulatory support.

and use of ECMO and Impella increased both overall and within each subtype of operation ($p < .03$).

Trends in pre-tMCS use are shown in Supporting Information: -Figure 2A. Neither overall use of pre-tMCS or within each subtype changed over the course of the study but there was an increase use of Impella preoperatively for all subgroups ($p \le .04$) other than combined CABG/valve ($p = .102$). ECMO was rarely used preoperatively (0.04% of overall cases) but there was a statistically significant trend toward increased usage in isolated CABG cases ($p = .037$).

Trends in same day or postoperative (sd/post-tMCS) usage are shown in Supporting Information: Figure 2B. There was no change in the use of sd/post-tMCS but sd/post-tMCS did decline significantly for isolated valve cases ($p = .011$). Overall sd/post-IABP use declined ($p = .001$) and sd/post-Impella ($p < .001$) and sd/post-ECMO ($p = .001$) increased. Sd/post-ECMO use also significantly increased for all subtypes of operative types ($p = .037$) while sd/post-Impella increased in isolated CABG and combined CABG/valve cases ($p \le .015$).

Clinical outcomes and resource utilization between hospitalizations of patients with and without tMCS are demonstrated in Table 2a and Figure 2. Patients who underwent tMCS had significant higher inpatient mortality (15.66% vs. 1.33%, aOR: 9.08, CI: 8.50–9.70, $p < .001$), longer LOS (14.4 vs. 8.5 days, aOR: 4.24, CI: 4.02–4.66, $p < .001$), and mean inflation-adjusted cost ($93,040 ± 1038 vs. $51,357 ± 295, $p < .001$). Table 2b compares overall clinical outcomes and resource utilization between hospitalizations of patients with pre-tMCS and sd/post-tMCS. Inpatient mortality (5.98% vs. 20.63%, aOR: 3.66, CI: 3.24–4.13, $p < .001$), mean inflation-adjusted cost ($82,621 ± 1152 vs. $98,381 ± 1242, AMD: 6667.77, CI: 4389.11–8946.42, $p < .001$), and LOS (13.87 ± 0.16 vs. 14.68 ± 0.16 days, AMD: −0.47, CI: −0.81 to −0.12, $p = .008$) were significantly lower for patients with pre-tMCS versus sd/post tMCS.

Baseline characteristics and outcomes between patients without tMCS versus those who underwent pre-tMCS, sd-tMCS, and post-tMCS are shown in Supporting Information: Tables 2 and 3, respectively. Inpatient mortality among these groups was 1.53%, 5.98%, 17.1%, and 49.05%, respectively ($p < .001$). Similar trends remained in multivariable analysis, with tMCS utilization of pre-surgery, sd, and postsurgery associated with ORs for mortality of 3.22 (CI: 2.84–3.65), 10.38 (CI: 9.61–11.21), and 32.64 (CI: 27.95–38.13), all $p < .001$, compared to patients who didn't undergo tMCS. Similar trends were seen with higher LOS (8.5, 13.87, 14.04, and 19.81 days respectively, $p < .001$) and higher costs ($51,357, $82,621, $90,046, and $157,499 respectively, $p < .001$).

Inpatient mortality between hospitalizations of patients with and without tMCS for each type of operation is shown in Table 3a, with mortality being significantly higher in patients requiring tMCS for each type of surgery. Table 3b demonstrates inpatient mortality between pre-tMCS and sd/post-tMCS within each class of operation, with mortality being higher in patients who had sd/post-tMCS compared to pre-tMCS for all surgery types.

TABLE 2a Comparison of overall clinical outcomes and resource utilization between patients with and without tMCS

				Unadjusted	95% confidence interval			Adjusted	95% confidence interval		
Variables	**No MCS (Weighted *n* = 1,297,075)**	**MCS (Weighted *n* = 86,445)**	**Total (Weighted *n* = 1,383,520)**	**OR/mean difference**	**Lower**	**Upper**	***p* Value**	**OR/AMD**	**Lower**	**Upper**	***p* Value**
Inpatient mortality	19,840 (1.53)	13,525 (15.66)	33,365 (2.41)	11.95	11.31	12.63	<.001	9.71	9.11	10.36	<.001
LOS (mean [SE]) days	8.5 (0.04)	14.4 (0.13)	8.87 (0.04)	5.90	5.66	6.14	<.001	4.54	4.32	4.76	<.001
Inflation- adjusted cost, US $ (mean [SE])	51,357.68 (295.55)	93,040.02 (1038.34)	53,960.9 (321.91)	41,682.34	39,916.23	43,448.45	<.001	35,814.54	34,259.50	37,369.57	<.001
Disposition to SNF/ICF or other facilty	245,405 (19.36)	26,035 (37.26)	271,440 (20.3)	2.47	2.38	2.57	.001	2.70	2.59	2.81	<.001

Abbreviations: AMD, adjusted mean differences; LOS, length of stay; OR, odd ratio; tMCS, temporary mechanical circulatory support.

