Utilization and Outcomes of Postcardiotomy Mechanical Circulatory Support

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Abstract

Background: This study evaluated the utilization and outcomes of postcardiotomy mechanical circulatory support (MCS). Methods: This was a retrospective, single institution analysis of adult cardiac surgery cases that required de novo MCS following surgery from 2011-2018. Patients that were bridged with MCS to surgery were excluded. The primary outcomes were early operative mortality and longitudinal survival. Secondary outcomes included postoperative complications, and five-year all-cause readmission. Results: 533 patients required de novo postcardiotomy MCS, with the most commonly performed procedure being isolated coronary artery bypass grafting (29.8%). Median cardiopulmonary bypass and cross clamp times were 185 (IQR 123-260) minutes and 122 (IQR 81-179) minutes, respectively. A total of 442 (82.9%) of patients were supported with intra-aortic balloon pump counterpulsation, 23 (4.3%) with an Impella device, and 115 (21.6%) with extracorporeal membrane oxygenation. Three (0.6%) patients had an unplanned ventricular assist device placed. Operative mortality was 29.8%. Longitudinal survival was 56.1% and 43.0% at 1- and 5-years, respectively. Survival was lowest in those supported with ECMO and highest with those supported with an Impella (P<0.001). Freedom from readmission was 61.4% at 5-years. Postoperative ECMO was an independent predictor of mortality (HR 5.1, 95% CI 2.0-12.9, P<0.001), but none of the MCS types predicted long-term hospital readmission after risk adjustment. Conclusions: Postcardiotomy MCS is associated with high operative mortality. Even patients that survive to discharge have compromised longitudinal survival, with nearly only half surviving to 1-year. Close follow-up and early referral to advanced heart failure specialists may be prudent in improving these outcomes.

Introduction

Postcardiotomy cardiogenic shock (PCCS), defined by inadequate end-organ perfusion due to low cardiac output, occurs after 1-5% of cardiac surgical procedures, and in about 1% of cases, patients may require post-operative mechanical circulatory support (MCS).[1,2]The typical presentation of PCCS is decreasing cardiac function along with the difficulty or inability to wean from cardiopulmonary bypass without high-dose inotropic support and/or advanced MCS. Current MCS strategies include the use of intra-aortic balloon (IABP) counterpulsation, extracorporeal membrane oxygenation (ECMO), percutaneously-implanted or surgically implanted left ventricular assist devices, or a combination of devices.[1] Despite advances in the development of support strategies, in-hospital mortality following PCCS remains high, with reports ranging from 40-90%.[3–10]

Due to the high costs of MCS usage following PCCS, along with the propensity for increased rates of further complication, prolonged intensive care and hospital stays, and ultimately high rate of death, it is often debated whether these measures are beneficial or futile. Furthermore, the long-term outcomes in survivors of PCCS have not been well-studied. Therefore, this study aimed to investigate our experience in using de novo MCS for PCCS following cardiac surgery, and examine short and long-term outcomes.

Materials and Methods

Study Population

This was a retrospective analysis of a single institutional experience of adult patients (18 years or older) who underwent cardiac surgery at a multi-hospital health system between January 2011 and June 2018. Patients were included if they were placed on de novo MCS either intraoperatively or postoperatively. Patients who were supported with MCS prior to surgery were excluded. This study was approved by the Institutional Review Board at the University of Pittsburgh (MOD18120143-003, approved 3/9/2020). Patient consent was waived due to retrospective nature of the study.

Primary and Secondary Outcomes

The primary outcomes of this study were operative mortality and longitudinal survival. Operative mortality was defined as occurring within 30 days of the operation or in-hospital during the index hospitalization following the operation. Secondary outcomes included postoperative complications and five-year all-cause hospital readmission.

Statistical Analysis

Continuous data are presented as mean (± standard deviation) for normally distributed variables or median [interquartile range (IQR)] for non-normally distributed variables. Categorical data are displayed as number (percentage). Kaplan Meier analysis was used to evaluate five-year survival and cumulative incidence of all-cause readmission.

