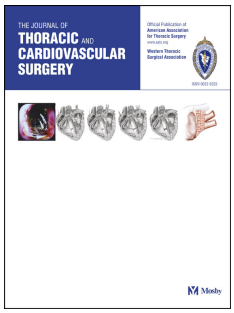

Identifying and Mitigating Risk of Post-Cardiotomy Cardiogenic Shock in Patients with Ischemic and Non-Ischemic Cardiomyopathy

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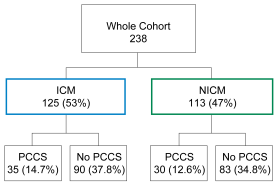
Predictors of Post-Cardiotomy Cardiogenic Shock in Ischemic and Non-Ischemic Cardiomyopathy

Methods & Results

January 2017 - 2020

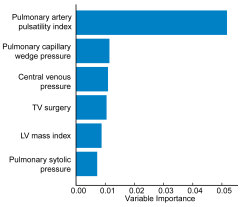
Cohort 238 patients
- EF <30% (209)
- EF <35% with at least moderately severe MR (32)

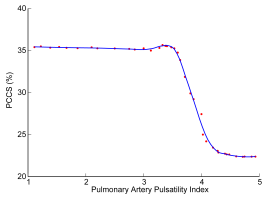
Primary outcome was PCCS, defined as need for Impella, extracorporeal membrane oxygenation, or vasoactive-inotropic score >25.



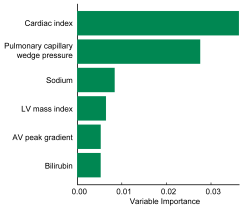
Random Forest analysis was used to identify predictors of PCCS

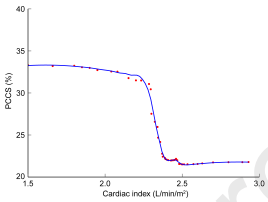
Ischemic Cardiomyopathy





Non-Ischemic Cardiomyopathy





Implications

Right heart function, measure by PAPi, is most predictive of PCCS in ICM, whereas degree of cardiac decompensation is most predictive of PCCS in NICM. This knowledge will help guide early use of mechanical circulatory support in high risk low ejection fraction patients.

AV: aortic valve, EF: Ejection fraction, ICM: Ischemic cardiomyopathy, LV: left ventricle, MR: Mitral regurgitation, NICM: Non-ischemic cardiomyopathy, PAPi: Pulmonary artery pulsatility index, PCCS: Post-cardiotomy cardiogenic shock, TV: Tricuspid valve

Identifying and Mitigating Risk of Post-Cardiotomy Cardiogenic Shock in Patients with Ischemic and Non-Ischemic Cardiomyopathy

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Word count: 3415

Glossary of Abbreviations:

ECMO: extracorporeal membrane oxygenation

EF: ejection fraction

IABP: intra-aortic balloon pump

ICM: ischemic cardiomyopathy

LVAD: left ventricular assist device

MCS: mechanical circulatory support

NICM: non-ischemic cardiomyopathy

PAPi: pulmonary artery pulsatility index

PCCS: post-cardiotomy cardiogenic shock

PCWP: pulmonary capillary wedge pressure

Central Message

Post-cardiotomy cardiogenic shock is predicted by right heart dysfunction in ischemic cardiomyopathy and by greater cardiac decompensation in non-ischemic cardiomyopathy.

Perspective Statement

Post-cardiotomy cardiogenic shock has high morbidity and mortality. Its predictors are right heart dysfunction in ischemic, and cardiac decompensation in non-ischemic cardiomyopathy. Preoperative right heart catheterization in patients with low ejection fraction will help identify patients at risk of post-cardiotomy cardiogenic shock and plan for possible temporary mechanical circulatory support.

Central Picture Legend: Top 6 predictors of post-cardiotomy cardiogenic shock in ischemic cardiomyopathy.

Abstract: 242/250 words

Objectives: To identify preoperative predictors of post-cardiotomy cardiogenic shock in patients with ischemic and non-ischemic cardiomyopathy and evaluate trajectory of postoperative ventricular function.

Methods: From 1/2017–1/2020, 238 patients with ejection fraction <30% (206/238) or 30-34% with at least moderately severe mitral regurgitation (32/238) underwent conventional cardiac surgery at Cleveland Clinic, 125 with ischemic and 113 with non-ischemic cardiomyopathy. Preoperative ejection fraction was 25±4.5%. The primary outcome was post-cardiotomy cardiogenic shock, defined as need for microaxial temporary left ventricular assist device, extracorporeal membrane oxygenation, or vasoactive-inotropic score >25. RandomForestSRC was used to identify its predictors.

Results: Post-cardiotomy cardiogenic shock occurred in 27% (65/238). Pulmonary artery pulsatility index <3.5 and pulmonary capillary wedge pressure >19 mmHg were the most important factors predictive of post-cardiotomy cardiogenic shock in ischemic cardiomyopathy. Cardiac index <2.2 $L \cdot min^{-1} \cdot m^{-2}$ and pulmonary capillary wedge pressure >21 mmHg were the most important predictive factors in non-ischemic cardiomyopathy. Operative mortality was 1.7%. Ejection fraction at 12 months post-surgery increased to 39% (CI: 35-40) in the ischemic group and 37% (CI: 35-38) in the non-ischemic cardiomyopathy group.

Conclusions: Predictors of post-cardiotomy cardiogenic shock were different in ischemic and non-ischemic cardiomyopathy. Right heart dysfunction, indicated by low pulmonary artery pulsatility index, was the most important predictor in ischemic cardiomyopathy, whereas greater degree of cardiac decompensation was the most important in nonischemic cardiomyopathy.

