Association of timing of percutaneous left ventricular assist device insertion with outcomes in patients undergoing cardiac surgery

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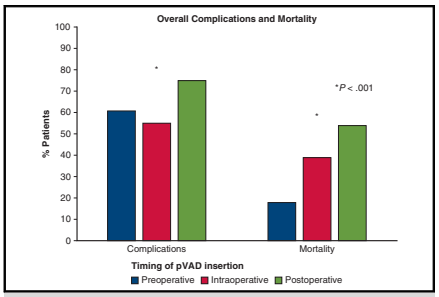
ABSTRACT

Objectives: The aim of this study was to explore the associations between percutaneous ventricular assist device (pVAD) insertion timing relative to cardiac surgery and patient outcomes.

Methods: The Nationwide Inpatient Sample was queried for patients undergoing cardiac surgery and pVAD insertion in the same admission from 2016 to 2019. Patients were stratified by timing of pVAD insertion. Preoperative characteristics, postoperative complications, and mortality were compared among groups.

Results: Overall, 3695 patients underwent cardiac surgery and pVAD insertion during the same hospitalization (pre: 1130, intra: 1690, and post: 875). The distribution of cardiac surgery procedures was similar across groups. Median Elixhauser Comorbidity Index was 13 for pre-, 15 for intra-, and 17 for postoperative pVAD patients ($P = .021$). Patients who received a postoperative pVAD were associated with increased mortality (pre: 18%, intra: 39%, and post: 54%; $P < .01$). Increased complication rates were also associated with postoperative pVAD insertion (pre: 61%, intra: 55%, and post: 75%; $P < .01$). Preoperative pVAD insertion was associated with increase rates of sepsis (pre: 18%, intra: 9.8%, and post: 17%; $P = .01$) and pneumonia (pre: 38%, intra: 23%, and post: 31%; $P < .01$). Postoperative pVAD insertion was associated with increased rates of gastrointestinal bleeding (pre: 2.2%, intra: 3.0%, and post: 7.4%; $P = .01$), renal failure (pre: 10%, intra: 9.2%, and post: 17%; $P = .01$), and prolonged ventilation (pre: 44%, intra: 41%, and post: 54%; $P = .02$).

Conclusions: Postoperative pVAD insertion following cardiac surgery was associated with increased complications and mortality compared with preoperative or intraoperative insertion. Further studies should explore optimal utilization and timing of pVAD insertion in patients undergoing cardiac surgery. (JTCVS Open 2023;16:430-46)



Worse outcomes associated with postoperative percutaneous ventricular assist device insertion.

CENTRAL MESSAGE

For patients undergoing cardiac surgery, insertion of a pVAD postoperatively was associated with worse outcomes compared with preoperative or intraoperative insertion.

PERSPECTIVE

Insertion of pVADs to support patients undergoing cardiac surgery can be performed in the pre-, intra-, and postoperative periods. Postoperative pVAD insertion was associated with worse outcomes in patients than preoperative or intraoperative insertion. Determining need and appropriate timing of pVAD insertion is important to optimize outcomes in high-risk cardiac surgery patients.

See Discussion on page 447.

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Abbreviations and Acronyms

CABG = coronary artery bypass grafting
CS = cardiogenic shock
ECI = Elixhauser Comorbidity Index
ECMO = extracorporeal membrane oxygenation
IABP = intra-aortic balloon pump
ICD10 = International Classification of Diseases 10th Revision
GI = gastrointestinal
LV = left ventricle
LOS = length of stay
NIS = Nationwide Inpatient Sample
pVAD = percutaneous ventricular assist device
tMCS = temporary mechanical circulatory support

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Percutaneous left ventricular assist devices (pVAD) are temporary mechanical circulatory support (tMCS) devices that can provide critical hemodynamic support for patients with severe left ventricular (LV) failure.[1] These devices are increasingly utilized in high-risk patients undergoing conventional cardiac surgery and can be inserted any time during a patient's perioperative course depending on need.[2] For instance, pVADs can be inserted preoperatively to support selected patients with severely reduced preoperative LV ejection fraction or in patients presenting in cardiogenic shock (CS) to enable time for clinical improvement and decision making for consideration of future definitive surgical intervention.[3-6] Moreover, intraoperative insertion of a pVAD at the same time as cardiac surgery can also be performed as part of a tailored support strategy for patients at high risk for postcardiotomy low cardiac output or in patients who fail to wean from cardiopulmonary bypass.[7] Furthermore, pVADs can be placed during the postoperative period in the setting of postcardiotomy CS refractory to medical management, the use of which has been demonstrated to improve survival to discharge and long-term survival.[8]

Overall, pVADs are a valuable tool in the management of patients with severe LV failure undergoing cardiac surgery. However, to date, no studies have directly compared patients undergoing cardiac surgery who had pVADs placed at different time points in their perioperative course. Thus, we conducted a study using a large national database to assess and compare patients who received a pVAD during the preoperative, intraoperative, or postoperative periods of the same hospital admission. We hypothesized that pVAD insertion earlier in the perioperative course would be linked to improved outcomes.

METHODS

Data Source and Study Population

The Nationwide Inpatient Sample (NIS) database (Healthcare Cost Utilization Project, Agency for Healthcare Research and Quality) was queried for all patients undergoing cardiac surgery between 2016 and 2019. The NIS is the largest publicly available all-payer inpatient database in the United States, containing unweighted data on more than 7 million and weighted data on more 35 million hospital stays per year.[9] Patients in the NIS represent a 20% stratified random sample of all discharges in a given year. The NIS includes discharge weights that were applied in this study to allow for reporting of national estimates. Patients undergoing cardiac surgery were identified using International Classification of Disease, 10th Revision, Clinical Modification (ICD10) procedure and diagnosis codes. Patients who underwent the following cardiac surgeries were included: isolated coronary artery bypass grafting (CABG), isolated valve(s) (one 1 more of tricuspid, mitral, or aortic), combinations of CABG and valve(s), isolated aortic, or combinations of aortic with CABG and/or valve(s) surgeries (Table E1). To be included, patients also must have undergone a pVAD insertion, defined using ICD10 codes (1 of 02HA3RJ, 02HA3RZ, or 02HA0RZ and 5A0221D) during the same hospitalization as their cardiac surgery. Patients were excluded if they underwent heart transplant, durable LV assist device or other non-pVAD tMCS device implantation during the same admission as pVAD insertion and cardiac surgery. Patients who received extracorporeal membrane oxygenation (ECMO) or intra-aortic balloon pumps (IABPs) were not excluded by these criteria, and data regarding the use of IABP and ECMO was also collected for patients who received these interventions along with cardiac surgery and pVAD.

Using the "procedure date" variable in the NIS, the timing of pVAD insertion relative to cardiac surgery was determined for each patient. Patients were then stratified into groups based on the timing of pVAD insertion. Preoperative insertion was defined as pVAD procedure date before cardiac surgery date, intraoperative insertion as the same procedure date for pVAD and cardiac surgery, and postoperative insertion as pVAD procedure date after cardiac surgery date. institutional review board and informed consent were waived because only de-identified, publicly available data was utilized.

Patient-level demographic characteristics and comorbidities were compared among groups. Patient comorbidities were defined using ICD10 codes and Elixhauser Comorbidity Software Refined for ICD10 (Agency for Healthcare Research and Quality).[10] The total Elixhauser Comorbidity Index (ECI) was then calculated for patients in each group. Using the total ECI, patients within each group were then stratified further into risk groups based on preoperative comorbidity burden, defined as low risk (ECI <6), medium risk (ECI = 6-15), or high risk (ECI >15).