Cox proportional hazards modeling was used to model postoperative mortality. In this model, all baseline characteristics and risk factors were assessed in a univariable model. Those with significant associations with mortality ($P<0.05$) were considered for inclusion in the final multivariable model. Backwards, stepwise elimination was performed to create the final model with covariable inclusion of $P<0.2$ into the final model. Significant covariable interactions and multicollinearity were investigated.

Competing risk regression was used to model all-cause hospital readmission. In this model, death was the competing event. Baseline characteristics and risk factors were assessed in a univariable model, and those with significant associations ($P<0.05$) with all-cause readmissions were included in the final multivariable model. Statistical analyses were performed using SAS version 9.2 software (SAS Institute, Cary, NC).

Results

A total of 533 patients were included in this study. Baseline characteristics and preoperative comorbidities are presented in**Table 1** . The majority of patients in this cohort were male (333 [63.4%]) and of white race (487 [91.4%]). A total of 310 (58.2%) cases were performed as an urgent procedure, and 62 (11.6%) were categorized as emergent or salvage procedures. Median Society of Thoracic Surgeons predicted risk of mortality was 3.8% (IQR 1.9% to 7.9%).

The most common procedure performed was isolated coronary arterial bypass grafting (CABG), performed in 159 (29.8%) cases. Other commonly performed procedures were double valve interventions (84 [15.8%]) and combined CABG and aortic valve replacement (60 [11.3%]). Operative characteristics are displayed in **Table 2** . Cardiopulmonary bypass was utilized in 91.6% of cases with a median perfusion time and cross clamp time of 185 minutes (IQR 123 to 260) and 122 minutes (IQR 81 to 179), respectively.

Intraoperatively, or within the postoperative period, a total of 442 (82.9%) of patients had an IABP placed (**Table 3**). A total of 23 (4.3%) had an Impella device placed, and 115 (21.6%) were placed on extracorporeal membrane oxygenation support. Three (0.6%) patients had an unplanned ventricular assist device placed. Most (487 [91.37%]) patients were supported with one circulatory support device, while 4 (0.75%) patients were exposed to three different forms of MCS during the intraoperative and postoperative period.

Postoperative outcomes are presented in **Table 4** . In this cohort, operative mortality was 29.8%. Blood products were administered in 80.9% of patients, and the rate of reoperation was 46.5%. Other complications

included prolonged mechanical ventilation (334 [62.7%]), renal failure (170 [31.9%]), pneumonia (116 [21.8%]), and stroke (31 [17.1%]). Patients spent a median time of 124 hours in an intensive care unit setting.

Long-Term Survival

Median follow up was 2.28 years (IQR 0.04 to 4.50 years). One- and five-year unadjusted actuarial survival was 56.1% and 43.0% for the entire cohort, respectively (**Figure 1A**). **Figure 1B**displays unadjusted survival, stratified by mechanism of MCS. In this analysis, patients were categorized by the highest level of support used (ECMO > Impella > IABP). At one and five years, actuarial survival was highest in patients bridged with an Impella device and lowest in patients bridged with ECMO.

Cox proportional hazards modeling was performed to identify predictors of mortality in patients bridged with MCS from CBP. In a univariable analysis, postoperative IABP insertion (HR 1.45, 95% CI 1.00 to 2.10, P=0.05), and either intraoperative (HR 1.59, 95% CI 1.12 to 2.26, P<0.001) or postoperative (HR 2.52, 95% CI 1.82 to 3.49, P<0.001) ECMO insertion were associated with increased hazards for mortality. Usage of an Impella device, either intraoperatively (HR 0.54, 95% CI 0.23 to 1.32, P=0.18) or postoperatively (HR 0.90, 95% CI 0.37 to 2.17, P=0.81) was not found to be associated with mortality. There were too few patients with durable ventricular assist device insertion to model.