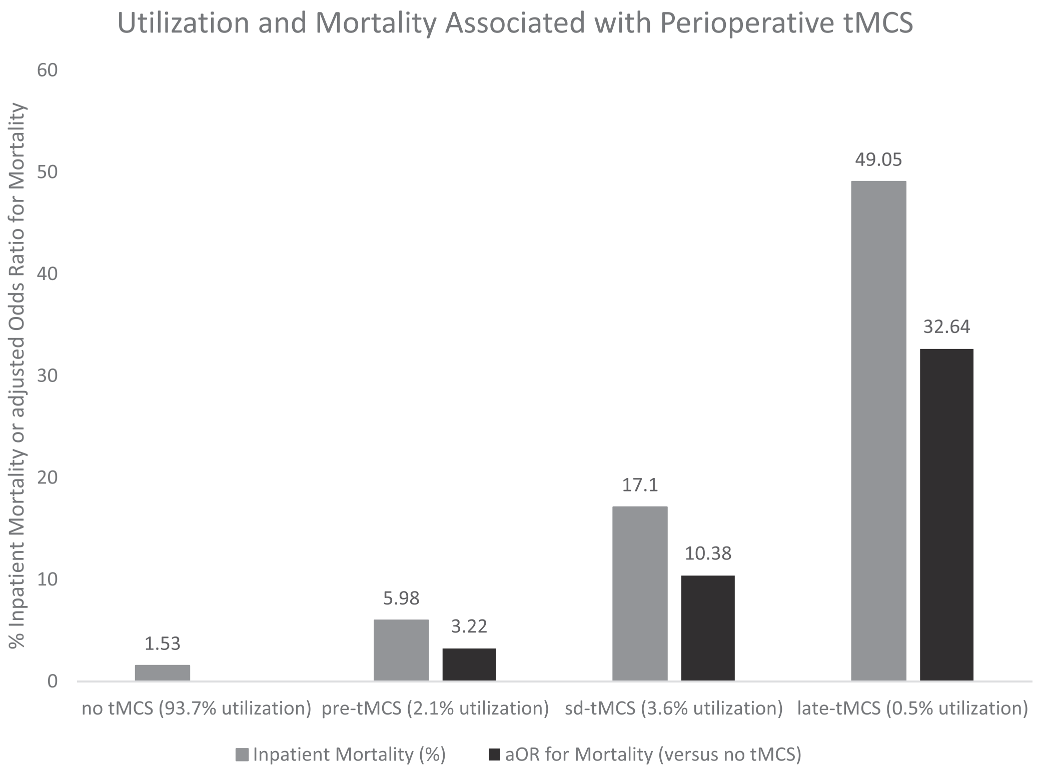

FIGURE 2 Utilization and mortality associated with perioperative tMCS. tMCS, temporary mechanical circulatory support.

4 | DISCUSSION

This analysis of a large, contemporary, national database demonstrates several important findings about current periprocedural use of tMCS in adults undergoing adult cardiac surgery operations (valve/CABG). tMCS is used in 6.25% of such cases (8.74% of CABG, 2.58% of isolated valve, and 9.71% of valve/CABG combination surgeries), with small increases in the use of Impella and ECMO and small decline in the use of IABP over the study period. Patients who received tMCS experienced approximately 10-fold higher inpatient mortality, and significant increases in LOS and inpatient costs. Approximately one-third of periprocedural tMCS is utilized before cardiac surgery, and those patients experience lower mortality and costs compared to tMCS use on the day of surgery or after. Patients who recieved late tMCS implantation after the date of surgery had significantly worse outcomes compared with patients undergoing earlier tMCS. These data have important implications for our understanding of current tMCS resource utilization and for highlighting inpatient outcomes for patients undergoing perioperative tMCS.

Historically, tMCS required surgical implantation and was used in transplant centers for patients with cardiogenic shock as a bridge to durable mechanical support or heart transplantation.[11] Stretch et al.[12] demonstrated that the use of percutaneously placed devices in an anticipatory capacity for high-risk percutaneous coronary or electrophysiology interventions was associated with concomitant reduction in hospital costs and mortality. However, there is limited data on the periprocedural use of tMCS for cardiac surgery. In the past, tMCS for cardiac surgery consisted primarily of IABP, with preoperative IABP use associated with improved hospital mortality and lower LOS compared to non-use.[13] Single center case series have also described the utilization of ECMO for postcardiotomy shock.[14,15] With technological advances in microaxial tMCS devices over the last decade, small case series have described their periprocedure use for cardiac surgery, demonstrating feasibility among high-risk patients.[2–5] Vallabhojusyula et al.[6] analyzed the NIS to characterize the postcardiac surgery use of tMCS (limited to patients with a diagnosis of cardiogenic shock). They identified that IABP remained the most frequent postoperative tMCS device and demonstrated that tMCS use was associated with higher mortality, higher costs, but not higher LOS in propensity adjusted models. The current manuscript builds on the prior literature with important additions regarding distinction between preprocedure and subsequent utilization as well as characterization of utilization among various common cardiac surgery types.