Outcomes

The primary outcome was in-hospital mortality and was defined as death before discharge. Additional secondary analyses compared other nonmortality complications between groups. These complications were defined using ICD10 codes and included stroke, gastrointestinal (GI), non-GI bleeding, any bleeding requiring transfusion, renal failure requiring dialysis, surgical site infection, sepsis, pneumonia, peripheral noncentral nervous system thromboembolism, pulmonary embolism/deep venous thrombosis, prolonged mechanical ventilation (>24 hours), and tracheostomy (Table E2). Length of stay (LOS) was also evaluated for all patients in each group as well as for patients who survived to discharge in each group. Additionally, propensity score-matched comparisons of each combination of pairs among the preoperative, intraoperative, and postoperative pVAD groups was conducted to control for confounders and further confirm the results demonstrated in the unmatched samples

(Appendix E1). These analyses and associated methods are presented in Tables E3-E5. Additionally, a sensitivity analysis examining these outcomes in the subgroup of patients who only underwent isolated CABG was also conducted (Table E6). Results were also further verified by conducting a sensitivity analysis excluding patients who received ECMO support (Table E7).

Statistical Analysis

Normally distributed continuous variables were reported as means ± SD and compared using Kruskal-Wallis rank-sum tests. Nonnormally distributed continuous variables were reported as median with interquartile range (IQR). Normality was graphically assessed with histograms. Categorical variables were reported as frequency counts with percentages and compared using χ^2 tests. Multivariable logistic regression was utilized to assess associations of patient characteristics with mortality and overall complications. Missing data were treated as truly missing and no imputation was applied. The patient cohort was created using Linux based SAS Software version 9.4 (TS1M7) (SAS Institute Inc) and data analysis was conducted using the *survey* package in R (R Foundation for Statistical Computing).

RESULTS

Overall Cohort

Overall, 1,049,755 patients underwent cardiac surgery during the study period of whom 4510 also underwent pVAD insertion during the same hospitalization. Following application of exclusion criteria, the final cohort consisted of 3695 patients who underwent cardiac surgery and pVAD insertion during the same hospitalization (Figure 1). Following stratification by timing of pVAD insertion, there were 1130 patients who had a pVAD inserted preoperatively, 1690 inserted intraoperatively, and 875 inserted postoperatively.

Demographic Characteristics and Comorbidities

The total cohort had a median age of 67 years (IQR, 60-74 years), which did not differ between groups ($P = .200$). Among the patients, 31% were women, and there was a higher percent of women receiving pVAD postoperatively compared with before and during the cardiac surgery (pre: 25%, intra: 32%, and post: 37%; $P = .046$). Patient demographic characteristics for the overall cohort and the stratified groups are listed in Table 1, whereas patient comorbidities are presented in Table 2. The patients who received a preoperative pVAD were more likely to have cardiogenic shock (pre: 73%, intra: 63%, and post: 71%; $P = .045$). Meanwhile, patients who received a postoperative pVAD more frequently had congestive heart failure (pre: 10%, intra: 9.8%, and post: 26%; $P < .001$), valvular disease (pre: 3.5%, intra: 3.8%, and post: 9.7%; $P = .005$), peripheral vascular disease (pre: 16%, intra: 17%, and post: 25%; $P = .030$) and hypertension complicated by end organ dysfunction (pre: 19%, intra: 32%, and post: 38%; $P < .001$).

The overall median total ECI was 15 (IQR, 6-23). When the data were examined by pVAD timing groups, the median total ECI was 13 (IQR, 6-22) for the preoperative group, 15 (IQR, 5-22) for the intraoperative group, and 17 (IQR, 8-26) for the postoperative group ($P = .021$). Based on the total ECI, patients in all pVAD timing groups were most frequently classified as high risk, but the postoperative pVAD group had the highest proportion of high-risk patients (pre: 42%, intra: 50%, and post: 54%; $P = .014$). Furthermore, preoperative pVAD insertion patients were more often classified as low risk compared with the other groups (pre: 36%, intra: 25%, and post: 29%; $P = .010$).

Operative Characteristics

Over the 4-year study time frame, the use of pVADs during the same admission as cardiac surgery steadily increased in frequency (Table 3). In 2016, 90 patients had

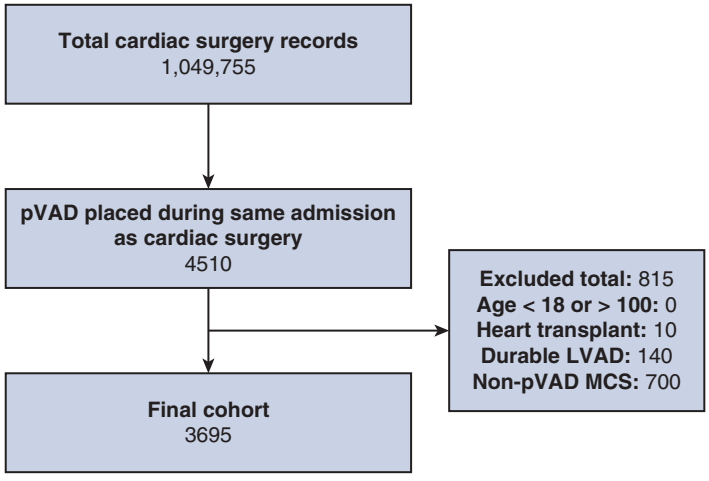


FIGURE 1. Consolidated standards of reporting trials diagram. The Nationwide Inpatient Sample was queried for patients undergoing cardiac surgery between 2016 and 2019 who received percutaneous ventricular assist devices (*pVAD*) during the same hospital admission. After applying exclusion criteria, a total of 3695 patients remained for analysis. *LVAD*, Left ventricular assist device; *MCS*, mechanical circulatory support.

TABLE 1. Patient demographic characteristics

Characteristic	Overall (N = 3695)	pVAD insertion timing			*P* value
		Preoperative (n = 1130)	Intraoperative (n = 1690)	Postoperative (n = 875)	
Age (y)	67 (60-74)	66 (59-72)	67 (59-76)	67 (60-73)	.200
Female	1140 (31)	285 (25)	535 (32)	320 (37)	.046
Expected primary payer					.082
Medicare	2125 (58)	580 (52)	990 (59)	555 (63)	
Medicaid	325 (8.8)	120 (11)	155 (9.2)	50 (5.7)	
Private insurance	980 (27)	300 (27)	455 (27)	225 (26)	
Self-pay	150 (4.1)	75 (6.7)	50 (3.0)	25 (2.9)	
No charge	< 11 (<0.3)	<11 (1.0)	0 (0)	0 (0)	
Other	100 (2.7)	40 (3.6)	40 (2.4)	20 (2.3)	
Unknown	< 11	< 11	0	0	
Urban-rural location					.120
Central metro (pop. ≥1 million)	885 (24)	305 (27)	415 (25)	165 (19)	
Fringe metro (pop. ≥1 million)	830 (23)	250 (22)	315 (19)	265 (30)	
pop. 250,000-999,999	990 (27)	295 (26)	495 (29)	200 (23)	
pop. 50,000-249,999	355 (9.7)	85 (7.6)	195 (12)	75 (8.6)	
Micropolitan	410 (11)	120 (11)	190 (11)	100 (11)	
Not metro or micropolitan	205 (5.6)	60 (5.4)	75 (4.5)	70 (8.0)	
Unknown	20	15	<11	0	
Race					.400
White	2655 (75)	770 (71)	1310 (80)	575 (71)	
Black	270 (7.6)	105 (9.7)	105 (6.4)	60 (7.4)	
Hispanic	375 (11)	120 (11)	145 (8.8)	110 (14)	
Asian or Pacific Islander	130 (3.7)	50 (4.6)	35 (2.1)	45 (5.6)	
Native American	20 (0.6)	< 11 (<1.0)	11 (<0.7)	< 11 (<1.3)	
Other	85 (2.4)	35 (3.2)	35 (2.1)	15 (1.9)	
Unknown	160	45	50	65	
Median income for zip code					.200
Quartile 1 (lowest)	1115 (31)	355 (32)	515 (31)	245 (28)	
Quartile 2	990 (27)	335 (30)	420 (25)	235 (27)	
Quartile 3	915 (25)	265 (24)	465 (28)	185 (21)	
Quartile 4 (highest)	625 (17)	155 (14)	270 (16)	200 (23)	
Unknown	50	20	20	10	