When adjusted for other significant baseline risk factors, postoperative ECMO cannulation was associated with a five-fold increased hazards for mortality in the final multivariable model (HR 5.12, 95% CI 2.04 to 12.85, P<0.001) (**Table 5**). Intraoperative ECMO cannulation did not reach statistical significance for mortality hazard (HR 2.47, 95% CI 0.96 to 6.33, P=0.06). Other factors associated with increased hazards for mortality include increasing age (per year, HR 1.04, 95% CI 1.01 to 1.07, P=0.01), presence of peripheral vascular disease (HR 3.55, 95% CI 1.93 to 6.52, P<0.001), and emergent operative status (HR 5.90, 95% CI 1.89 to 18.44, P<0.001). After risk adjustment, bridging with either Impella or IABP were not found to be associated with mortality, and were removed from the final model.

Long-Term Readmission

Thirty-day readmission was 13.1%. At one and five years, 28.3% and 38.7% of patients were readmitted to the hospital for any reason (**Figure 2**). Overall rate of rate of cardiac-related readmission in this study period was 34.2%.

Competing risk regression was used to model risk factors for all-cause readmission. In a univariable analysis, postoperative ECMO (HR 0.37, 95% CI 0.19 to 0.74, P=0.01) was associated with a decreased hazards for readmission, which may reflect the high in-hospital mortality associated with its usage. Implantation of a ventricular assist device was associated with a four-fold risk of readmission (HR 4.31, 95% CI 2.80 to 6.63, P<0.001).

In a multivariable model, none of the bridging strategies were significantly associated with readmission after risk adjustment (**Table 6**). In this model, increasing baseline creatinine level (per 1 mg/dL, HR 1.86, 95% CI 1.03 to 3.36, P=0.04) was associated with increased risk of readmission. However, preoperative dialysis dependency was associated with drastically reduced hazards for readmission (HR 0.07, 95% CI 0.01 to 0.75, P=0.03), likely representing a high operative mortality in this subpopulation.

Discussion

The development of postcardiotomy cardiogenic shock is a feared complication following cardiac surgery. Though risk factors for this condition are not well described, many cases are often attributed to poor preoperative cardiac function, prolonged cardiopulmonary bypass and cross-clamp times, poor myocardial protection, and or ongoing ischemia. Once believed to be a mortal complication, early mortality following these cases have been high, ranging from 40% to 90%,[11,12] with rates highest following coronary bypass grafting or combined bypass grafting and valvular operations.[13] Due to this low rate of survival, the discussion regarding the practicality of postoperative transition to MCS, especially higher-level forms such as ECMO, remains ongoing in efforts to mitigate futile and costly practices.

The interpretation of the results from our series can be viewed from different perspectives. The fact that 56% survived to 1-year suggests that postcardiotomy MCS in general is not a futile practice, and that patients can survive not only the early postoperative period but longitudinally for several years as well. Even in those requiring ECMO support, over one third of these patients survived to one year, with a quarter reaching five-year survival. These outcomes are comparable to those reported by Biancari and colleagues,[14] who reported a five-year survival of 27.7% in a series of 665 patients bridged with veno-arterial ECMO following development of postcardiotomy shock. In their series, increased age was the greatest pre-ECMO predictor of mortality for these patients, with a five-year survival of 13.0% in those 80 years or older. In our analysis, we observed a 4% increase in hazards for mortality per year of age (HR 1.04, 95% CI 1.01 to 1.07, P=0.01), once again drawing attention to this pre-MCS risk factor. Thus age and overall life expectancy should be considered prior to initiation of MCS for this advanced age subset.

Another interpretation of our data is that nearly half of patients die within 1-year of postcardiotomy MCS support. Although not all of these patients likely succumb to advanced heart failure, close follow-up of this patient cohort appears to be prudent. Other measures and interventions such as continued rehabilitation, prevention of infection, nutritional optimization, and early referral to advanced heart failure providers may all be important in improving survival and quality of life in this challenging cohort.

The choice of MCS for the patient in postcardiotomy shock is nuanced, and decisions are often tailored to the specific needs of the patient. For the patient with depressed left ventricular function and/or high inotropic requirement in order to separate from cardiopulmonary bypass, an IABP is often inserted as a first measure to support hemodynamic performance and/or coronary perfusion. Should these measures be insufficient, or the patient develops overwhelming right ventricular dysfunction/failure and/or pulmonary insufficiency, consideration for ECMO cannulation is entertained.