Particularly, distinction between preprocedure use and same day/postprocedure utilization may have important clinical implications. Among patients with cardiogenic shock, early intervention with tMCS is advocated and an early strategy is associated with improved outcomes.[16] A similar paradigm shift may occur for surgical patients regarding the importance in early identification of hemodynamic compromise and stabilization with tMCS.

In our study, one-third of devices were implanted before the day of surgery and two-thirds on or after the day of surgery. Compared to patients implanted same day or postsurgery, those implanted before surgery were more likely to be female, white, and have lower Elixhouser comorbidity index. Patients who had tMCS inserted before the day of

TABLE 2b Comparison of overall clinical outcomes and resource utilization between pre-tMCS and sd/post-tMCS

Variables	Presurgery day MCS (Weighted *n* = 29,325)	Postsurgery/same day MCS (Weighted *n* = 57,120)	Total (Weighted *n* = 86,445)	Unadjusted OR/mean difference	% confidence interval		*p* Value	Adjusted OR/AMD	% confidence interval		*p* Value
					Lower	Upper			Lower	Upper	
Inpatient mortality	1750 (5.98)	11,775 (20.63)	13,525 (15.66)	4.09	3.64	4.59	<.001	3.66	3.24	4.13	<.001
LOS (mean [SE]) days	13.87 (0.16)	14.68 (0.16)	14 (0.13)	0.8	0.42	1.19	<.001	−0.47	−0.81	−0.12	.008
Inflation-adjusted cost, US $ (mean [SE])	82,622 (1153)	98,382 (1242)	93,040 (1038)	15,760	13,131	18,388	<.001	6668	4389	8946	<.001
Disposition to SNF/ICF or other facility	9410 (35.05)	16,625 (38.64)	26,035 (37.26)	1.17	1.09	1.25	<.001	1.14	1.05	1.24	.002

Abbreviations: AMD, adjusted mean differences; LOS, length of stay; tMCS, temporary mechanical circulatory support.

TABLE 3a Comparison of inpatient mortality between patients with and without tMCS within each type of operation

	No MCS	MCS	Total	Unadjusted	% confidence interval		*p* Value	Adjusted	% confidence interval		*p* Value
					Lower	Upper			Lower	Upper	
Isolated CABG	6505 (1.04)	6080 (10.2)	12,585 (1.84)	10.76	9.92	11.68	<.001	6.89	6.25	7.59	<.001
Isolated valve surgery	9945 (1.76)	4380 (29.35)	14,325 (2.48)	23.12	21.05	25.4	<.001	15.45	13.66	17.47	<.001
CABG + valve surgery	3390 (3.08)	3065 (25.9)	6455 (5.29)				<.001				<.001

Abbreviations: CABG, coronary artery bypass grafting; tMCS, temporary mechanical circulatory support.

TABLE 3b Comparison of inpatient mortality between pre-tMCS and post-tMCS within each type of operation

	Presurgery day MCS	Postsurgery/same day MCS	Total	Unadjusted	% confidence interval		p Value	Adjusted	% confidence interval		p Value
					Lower	Upper			Lower	Upper	
Isolated CABG	1020 (4.21)	5060 (14.31)	6080 (10.2)	3.8	3.26	4.43	<.001	3.4	2.9	3.99	<.001
Isolated valve surgery	415 (16.18)	3965 (32.08)	4380 (29.35)	2.45	1.9	3.15	<.001	2.87	2.17	3.81	<.001
CABG + valve surgery	315 (12.73)	2750 (29.38)	3065 (25.9)	2.85	2.15	3.79	<.001	2.86	2.11	3.88	<.001

Abbreviations: CABG, coronary artery bypass grafting; tMCS, temporary mechanical circulatory support.

surgery had better outcomes and incurred less expense, including in multivariable analyses. While a direct comparison of outcomes in the patients in our series who received tMCS before the day of surgery with those who received tMCS on or after the day of surgery is problematic due to potential selection bias, unmeasured confounding, and lack of availability of key clinical data such as device indication and hemodynamic profiles, the results nevertheless suggest the need for further evaluation of the role and optimal patient selection for tMCS before cardiac surgery.