Values are presented as median (interquartile range) or n (%). *pVAD*, Percutaneous ventricular assist device; *pop*., population.

both a cardiac surgery and pVAD insertion during the same admission and by 2019, this number had increased to 1415 patients. The most common type of cardiac surgery in the overall cohort was isolated CABG (85%) and in total 2795 (76%) admissions were classified as urgent, as opposed to elective. Following stratification into pVAD timing groups, isolated CABG remained the most common cardiac surgery performed in each group (pre: 88%, intra: 85%, and post: 80%; $P = .038$). Additionally, urgent admissions occurred more frequently in the preoperative pVAD insertion group (pre: 960 [85%], intra: 1195 [71%], and post: 640 [73%]; $P < .01$) (Table 3).

Out of the total cohort, 1040 (28%) patients had an IABP placed during the same hospitalization with the highest percentage of patients receiving an IABP in the postoperative pVAD group (pre: 14%, intra: 26%, and post: 51%; $P < .001$). In patients who did receive an IABP, the insertion of the IABP more commonly occurred before pVAD insertion possibly demonstrating an escalation of support (Table 4). Additionally, 355 (9.6%) patients received ECMO during the same hospitalization with the highest percentage of patients who received ECMO in the postoperative pVAD group (pre: 5.3%, intra: 7.4%, and post: 19%; $P < .001$). Most patients who received ECMO did so before pVAD insertion possibly demonstrating a de-escalation of tMCS to a more ventricular specific strategy ($P < .001$) (Table 4).

Outcomes

Overall, 1340 (36%) of patients died and 2280 (62%) experienced complications (Figure 2). Death occurred in 205 (18%) patients in the preoperative pVAD group, 665 (39%) patients in the intraoperative pVAD group, and 470 (54%) patients in the postoperative pVAD group ($P < .001$) (Table 5). Complications occurred in 690

TABLE 2. Patient comorbidities

Characteristic	Overall (N = 3695)	pVAD insertion timing			P value
		Preoperative (n = 1130)	Intraoperative (n = 1690)	Postoperative (n = 875)	
History of stroke	265 (7.2)	100 (8.8)	120 (7.1)	45 (5.1)	.300
Previous MI	425 (12)	125 (11)	205 (12)	95 (11)	.900
History of PCI	315 (8.5)	95 (8.4)	145 (8.6)	75 (8.6)	> .900
History of CABG	125 (3.4)	25 (2.2)	60 (3.6)	40 (4.6)	.400
Cardiogenic shock	2510 (68)	820 (73)	1070 (63)	620 (71)	.045
CHF	510 (14)	115 (10)	165 (9.8)	230 (26)	< .001
Valvular disease	190 (5.1)	40 (3.5)	65 (3.8)	85 (9.7)	.005
Peripheral vascular disease	680 (18)	180 (16)	280 (17)	220 (25)	.030
Other neurological disorder	240 (6.5)	50 (4.4)	135 (8.0)	55 (6.3)	.200
Chronic lung disease	855 (23)	230 (20)	430 (25)	195 (22)	.300
Diabetes, uncomplicated	460 (12)	150 (13)	215 (13)	95 (11)	.700
Diabetes, complicated	1285 (35)	410 (36)	525 (31)	350 (40)	.100
Hypothyroidism	320 (8.7)	65 (5.8)	185 (11)	70 (8.0)	.074
Renal failure	850 (23)	265 (23)	335 (20)	250 (29)	.074
Liver disease	120 (3.2)	20 (1.8)	80 (4.7)	20 (2.3)	.120
Peptic ulcer disease	15 (0.4)	5 (0.4)	5 (0.3)	5 (0.6)	.900
AIDS	5 (0.1)	0 (0)	5 (0.3)	0 (0)	.600
Lymphoma	15 (0.4)	0 (0)	15 (0.9)	0 (0)	.200
Metastatic cancer	5 (0.1)	5 (0.4)	0 (0)	0 (0)	.013
Solid tumor without metastasis	80 (2.2)	20 (1.8)	40 (2.4)	20 (2.3)	.900
Coagulopathy	1920 (52)	575 (51)	895 (53)	450 (51)	.900
Obesity	1000 (27)	300 (27)	435 (26)	265 (30)	.500
Weight loss	500 (14)	155 (14)	210 (12)	135 (15)	.700
Fluid/electrolyte disorder	2390 (65)	690 (61)	1070 (63)	630 (72)	.050
Blood loss anemia	55 (1.5)	25 (2.2)	30 (1.8)	0 (0)	.200
Deficiency anemia	660 (18)	185 (16)	305 (18)	170 (19)	.700
Alcohol abuse	95 (2.6)	35 (3.1)	30 (1.8)	30 (3.4)	.500
Drug abuse	60 (1.6)	35 (3.1)	10 (0.6)	15 (1.7)	.071
Psychosis	40 (1.1)	20 (1.8)	10 (0.6)	10 (1.1)	.400
Depression	285 (7.7)	95 (8.4)	145 (8.6)	45 (5.1)	.300
Hypertension, complicated	1085 (29)	220 (19)	535 (32)	330 (38)	< .001
Elixhauser Comorbidity Index	15 (6-23)	13 (6-22)	15 (5-22)	17 (8-26)	.021
Elixhauser in-hospital mortality risk group					.014
High risk (>15)	1785 (48)	470 (42)	845 (50)	470 (54)	
Medium risk (6-15)	840 (23)	255 (23)	430 (25)	155 (18)	
Low risk (<6)	1070 (29)	405 (36)	415 (25)	250 (29)	

Values are presented as n (%) or median (interquartile range). *pVAD*, Percutaneous ventricular assist device; *MI*, myocardial infarction; *pCI*, percutaneous coronary intervention; *CABG*, coronary artery bypass grafting; *CHF,* congestive heart failure.