Insertion of a durable left ventricular assist device or a temporary device such as the Impella is not routinely considered at the time of index operation. In these patients, the more typical course is the presence of preexisting ventricular dysfunction that fails to improve after surgical intervention and/or revascularization, or more rarely, left ventricular dysfunction that develops as a consequence of the operation without recovery. For these patients, they may be initially stabilized with another form of MCS, and once left ventricular recovery is deemed improbable, these devices are considered. Depending on baseline characteristics at this time, durable ventricular assist therapy may be chosen, or an Impella may be inserted with the goal of transplantation. The benefits of durable or temporary ventricular assist devices is their ability to unload the left ventricle, reduce ventricular distension, and thereby improve myocardial recovery. Several types of MCS devices may also be used in combination to achieve the goals of left ventricular unloading, oxygenation, and improved perfusion.

One of the most important tenets of MCS is early initiation. This concept was solidified in our analysis where postoperative placement of ECMO had a greater impact on mortality risk than intraoperative placement. Patients who are weaned from cardiopulmonary bypass on very high levels of inotropic support and with marginal hemodynamics typically will deteriorate over the ensuing minutes or hours. Poor perfusion and associated acidosis can lead to lethal arrhythmias or end organ failure in a short period of time and dramatically increase mortality risk in these patients. As has been shown in the cardiogenic shock literature, early MCS including in the postcardiotomy setting should be employed to help offload demands of the myocardium and to improve perfusion and limit acid-base disturbances.

Limitations

This study was prone to limitations. This study was a retrospective review of patients who received unplanned de novo MCS after cardiac surgery, and thus was not randomized. As such, direct comparisons of MCS strategies are not possible within the limits of this study. Mechanical support may be initiated for various reasons, and the choice of bridging support is often tailored to the individual needs of the patient or preferences of the surgeon. As a result, selection bias likely exists. The scope of this study is to report upon a large experience of MCS support following cardiac surgery and to evaluate both early and longitudinal

outcomes, and to not advocate the usage of one form of support over another.

Conclusions

In this review of 533 patients requiring unplanned MCS following conventional cardiac surgical procedures, we observed a high rate of operative mortality and morbidity, with the highest rate of mortality in those supported with ECMO. Even though the majority survive the perioperative period, nearly half of the patients had died by one year. These findings suggest that continued surveillance and close follow-up of these patients is important to improving longitudinal outcomes in this challenging patient subset.

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Disclosures

Arman Kilic, MD is on the medical advisory board for Medtronic, Inc. This affiliation does not create any direct conflicts with the contents of this manuscript.

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Table 1. Patient demographics and preoperative comorbidities of patients who were supported with de novo mechanical circulatory support following cardiac surgery

Characteristics	N (%) or Median (IQR) N=533
Female	195 (36.59%)
Race	
White	487 (91.37%)
Black	35 (6.57%)

Characteristics	N (%) or Median (IQR) N=533
Other	11 (2.06%)
Age (years)	67.00 (58.00-75.00)
BMI (kg/m^2)	28.13 (24.49-32.50)
BSA (m^2)	1.98 ± 0.27
Diabetes mellitus	222 (41.65%)
Dialysis dependency	23 (4.32%)
Chronic obstructive pulmonary disease	173 (32.46%)
Hypertension	433 (81.24%)
Immunosuppression	43 (8.07%)
Cerebrovascular disease	133 (24.95%)
Peripheral vascular disease	123 (23.08%)
Previous myocardial infarction	300 (56.29%)
Cardiac symptoms at admission	
No symptoms	111 (20.83%)
Symptoms unlikely to be ischemia	46 (8.63%)
Stable angina	22 (4.13%)
Unstable angina	83 (15.57%)
NSTEMI	101 (18.95%)
STEMI	27 (5.07%)
Symptoms equivalent to angina	1 (0.19%)
Other	142 (26.64%)
Operative status	
Elective	161(30.21%)
Urgent	310 (58.16%)
Emergent or salvage	62(11.63%)
NYHA class symptoms	
I	244 (45.78%)
II	22 (4.13%)
III	100 (18.76%)
IV	167 (31.33%)
Previous congestive heart failure	246 (46.15%)
History of cardiac arrhythmia	208 (39.02%)
Preoperative creatinine (mg/dL)	1.10 (0.90-1.40)
Preoperative total bilirubin (mg/dL)	0.70 (0.50-1.00)
Preoperative albumin (g/dL)	3.60 (3.20-3.80)
Preoperative LVEF	45.00 (28.00-58.00)