Similarly, the current data demonstrate that patients who received tMCS after the date of surgery have significantly higher inpatient mortality, LOS, and inpatient costs compared to patients who didn't undergo tMCS or who underwent tMCS earlier in the hospital course. Although such late tMCS utilization is rare, a focus on this population is important because such patients experience significantly worse outcomes. There are several possible explanations for this observation. Unrecognized hemodynamic instability in the operating room may lead to abnormal end organ function which may adversely affect outcomes even if tMCS is later utilized. Similar findings have been previously demonstrated among patients undergoing implantation of durable left ventricular assist device, where delayed implantation of right ventricular support has been associated with poorer outcomes.[17] Additionally, early surgical complications may lead to subsequent hemodynamic instability and may be associated with both the need for tMCS and the adverse outcomes that we report.

Another novel finding in this study is the characterization of tMCS utilization among different types of cardiac surgery. Any tMCS utilization was more common with combined CABG/valve surgeries, followed by CABG alone, and less frequent in isolated valve surgeries. On the contrary, presurgical tMCS was more common among patients undergoing CABG alone. Among CABG patients with periprocedural use of tMCS, 41% was preprocedural while only 17% of isolated valve surgery and 21% of combined CABG/valve surgery involved preprocedural placement. These data suggest that use of tMCS as a preoperative optimization strategy is more commonly considered in isolated CABG while its use as a salvage strategy is more broadly distributed between valve and combined CABG/valve cases. There are several possible explanations for these findings, which have not been well characterized in prior literature. Knowledge of coronary anatomy with high-risk features or hemodynamic instability during presentation of acute coronary syndrome in the cardiac catheterization lab may lead to early utilization of tMCS, which may then be continued through CABG surgical intervention. While the current analysis does provide breakdown by specific types of valve surgery, it is possible that certain valve pathologies (such as aortic regurgitation or stenosis) limit tMCS options, which may reduce preoperative use. Additionally, isolated valve procedures may be more likely to be performed electively, which may reduce preemptive tMCS utilization. Given the potential benefits of presurgical tMCS identified in this study, additional focus may be needed on the hemodynamic profiles, patient characteristics, and specific types of cardiac surgery which may derive the most benefit from periprocedural tMCS.

Irrespective of timing and indication, the utilization of tMCS identifies a higher risk cohort for increased costs and inpatient mortality, with particularly high rates of adverse events among patients implanted with tMCS after the day of surgery. Appreciation of prognosis can be helpful for patient and family decision making. Likewise, costs and value of care are important to financial stakeholders. Given lack of universally accepted indication for tMCS utilization for both cardiogenic shock and potential non-shock indication, additional focus on resource-heavy tMCS will be needed, preferably through randomized trials focusing specifically on the cardiac surgical population. This would allow confirmation of benefit and optimal tMCS timing, identification of specific patient populations that most benefit from tMCS, as well as evaluation of which tMCS device is most beneficial in various specific circumstances.

Limitations of our study include those inherent to the NIS itself and several other considerations. The NIS is an administrative database that lacks granularity and for which there is potential for inaccurate data collection and classification which may have affected results. There was no way to distinguish whether tMCS in the sd group was inserted before or after surgery, and these patients were grouped in the "sd/post" category for some analyses; however it is likely that most patients who underwent tMCS implantation sd as surgery had their tMCS placed in the operating room postsurgery as these patients had higher rates of adverse events compared to patients who underwent pre-tMCS. The indication for tMCS cannot be well identified from this data set, although tMCS use presumably reflects concern for hemodynamic compromise or other high-risk features. Operative risks such as STS score, medication requirements, and physiologic parameters are not available in this data set. Some specific tMCS types (IABP, ECMO, Impella) are easily identified through the procedure codes available through the NIS, while others may not be. Therefore, while this analysis includes a broad number of tMCS procedure codes (as provided in the supplement), some tMCS devices were not further categorized for analyses.

In conclusion, tMCS is common among patients undergoing cardiac surgery, with IABP remaining the most utilized device but with increasing consideration of newer tMCS devices such as Impella. The use of tMCS is associated with significant system costs, longer LOS, and higher inpatient mortality. Utilization of tMCS before the day of surgery occurs in about a third of cases of total tMCS use, and such use is associated with lower costs and mortality compared to same day/postoperative tMCS. Implantation of tMCS after the day of surgery was associated with much higher rates of adverse events. This data has important clinical implications for patient prognostication, appreciation of system costs, and implies a potential benefit of preoperative compared to later tMCS use which warrants further evaluation.

5 | CLINICAL PERSPECTIVES

The clinical implications of our manuscript include raising awareness of the frequency with which temporary mechanical support is used in modern cardiac surgery and the consideration that tMCS be used in an anticipatory rather than in a reactive fashion: as a method of optimizing patients before surgery or instituted promptly on the day of surgery rather than later in the perioperative period.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

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

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