(61%) preoperative pVAD patients, 930 (55%) intraoperative pVAD patients, and 660 (75%) postoperative pVAD patients ($P < .001$). Preoperative pVAD insertion was associated with increased rates of sepsis (pre: 18%, intra: 9.8%, and post: 17%; $P = .011$) and pneumonia (pre: 38%, intra: 23%, and post: 31; $P < .001$), whereas

TABLE 3. Operative characteristics

Characteristic	Overall (N = 3695)	pVAD insertion timing			*P* value
		Preoperative (n = 1130)	Intraoperative (n = 1690)	Postoperative (n = 875)	
Type of surgery					.038
Isolated aortic	45 (1.2)	< 11 (<1.0)	25 (1.5)	15 (1.7)	
Isolated CABG	3130 (85)	990 (88)	1440 (85)	700 (80)	
CABG + valve	165 (4.5)	40 (3.5)	70 (4.1)	55 (6.3)	
Isolated valve	240 (6.5)	80 (7.1)	115 (6.8)	45 (5.1)	
Combination aortic	115 (3.1)	15 (1.3)	40 (2.4)	60 (6.9)	
Year of surgery					> .900
2016	90 (2.4)	35 (3.1)	45 (2.7)	< 11 (1.3)	
2017	895 (24)	265 (23)	420 (25)	210 (24)	
2018	1295 (35)	395 (35)	585 (35)	315 (36)	
2019	1415 (38)	435 (38)	640 (38)	340 (39)	
Elective/urgent					
Elective	890 (24)	165 (15)	490 (29)	235 (27)	< .001
Urgent	2795 (76)	960 (85)	1195 (71)	640 (73)	
Unknown	10	5	5	0	

Values are presented as n (%). *pVAD*, Percutaneous ventricular assist device; *CABG*, coronary artery bypass grafting.

postoperative pVAD insertion was associated with increased rates of GI bleeding (pre: 2.2%, intra: 3.0%, and post: 7.4%; $P = .011$), renal failure requiring dialysis (pre: 10%, intra: 9.2%, and post: 17%; $P = .031$), and prolonged mechanical ventilation (pre: 44%, intra: 41%, and post: 54%; $P = .023$). Table 5 provides a complete list of outcomes stratified by timing of pVAD insertion. Furthermore, in a sensitivity analysis of CABG-only patients, results were highly like those in the unmatched, overall cohort. Similarly, when patients who received ECMO were excluded, the pattern of results from the overall cohort was further confirmed.

Additionally, multivariable logistic regression revealed that postoperative pVAD (odds ratio [OR], 4.5; 95% CI, 2.80-7.22) and intraoperative pVAD (OR, 2.81; 95% CI, 1.85-4.27) insertion were associated with significantly increased odds of mortality. Furthermore, patients in the high-risk ECI group (OR, 1.62; 95% CI, 1-08-2.42) also had significantly increased risk of mortality. Factors associated with increased odds of experiencing any complication were postoperative pVAD insertion (OR, 1.93; 95% CI, 1.21-3.09) and isolated valve procedures (OR, 2.33; 95% CI, 1.10-4.95), as well as high risk (OR, 5.75; 95% CI, 3.77-8.75) and medium risk (OR, 2.75; 95% CI, 1.78-4.22) ECI groups (Table 6). The median LOS for all patients was 13 days (IQR, 7-22 days). The longest LOS was observed in patients who underwent preoperative pVAD insertion (pre: 16 days [IQR, 10-23 days], intra: 10 days [IQR, 8-22 days], and post: 14 days [IQR, 6-28 days]; $P < .001$). However, after removing patients who died

TABLE 4. Intra-aortic balloon pump (IABP) and extracorporeal membrane oxygenation (ECMO) support

Characteristic	Overall (N = 3695)	pVAD insertion timing			*P* value
		Preoperative (n = 1130)	Intraoperative (n = 1690)	Postoperative (n = 875)	
IABP	1040 (28)	155 (14)	435 (26)	450 (51)	< .001
IABP timing relative to pVAD					< .001
Preceding days	480 (13)	35 (3.1)	45 (2.7)	400 (46)	
Same day	425 (12)	30 (2.7)	365 (22)	30 (3.4)	
Following days	135 (3.7)	90 (8.0)	25 (1.5)	20 (2.3)	
ECMO	355 (9.6)	60 (5.3)	125 (7.4)	170 (19)	< .001
ECMO timing relative to pVAD					< .001
Preceding days	90 (2.4)	0 (0)	0 (0)	90 (10)	
Same day	145 (3.9)	20 (1.8)	85 (5.0)	40 (4.6)	
Following days	120 (3.2)	40 (3.5)	40 (2.4)	40 (4.6)	

Values are presented as n (%). *pVAD*, Percutaneous ventricular assist device.

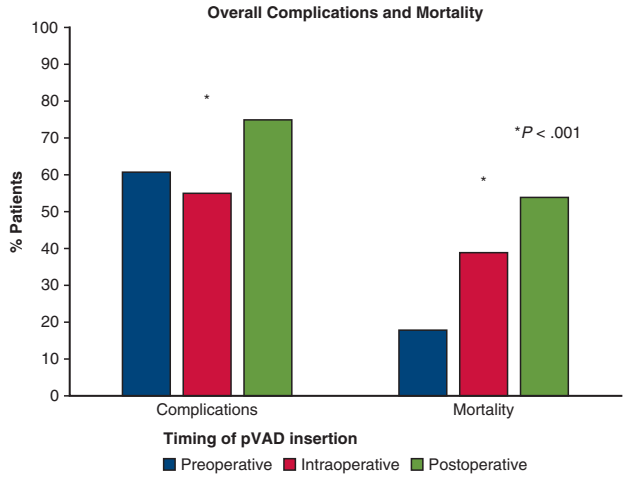


FIGURE 2. Worse outcomes associated with postoperative percutaneous ventricular assist device insertion.

during their hospitalization and assessing only patients who survived to discharge, those who underwent postoperative pVAD insertion had the longest LOS (pre: 16 days [IQR, 11-22 days], intra: 14 days [IQR, 8-22 days], and post: 25 days [IQR, 12-37 days]; $P < .001$).

DISCUSSION

This study aimed to investigate associations between the timing of pVAD insertion and perioperative mortality and complication rates in patients undergoing cardiac surgery, using a nationally representative cohort from the NIS between 2016 and 2019. The study findings revealed an increasing trend in pVAD utilization in patients undergoing cardiac surgery over time. However, the results also highlighted that postoperative pVAD insertion had higher associated mortality and complication rates compared with preoperative or intraoperative insertion (Figure 3). Moreover, patients who received a postoperative pVAD insertion had a higher preoperative comorbidity burden than those who received preoperative or intraoperative placement, as evidenced by a significantly increased median total ECI.

Overall, this study found a steady increase in the use of pVADs in patients undergoing cardiac surgery across the study time frame. Prior analysis of NIS data from 2007 to 2012 demonstrated an increasing use of pVADs across indications[11]; thus, this study adds to the increasing evidence supporting the efficacy of pVADs in cardiac surgery patients needing tMCS during their perioperative course.[4,6,12] Additionally, improvements in pVAD technology over time that allows for easier insertion, improved cardiac output support, and lower complication rates also has likely contributed to the increased use.[13,14] Thus, this trend necessitates further exploration of optimal pVAD use.