BMI = body mass index; BSA = body surface area; IQR = interquartile range; LVEF = left ventricular ejection fraction; NSTEMI = non-ST-elevation myocardial infarction; NYHA = New York Heart Association; STEMI = ST-elevation myocardial infarction

Table 2. Operative details and postoperative support for patients who were started on mechanical circulatory support following cardiac surgery

Characteristic	N (%) or Median (IQR)
STS predicted risk of mortality (%)	3.83 (1.86- 7.90)
Cardiopulmonary bypass utilization	488 (91.56%)
Perfusion time (minutes)	185.0 (123.5-260.0)
Cross clamp time (minutes)	122.0 (81.00-179.0)

Characteristic	N (%) or Median (IQR)
Operation performed	
Aortic Root	41 (7.69%)
CABG + AVR	60 (11.26%)
CABG + MVr/MVR	48 (9.01%)
Double Valve	84 (15.76%)
Isolated AVR	34 (6.38%)
Isolated CABG	159 (29.83%)
Isolated MVr/MVR	31 (5.82%)
Isolated TVR	4 (0.75%)
Triple Valve	13 (2.44%)
TAVR	7 (1.31%)
Other	52 (9.76%)

AVR, aortic valve replacement

CABG, coronary artery bypass grafting

IABP, intra-aortic balloon pump

MVr, mitral valve repair

MVR, mitral valve replacement

STS, Society of Thoracic Surgeons

TAVR, transcatheter aortic valve replacement

TVR, tricuspid valve replacement

Table 3. Timing and indication of mechanical circulatory support usage

Variable	N (%)
Intra-aortic balloon pump placement	
Intraoperative	352 (66.04%)
Postoperative	90 (16.89%)
Intra-aortic balloon pump indications	
Hemodynamic instability	201 (45.48%)
PCI or other procedural	12 (2.71%)
Unstable angina	2 (0.45%)
Weaning from cardiopulmonary bypass	210 (47.51%)
Prophylatic	17 (3.85%)
Impella placement	
Intraoperative	13 (2.44%)
Postoperative	10 (1.88%)
Impella indications	
Hemodynamic instability	15 (65.22%)
Weaning from cardiopulmonary bypass	6 (26.09%)
PCI or other procedural support	2 (8.70%)
ECMO placement	
Intraoperative	60 (11.26%)
Postoperative	55 (10.32%)
ECMO indications	

Variable	N (%)
Cardiac failure	72 (62.61%)
Respiratory	35 (30.43%)
Rescue/salvage	8 (6.96%)
Ventricular assist device placement	3 (0.56%)
VAD indication	
Bridge to transplantation	1 (33.33%)
Destination therapy	2 (66.67%)
Total number of devices inserted	
1	487 (91.37%)
2	42 (7.88%)
3	4 (0.75%)

ECMO = extracorporeal membrane oxygenation; PCI = percutaneous coronary intervention; VAD = ventricular assist device

Table 4. Postoperative complications and outcomes following surgery

Adverse Event or Outcome	N (%) or Median (IQR)
Operative mortality	159 (29.83%)
Reoperation	248 (46.53%)
Blood product transfusion	431 (80.86%)
Prolonged mechanical ventilation	334 (62.66%)
Pneumonia	116 (21.76%)
Renal failure	170 (31.89%)
Stroke	31 (5.82%)
Sepsis	43 (8.07%)
Superficial wound infection	12 (2.25%)
Deep sternal wound infection	2 (0.38%)
Atrial fibrillation	187 (35.08%)
Total ICU hours	123.5 (70.83-292.00)

ICU = intensive care unit; IQR = interquartile range

Table 5. Multivariable Cox proportional hazards model for postoperative mortality