The preemptive insertion of pVADs before and during cardiac surgery may represent a strategy for mitigation of morbidity and mortality in high-risk patients. A prior study of 14 patients undergoing cardiac surgery with LV ejection fraction <30% who received preoperative pVAD support

TABLE 5. Postoperative mortality and complications

Characteristic	Overall (N = 3695)	pVAD insertion timing			P value
		Preoperative (n = 1130)	Intraoperative (n = 1690)	Postoperative (n = 875)	
Died	1340 (36)	205 (18)	665 (39)	470 (54)	< .001
Any complication	2280 (62)	690 (61)	930 (55)	660 (75)	< .001
Any stroke	270 (7.3)	105 (9.3)	100 (5.9)	65 (7.4)	.300
Ischemic stroke	255 (6.9)	100 (8.8)	95 (5.6)	60 (6.9)	.300
Hemorrhagic stroke	40 (1.1)	15 (1.3)	10 (0.6)	15 (1.7)	.500
Non-GI bleeding	85 (2.3)	20 (1.8)	35 (2.1)	30 (3.4)	.500
GI bleeding	140 (3.8)	25 (2.2)	50 (3.0)	65 (7.4)	.011
Bleeding (any) requiring transfusion	65 (1.8)	15 (1.3)	25 (1.5)	25 (2.9)	.400
Renal failure requiring dialysis	415 (11)	115 (10)	155 (9.2)	145 (17)	.031
Surgical site infection	20 (0.5)	< 11 (<1.0)	< 11 (0.7)	< 11 (1.3)	> .900
Sepsis	515 (14)	205 (18)	165 (9.8)	145 (17)	.011
Pneumonia	1085 (29)	425 (38)	390 (23)	270 (31)	< .001
Peripheral non-CNS thromboembolism	155 (4.2)	40 (3.5)	55 (3.3)	60 (6.9)	.130
PE/DVT	40 (1.1)	< 11 (<1.0)	20 (1.2)	<11 (1.3)	> .900
Prolonged mechanical ventilation	1655 (45)	495 (44)	690 (41)	470 (54)	.023
Tracheostomy	120 (3.2)	35 (3.1)	35 (2.1)	50 (5.7)	.082

Values are presented as n (%). *pVAD*, Percutaneous ventricular assist device; *GI*, gastrointestinal; *CNS*, central nervous system; *PE/DVT*, pulmonary embolism/deep venous thrombosis.

TABLE 6. Multivariable logistic regression for mortality and overall complications

Predictor	Mortality			Overall complications		
	Odds ratio	95% CI	*P* value	Odds ratio	95% CI	*P* value
Postoperative pVAD	4.5	2.80-7.22	< .001	1.93	1.21-3.09	.006
Intraoperative pVAD	2.81	1.85-4.27	< .001	0.73	0.50-1.07	.11
2017	0.75	0.23-2.41	.622	1.09	0.36-3.30	.872
2018	0.56	0.18-1.78	.328	0.92	0.31-2.72	.878
2019	0.57	0.18-1.80	.335	0.72	0.24-2.13	.553
Female	1.14	0.81-1.62	.452	0.99	0.70-1.41	.954
Black race	0.88	0.45-1.74	.713	0.88	0.46-1.70	.711
Asian/Pacific Islander race	1.69	0.68-4.16	.256	0.81	0.32-2.05	.662
Hispanic race	1.32	0.77-2.25	.312	1.35	0.79-2.32	.27
Native American race	0.66	0.06-7.32	.731	2.92	0.13-66.71	.5
Other race	0.72	0.25-2.09	.549	1.22	0.38-3.99	.737
Isolated valve	1.37	0.71-2.64	.342	2.33	1.10-4.95	.028
Isolated aortic	2.7	0.51-14.26	.241	3.76	0.33-42.52	.284
CABG + valve	1.82	0.92-3.60	.087	0.77	0.39-1.52	.443
Combination aortic	2.32	0.93-5.81	.072	0.59	0.24-1.44	.247
ECI high risk	1.62	1.08-2.42	.02	5.75	3.77-8.75	< .001
ECI medium risk	1.17	0.75-1.83	.487	2.75	1.78-4.22	< .001

pVAD, Percutaneous ventricular assist device; *CABG*, coronary artery bypass grafting; *ECI*, Elixhauser Comorbidity Index.

reported 30-day survival of 92.85%.[4] Our study observed an index mortality of 18% in patients who underwent preoperative pVAD insertion compared with 54% of patients with postoperative pVAD insertion. These patients also had the highest preoperative comorbidity burden, which suggests they may have been at higher preoperative risk and suggests a potential need for improved recognition of high-risk patients before cardiac surgery. Furthermore, this subset of patients likely requires further investigation to determine if they may potentially benefit from additional preoperative optimization both through medical and tMCS strategies.

The observed relationship between postoperative pVAD placement and higher mortality may partially represent the influence of attempted salvage in the setting of postcardiotomy CS. Postcardiotomy CS occurs in 0.2% to 6% of patients undergoing cardiac surgery with a mortality of 50% to 80%.[12,15] The use of pVADs for tMCS in postcardiotomy CS has been previously explored with a single-center analysis of 29 patients reporting index mortality of 41.4%,[8] and another analysis of 77 patients reporting index mortality of 42%.[16] Comparatively, patients in this study who underwent postoperative pVAD insertion, some of whom may potentially represent those with postcardiotomy CS, had mortality of 54%. These findings potentially suggest that even with attempted salvage via pVAD insertion, mortality remains high. However, comparatively, the observed mortality rates in pVAD patients with potential postcardiotomy CS are lower than those reported for postcardiotomy CS patients supported with IABP and/or ECMO.[17-19] Therefore, perioperative and intraoperative strategies to prevent and mitigate postcardiotomy CS, as well as postoperative management techniques may be an impactful area of further study. Furthermore, pVAD insertion has its own inherent risks and these may have played a role in increased morbidity and mortality among already critically ill postcardiotomy CS patients. Thus, it is also possible these patients may have benefitted more from an alternative intervention, such as medical therapy or other tMCS insertion, or no intervention at all. However, the NIS does not allow for-certain determination that patients who underwent postoperative pVAD insertion presented with postcardiotomy CS. Therefore, additional studies with more clinically granular data are needed to determine specific indications for pVAD insertion at different perioperative time points. This information will provide further insight into the specific roles of postoperative pVAD insertion in patients undergoing cardiac surgery.

Specifically, postoperative pVAD insertion was associated with increased rates of GI bleeding, renal failure requiring dialysis, and prolonged mechanical ventilation. These complications could also represent the consequences of postcardiotomy CS resulting in end organ dysfunction.[20] Specifically, GI bleeding among patients with CS receiving percutaneous MCS has been independently associated with increased in-hospital mortality.[21] Conversely, preoperative pVAD insertion was associated with increased rates of sepsis and pneumonia. This is potentially due to patients having a pVAD implanted for longer durations, or patients

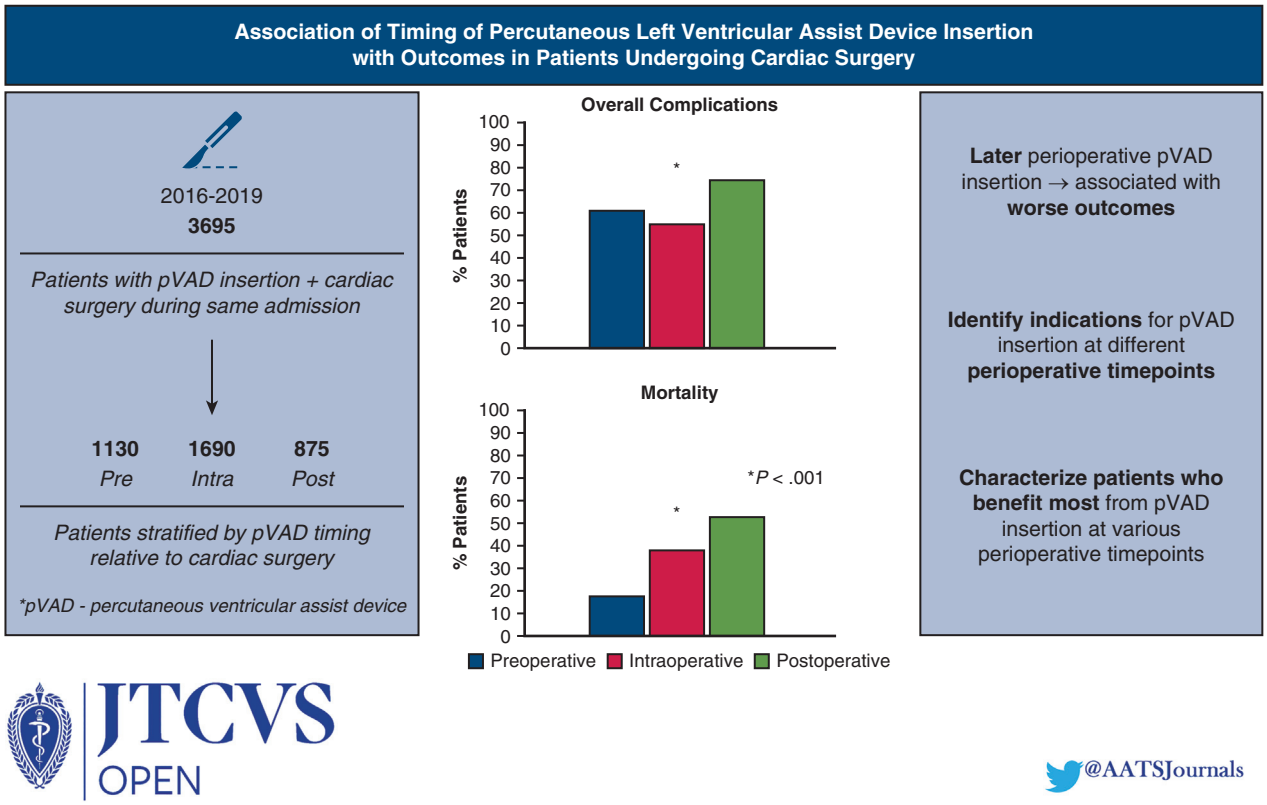


FIGURE 3. Analysis of the Nationwide Inpatient Sample demonstrated that patients who underwent postoperative percutaneous ventricular assist device (*pVAD*) insertion had worse outcomes.

with active infections before pVAD insertion who underwent this procedure to improve their stability before cardiac surgery.[22]

Additionally, the overall complication rate was lowest among patients with pVADs placed during the intraoperative period who may have had this procedure as a planned addition to their cardiac surgery. Therefore, this may have allowed for preoperative optimization that contributed to improved outcomes compared with patients undergoing urgent preoperative or postoperative pVAD insertion. Alternatively, preoperative pVAD insertion may have been a bridge to cardiac surgery for patients requiring more immediate stabilization. An analysis of patients with CS who underwent delayed cardiac surgery after pVAD insertion demonstrated significantly improved preoperative end-organ function and 30-day mortality of 14.3%.[23] This suggests that preoperative pVAD placement may allow for resolution of instability and subsequent improvement in preoperative clinical status for those patients ultimately who become candidates for cardiac surgery.

Furthermore, pVADs can be utilized in patients undergoing cardiac surgery in combination with other tMCS strategies either simultaneously or in a stepwise escalation/de-escalation fashion. This study found that overall, 28% of patients also had IABPs placed and 9.6% had ECMO support during the same hospitalization as their pVAD and cardiac surgery. Overall, the use of IABP support mostly occurred before pVAD insertion.[24] This was especially prominent in patients undergoing postoperative pVAD insertion, with 46% receiving prior IABP support. Although speculative, this may indicate a worsening of their clinical status refractory to medical and IABP therapy requiring escalation to pVAD support.[24] The use of ECMO was also most common in patients undergoing postoperative pVAD insertion, again with most undergoing ECMO initiation before pVAD insertion, which may reflect de-escalation of therapy to a more ventricle-specific support strategy.[25] Together, these findings further highlight the potential role of pVADs as an additional tMCS tool in tailored shock therapy approaches.

However, selection bias likely plays a role in the outcomes of this study. Patients in the preoperative pVAD insertion group represent those who survived following their initial presentation and pVAD insertion and remained stable enough to undergo cardiac surgery. Patients who underwent pVAD insertion and died before undergoing any further surgical intervention were not captured with the available data in the NIS. Furthermore, patients undergoing intraoperative pVAD insertion were likely stable enough to allow for a planned insertion, rather than a more urgent unplanned insertion either preoperative or postoperative.

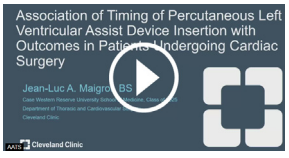
This study is subject to the limitations shared among all observational retrospective studies. We analyzed discharge-level data, which lacks clinical granularity and prevented assessment of precise preoperative clinical status. Furthermore, because the NIS does not report the timing of diagnoses within a hospitalization, we were unable to determine with certainty when a complication occurred relative to cardiac surgery and pVAD placement. The NIS also does not distinguish which type of pVAD was utilized. Because different pVADs provide varying degrees of circulatory support, the effect of device type may also contribute to differences in outcomes.[16] More recent advances in pVAD technology may have also led to increased device utilization after the conclusion of the study time frame, which would not be captured in the results of this study. Finally, administrative data has the general potential for inaccuracies and misclassifications in diagnosis and procedure coding.[26]

CONCLUSIONS

This study demonstrates that postoperative pVAD insertion among patients undergoing cardiac surgery was associated with higher morbidity and mortality compared with preoperative or intraoperative insertion. Patients undergoing postoperative pVAD insertion also had the highest preoperative comorbidity burden, suggesting higher preoperative risk in this population. Thus, further studies to characterize patients undergoing pVAD insertion at different perioperative time points, along with their indications for pVAD insertion, are necessary. These may inform investigations of improved risk-stratification processes that could identify subsets of high-risk patients undergoing cardiac surgery who might benefit from earlier pVAD insertion.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/association-of-timing-of-percutaneous-left-ventricular-assist-device-insertion-with-outcomes-in-patients-undergoing-cardiac-surgery.



Conflict of Interest Statement

Dr Tong has received consulting and speaker honorarium for Abiomed and Abbott. Dr Soltesz has received consulting and speaker honorarium for Abiomed, Abbott, and Atricure. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: temporary mechanical circulatory support, national database, outcomes, transvalvular microaxial pump, Impella, Impella-assisted cardiac surgery

APPENDIX E1. SUPPLEMENTAL PROPENSITY SCORE-MATCHING METHODS

Propensity score matching (PSM) was conducted for each combination of pairs among the preoperative, intraoperative, and postoperative percutaneous ventricular assist device (pVAD) insertion groups to control for confounders and further confirm the results demonstrated in the unmatched samples. We used a 1:1 greedy matching algorithm with a caliper of 0.2 of the pooled SD of the logit propensity score. For all covariates, χ^2 tests were performed. Variables in the matching algorithm were type of cardiac surgery, elective/urgent surgery status, sex, and age as well as select comorbidities based on International Classification of Diseases-10th Revision codes, including history of myocardial infarction, diabetes, renal failure, hypertension with end organ complications, peripheral vascular disease, and history of congestive heart failure. Variables for PSM were selected from those that were significantly different between the unmatched groups. Patients with missing values for variables used in the PSM algorithm were excluded from the final set of matched pairs.