Covariable	Hazard Ratio	95% Confidence Interval Limits	95% Confidence Interval Limi
ECMO			
None	Ref	Ref	Ref
Intraoperative cannulation	2.47	0.96	6.33
Postoperative cannulation	5.12	2.04	12.85
Race			
White	Ref	Ref	Ref
Black	1.40	0.34	5.79
Other	5.65	0.86	37.04
Chronic obstructive pulmonary disease	1.60	0.89	2.89
Family history of CAD	0.55	0.23	1.33
Peripheral vascular disease	3.55	1.93	6.52
Cardiac symptoms at admission			

Covariable	Hazard Ratio	95% Confidence Interval Limits	95% Confidence Interval Limi
No symptoms	Ref	Ref	Ref
Symptoms unlikely to be ischemia	1.54	0.54	4.42
Stable angina	0.18	0.02	1.81
Unstable angina	2.33	0.64	8.48
NSTEMI	1.73	0.49	6.11
STEMI	0.09	0.01	0.57
Other	0.75	0.30	1.86
NYHA class symptoms			
I	Ref	Ref	Ref
II	10.02	1.85	54.43
III	1.58	0.74	3.35
IV	1.86	0.83	4.20
Operative status			
Elective	Ref	Ref	Ref
Urgent	0.91	0.41	2.02
Emergent/salvage	5.90	1.89	18.44
Procedure performed			
Isolated CABG	Ref	Ref	Ref
Aortic root	0.53	0.13	2.25
CABG + AVR	2.62	0.97	7.06
CABG + MVr/MVR	0.18	0.05	0.62
Double Valve	0.70	0.18	2.64
Single valve	0.54	0.17	1.75
Age, increasing, per year	1.04	1.01	1.07
Albumin (increasing, per 1 g/dL)	0.31	0.16	0.62
Preoperative LVEF (increasing, per 1%)	1.02	0.99	1.04
Total bilirubin (increasing, per 1 mg/dL)	1.99	1.11	3.59

AVR = aortic valve replacement; BMI = body mass index; BSA = body surface area; CABG = coronary artery bypass grafting; CAD = coronary artery disease; ECMO = extracorporeal membrane oxygenation; LVEF = left ventricular ejection fraction; MVr = mitral valve repair; MVR = mitral valve replacement; NSTEMI = non-ST-elevation myocardial infarction; NYHA = New York Heart Association; STEMI = ST-elevation myocardial infarction

Table 6. Competing risk regression for all-cause hospital readmission

Covariable	Hazard Ratio	95% Confidence Interval Limits	95% Confidence Interval Li
ECMO			
Not used	Ref	Ref	Ref
Intraoperative cannulation	0.90	0.33	2.51
Postoperative cannulation	0.46	0.11	2.00
Preoperative LVEF (increasing, per 1%)	0.99	0.97	1.01
Serum creatinine (increasing, per 1 mg/dL)	1.86	1.03	3.36
History of congestive heart failure	1.18	0.62	2.22
Cardiac symptoms at admission			
No symptoms	Ref	Ref	Ref
Symptoms unlikely to be ischemia	1.08	0.32	3.65
Stable angina	1.87	0.47	7.39
Unstable angina	0.58	0.17	2.01

Covariable	Hazard Ratio	95% Confidence Interval Limits	95% Confidence Interval Li
NSTEMI	1.55	0.61	3.95
STEMI	1.30	0.25	6.71
Other	0.73	0.27	2.01
Dialysis dependency	0.07	0.01	0.75

ECMO = extracorporeal membrane oxygenation; LVEF = left ventricular ejection fraction; NSTEMI = non-ST-elevation myocardial infarction; STEMI = ST-elevation myocardial infarction

Figure Legend

Figure 1. Five-year actuarial survival in patients placed on de novo mechanical circulatory support following conventional cardiac surgical procedures. A) displays survival for the entire cohort, while B) stratifies patients by highest level of support utilized

Figure 2. Five-year all-cause readmission following de novo institution of mechanical circulatory support following conventional cardiac surgical procedures