TABLE E1. International Classification of Diseases–10th Revision (ICD10) codes for inclusion and exclusion criteria

Variable	ICD10 codes
Percutaneous left ventricular assist device insertion	02HA3RJ, 02HA3RZ, 02HA3RS, 02HA0RZ, 5A0221D
Heart transplant	02YA0Z0, 02YA0Z1, 02YA0Z2
Durable left ventricular assist device	02HA0QZ
Other non-pVAD mechanical circulatory support	02HA0RJ, 02HA0RS, 02HA0RZ, 02HA0YZ, 02HA3QZ, 02HA3RS, 02HA3YZ, 02HA4QZ, 02HA4RJ, 02HA4RS, 02HA4RZ, 02HA4YZ
Coronary artery bypass grafting	02100, 02110, 02120, 02130
Aortic valve replacement or repair	02QF0ZZ, 02RF07Z, 02RF08Z, 02RF0JZ, 02RF0KZ
Mitral valve replacement or repair	02QG0ZE, 02QG0ZZ, 02RG07Z, 02RG08Z, 02RG0JZ, 02RG0KZ
Triscupid valve replacement or repair	02QJ0ZG, 02QJ0ZZ, 02RJ07Z, 02RJ08Z, 02RJ0JZ, 02RJ0KZ
Pulmonic valve replacement or repair	02QH0ZZ, 02RH07Z, 02RH08Z, 02RH0JZ, 02RH0KZ
Aortic procedures	02BW0ZZ, 02BX0ZZ, 02QX0ZZ, 02QW0ZZ, 02RX07Z, 02RX08Z, 02RX0JZ, 02RX0KZ, 02RW07Z, 02RW08Z, 02RW0JZ, 02RW0KZ

pVAD, Percutaneous ventricular assist device.

TABLE E2. International Classification of Diseases–10th Revision (ICD10) codes for complications

Complication	ICD10 codes
Stroke	G43601 G43609 G43611 G43619 I6300 I63011 I63012 I63013 I63019 I6302 I63031 I63032 I63033 I63039 I6309 I6310 I63111 I63112 I63113 I63119 I6312 I63131 I63132 I63133 I63139 I6319 I6320 I63211 I63212 I63213 I63219 I6322 I63231 I63232 I63233 I63239 I6329 I6330 I63311 I63312 I63313 I63319 I63321 I63322 I63323 I63329 I63331 I63332 I63333 I63339 I63341 I63342 I63343 I63349 I6339 I6340 I63411 I63412 I63413 I63419 I63421 I63422 I63423 I63429 I63431 I63432 I63433 I63439 I63441 I63442 I63443 I63449 I6349 I6350 I63511 I63512 I63513 I63519 I63521 I63522 I63523 I63529 I63531 I63532 I63533 I63539 I63541 I63542 I63543 I63549 I6359 I636 I638 I6381 I6389 I639 I6930 I6931 I69310 I69311 I69312 I69313 I69314 I69315 I69318 I69319 I69320 I69321 I69322 I69323 I69328 I69331 I69332 I69333 I69334 I69339 I69341 I69342 I69343 I69344 I69349 I69351 I69352 I69353 I69354 I69359 I69361 I69362 I69363 I69364 I69365 I69369 I69390 I69391 I69392 I69393 I69398 I6980 I6981 I69810 I69811 I69812 I69813 I69814 I69815 I69818 I69819 I69820 I69821 I69822 I69823 I69828 I69831 I69832 I69833 I69834 I69839 I69841 I69842 I69843 I69844 I69849 I69851 I69852 I69853 I69854 I69859 I69861 I69862 I69863 I69864 I69865 I69869 I69890 I69891 I69892 I69893 I69898 I6990 I6991 I69910 I69911 I69912 I69913 I69914 I69915 I69918 I69919 I69920 I69921 I69922 I69923 I69928 I69931 I69932 I69933 I69934 I69939 I69941 I69942 I69943 I69944 I69949 I69951 I69952 I69953 I69954 I69959 I69961 I69962 I69963 I69964 I69965 I69969 I69990 I69991 I69992 I69993 I69998
Pulmonary embolism and deep venous thrombosis	I2602 I2609 I2692 I2693 I2694 I2699 I824 I8262
Prolonged mechanical ventilation	5A1945Z 5A1955Z
Tracheostomy	0B113F4
Pneumonia	A0103 A0222 A202 A212 A221 A310 A3791 A430 A481 B012 B052 B0681 B250 B371 B380 B381 B382 B390 B391 B392 B583 B59 B7781 J120 J121 J122 J123 J1281 J1289 J129 J13 J14 J150 J151 J1520 J15211 J15212 J1529 J153 J154 J155 J156 J157 J158 J159 J160 J168 J180 J181 J188 J189 J690 J691 J698 J851 J930 J9311 J9381 J9382 J9383 J939
Surgical site infection	T8140 T8141 T8142 T8143 T8149 A49
Sepsis	T8144 A419 R6520 R6521
Renal failure requiring dialysis	N170 N171 N172 N178 N179 N990 N19 AND 5A1D00Z 5A1D60Z 5A1D70Z 5A1D80Z 5A1D90Z EXCLUDING Z992
Gastrointestinal bleeding	K921 K922 K31811 I8501 I8511 K2211 K2971 K2901 K2961 K2991 K250 K252
Nongastrointenstinal bleeding	I974 I976 T82837 D683 D699 I230 I312 S26.0 K66.1 R58
Transfusion required	30230N0 30230N 30233N0 30233N1 30240N0 30240N1 30243N0 30243N1 30250N0 30250N1 30253N0 30253N1 30260N0 30260N1 30263N0 30263N1 30273N1 30277N1 30230H0 30230H1 30233H0 30233H1 30240H0 30240H1 30243H0 30243H1 30250H0 30250H1 30253H0 30253H1 30260H0 30260H1 30263H0 30263H1 30273H1 30277H1
Noncentral nervous system peripheral thromboembolism	I7401 I7409 I7410 I7411 I7419 I742 I743 I744 I745 I748 I749 I75011 I75012 I75013 I75019 I75021 I75022 I75023 I75029 I7581 I7589

TABLE E3. Postoperative mortality and complications for propensity score-matched preoperative and postoperative percutaneous ventricular assist device (pVAD) insertion groups

Characteristic	pVAD insertion timing		
	Preoperative (n = 705)	Postoperative (n = 705)	*P* value
Mortality	140 (20)	360 (51)	< .001
Any complication	440 (62)	530 (75)	.014
Any stroke	80 (11)	50 (7.1)	.2
Ischemic stroke	75 (11)	45 (6.4)	.2
Hemorrhagic stroke	10 (1.4)	15 (2.1)	.6
Non-GI bleeding	10 (1.4)	15 (2.1)	.6
GI bleeding	15 (2.1)	55 (7.8)	.028
Bleeding (any) requiring transfusion	10 (1.4)	20 (2.8)	.4
Renal failure requiring dialysis	85 (12)	115 (16)	.3
Surgical site infection	5 (0.7)	0 (0)	.3
Sepsis	140 (20)	130 (18)	.8
Pneumonia	260 (37)	200 (28)	.1
Peripheral non-CNS thromboembolism	35 (5.0)	45 (6.4)	.6
PE/DVT	10 (1.4)	10 (1.4)	> .9
Prolonged ventilation	320 (45)	355 (50)	.4
Tracheostomy	35 (5.0)	20 (2.8)	.3

Values are presented as n (%). *GI*, Gastrointestinal; *CNS*, central nervous system; *PE/DVT*, pulmonary embolism/deep venous thrombosis.

TABLE E4. Postoperative mortality and complications for propensity score-matched intraoperative and postoperative percutaneous ventricular assist device (pVAD) insertion groups

Characteristic	pVAD insertion timing		
	Intraoperative (n = 830)	Postoperative (n = 830)	*P* value
Mortality	295 (36)	445 (54)	< .001
Any complication	490 (59)	620 (75)	.002
Any stroke	45 (5.4)	60 (7.2)	.4
Ischemic stroke	40 (4.8)	55 (6.6)	.4
Hemorrhagic stroke	10 (1.2)	10 (1.2)	> .9
Non-GI bleeding	15 (1.8)	20 (2.4)	.7
GI bleeding	40 (4.8)	60 (7.2)	.3
Bleeding (any) requiring transfusion	15 (1.8)	25 (3.0)	.5
Renal failure requiring dialysis	85 (10)	140 (17)	.063
Surgical site infection	0 (0)	5 (0.6)	.3
Sepsis	115 (14)	140 (17)	.5
Pneumonia	215 (26)	245 (30)	.5
Peripheral non-CNS thromboembolism	40 (4.8)	60 (7.2)	.3
PE/DVT	10 (1.2)	10 (1.2)	> .9
Prolonged ventilation	390 (47)	445 (54)	.2
Tracheostomy	35 (4.2)	45 (5.4)	.6

Values are presented as n (%). *GI*, Gastrointestinal; *CNS*, central nervous system; *PE/DVT*, pulmonary embolism/deep venous thrombosis.

TABLE E5. Postoperative mortality and complications for propensity score-matched preoperative and intraoperative percutaneous ventricular assist device (pVAD) insertion groups

Characteristic	pVAD insertion timing		
	Preoperative (n = 1125)	Intraoperative (n = 1125)	*P* value
Mortality	205 (18)	430 (38)	< .001
Any complication	685 (61)	600 (53)	.091
Stroke, any	105 (9.3)	60 (5.3)	.085
Ischemic stroke	100 (8.9)	60 (5.3)	.12
Hemorrhagic stroke	15 (1.3)	5 (0.4)	.3
Non-GI bleeding	20 (1.8)	15 (1.3)	.7
GI bleeding	25 (2.2)	35 (3.1)	.5
Bleeding (any) requiring transfusion	15 (1.3)	15 (1.3)	> .9
Renal failure requiring dialysis	115 (10)	95 (8.4)	.5
Surgical site infection	5 (0.4)	10 (0.9)	.5
Sepsis	200 (18)	120 (11)	.026
Pneumonia	420 (37)	260 (23)	< .001
Peripheral non-CNS thromboembolism	40 (3.6)	25 (2.2)	.4
PE/DVT	10 (0.9)	15 (1.3)	.7
Prolonged ventilation	490 (44)	460 (41)	.6
Tracheostomy	35 (3.1)	30 (2.7)	.8

Values are presented as n (%). *GI*, Gastrointestinal; *CNS*, central nervous system; *PE/DVT*, pulmonary embolism/deep venous thrombosis.

TABLE E6. Postoperative mortality and complications for patients undergoing isolated coronary artery bypass grafting

Characteristic	Overall, (N = 3130)	pVAD insertion timing			*P* value
		Preoperative (n = 990)	Intraoperative (n = 1440)	Postoperative (n = 700)	
Mortality	1065 (34)	190 (19)	520 (36)	355 (51)	< .001
Any complication	1890 (60)	595 (60)	770 (53)	525 (75)	< .001
Any stroke	230 (7.3)	100 (10)	80 (5.6)	50 (7.1)	.14
Ischemic stroke	220 (7.0)	95 (9.6)	80 (5.6)	45 (6.4)	.2
Hemorrhagic stroke	30 (1.0)	15 (1.5)	0 (0)	15 (2.1)	.065
Non-GI bleeding	55 (1.8)	10 (1.0)	25 (1.7)	20 (2.9)	.3
GI bleeding	115 (3.7)	15 (1.5)	45 (3.1)	55 (7.9)	.006
Bleeding (any) requiring transfusion	40 (1.3)	5 (0.5)	15 (1.0)	20 (2.9)	.14
Renal failure requiring dialysis	320 (10)	95 (9.6)	110 (7.6)	115 (16)	.014
Surgical site infection	20 (0.6)	5 (0.5)	10 (0.7)	5 (0.7)	> .9
Sepsis	390 (12)	150 (15)	115 (8.0)	125 (18)	.007
Pneumonia	895 (29)	355 (36)	325 (23)	215 (31)	.003
Peripheral non-CNS thromboembolism	150 (4.8)	40 (4.0)	55 (3.8)	55 (7.9)	.15
PE/DVT	30 (1.0)	10 (1.0)	10 (0.7)	10 (1.4)	.8
Prolonged mechanical ventilation	1350 (43)	415 (42)	560 (39)	375 (54)	.016
Tracheostomy	100 (3.2)	30 (3.0)	25 (1.7)	45 (6.4)	.033

Values are presented as n (%). *pVAD*, Percutaneous ventricular assist device; *GI*, gastrointestinal; *CNS*, central nervous system; *PE/DVT*, pulmonary embolism/deep venous thrombosis.

TABLE E7. Postoperative mortality and complications: Patients with extracorporeal membrane oxygenation excluded

Characteristic	Overall (N = 3340)	pVAD insertion timing			*P* value
		Preoperative (n = 1070)	Intraoperative (n = 1565)	Postoperative (n = 705)	
Mortality	1120 (34)	190 (18)	575 (37)	355 (50)	< .001
Any complication	2010 (60)	635 (59)	850 (54)	525 (74)	< .001
Any stroke	215 (6.4)	95 (8.9)	90 (5.8)	30 (4.3)	.14
Ischemic stroke	205 (6.1)	90 (8.4)	90 (5.8)	25 (3.5)	.13
Hemorrhagic stroke	25 (0.7)	15 (1.4)	5 (0.3)	5 (0.7)	.4
Non-GI bleeding	65 (1.9)	20 (1.9)	25 (1.6)	20 (2.8)	.6
GI bleeding	90 (2.7)	20 (1.9)	35 (2.2)	35 (5.0)	.12
Bleeding (any) requiring transfusion	45 (1.3)	15 (1.4)	15 (1.0)	15 (2.1)	.6
Renal failure requiring dialysis	370 (11)	115 (11)	130 (8.3)	125 (18)	.008
Surgical site infection	20 (0.6)	5 (0.5)	10 (0.6)	5 (0.7)	> .9
Sepsis	460 (14)	180 (17)	150 (9.6)	130 (18)	.01
Pneumonia	960 (29)	380 (36)	360 (23)	220 (31)	.003
Peripheral non-CNS thromboembolism	135 (4.0)	40 (3.7)	55 (3.5)	40 (5.7)	.5
PE/DVT	40 (1.2)	10 (0.9)	20 (1.3)	10 (1.4)	> .9
Prolonged ventilation	1455 (44)	445 (42)	620 (40)	390 (55)	.007
Tracheostomy	115 (3.4)	35 (3.3)	30 (1.9)	50 (7.1)	.018

Values are presented as n (%). *pVAD*, Percutaneous ventricular assist device; *GI*, gastrointestinal; *CNS*, central nervous system; *PE/DVT*, pulmonary embolism/deep venous thrombosis.