Therefore preoperative right heart catheterization will help identify patients with low ejection fraction that are at higher risk of post-cardiotomy cardiogenic shock.

Keywords: low ejection fraction, cardiac surgery, right heart catheterization, mechanical circulatory support

INTRODUCTION

Patients with low preoperative ejection fraction (EF) and treatable cardiac lesions have the most to gain from surgery but are at high risk of death from post-cardiotomy cardiogenic shock (PCCS), which carries mortality as high as 50% to 75%.[1–6] High-dose inotropic and vasopressor support typically are required to separate these patients from cardiopulmonary bypass and during early postoperative care; however, these drugs at high doses are toxic and lead to peripheral ischemia, tissue hypoxia, acidosis, and multiorgan failure and exacerbate myocardial dysfunction.[7] Temporary mechanical circulatory support (MCS) in this setting is beneficial for myocardial perfusion and recovery by unloading the left ventricle and normalizing cardiac output to the body while awaiting myocardial recovery. However, deploying these devices takes time and resources and may not be readily available when separating from cardiopulmonary bypass. Delay in deployment increases cardiopulmonary bypass time or leaves the patient in cardiogenic shock, which have deleterious effects downstream.

Predicting which patients are at the most risk for developing PCCS would allow earlier or planned deployment of temporary MCS, and may improve outcomes; however, these risk factors may be different between patients with ischemic cardiomyopathy (ICM) and non-ischemic cardiomyopathy (NICM). Thus, the main objective of this study was to identify the patients most at risk of PCCS in ICM and NICM so that any future MCS protocols can include these risk factors. An additional objective was to evaluate these outcomes in the contemporary era of using temporary MCS as rescue.

METHODS

Study Population

From January 1, 2017 to January 1, 2020 238 patients with left ventricular EF <30% (206/238) or EF 30-34% with at least moderately severe (3+) mitral regurgitation (32/238) underwent conventional cardiac surgery at Cleveland Clinic. Patients who underwent planned durable left ventricular assist device implant, cardiac transplantation, or congenital operations were excluded. Of the 238 patients, 125 had ICM and 113 NICM.

Patients were assigned to the ICM group if coronary artery disease was the primary driver of their disease state. In general, patients were classified as ICM when there was a severe lesion in a territory with decreased function. However, there were patients with NICM and coronary artery disease, but it was not the driver of the cardiomyopathy. The majority of the reduced function was not explained by the severity and territory of coronary artery disease for the patients in the NICM group.

*Referral for Formal MCS Evaluation and **Backup***

Patients felt to be at high risk for PCCS underwent a formal temporary MCS backup evaluation. Patients are assessed preoperatively by the advanced heart failure team for left ventricular assist device implant or transplant, and preparation is made in the operating room to have the Impella equipment available. Patients that underwent this process will be described as being in the MCS Backup group. Depending on surgeon preference and gestalt for the risk of PCCS, intraoperatively the right axillary artery is exposed and a 10 mm woven polyester graft may be sewn end to side prior to commencing cardiopulmonary bypass.[8] Once the operation is complete and the patient is being weaned from cardiopulmonary bypass, if the patient fails to separate from cardiopulmonary bypass, is hemodynamically unstable after weaning, or requires high dose inotropes and vasopressors, then temporary MCS is instituted at the discretion of the

surgeon using either extracorporeal membrane oxygenation (ECMO) or Impella. Impella 5.0/5.5 was the preferred device for patients with isolated left heart failure.

Data

Patient demographics, procedural details, and postoperative outcomes were obtained from institutional registries maintained by professional abstractors for national quality reporting. Preoperative hemodynamics data was obtained from right heart catheterization reports and from measurements recorded closest to the date of surgery for patients who had a preoperative Swan-Ganz catheter in place in the intensive care unit (ICU). Additional patient data, including results of preoperative echocardiography and catheterizations, were obtained through medical records review. The Institutional Review Board (IRB) of the Cleveland Clinic approved the study protocol and publication of data. Patient written consent for the publication of the study data was waived by the IRB given its retrospective review of data. (IRB No. 17-270, approved 3/1/2017)

In patients with ischemic heart disease, function, viability and quality of coronary targets were collected for each of the 3 main territories: left anterior descending, circumflex, and right coronary artery. Echocardiography was used to assess function with a score given based on the worst segment in that territory. The scores ranged from 0 to 4: normal (0), mild/moderate hypokinesis (1), moderately severe to severely hypokinetic (2), akinetic (3) and dyskinetic (4) (Table 2). Viability was assessed with either cardiac positron emission tomography scans or cardiac magnetic resonance imaging with gadolinium contrast. A scar score was calculated for each myocardial territory, as follows: 0 no scar, 1 small scar, 2 large scar (Supplementary Table 1). A weighted total scar score was also calculated (Supplementary Appendix 1). Coronary artery quality was assessed by coronary angiography and assigned 0 for optimal target; 1, suboptimal

target; 2, poor target, 3, no significant stenosis or patent bypass graft present (Table 2). Additional information on ischemia evaluation is detailed in Supplementary Appendix 1.

Endpoints

The primary endpoint is occurrence of PCCS, defined by fulfilling any of the following: requiring placement of Impella during surgery, instituting ECMO during or after surgery, need for continuation of preoperative ECMO, or vasoactive inotropic score of >25 (Supplementary Appendix 2) The vasoactive inotropic score is calculated by using a formula to add up the patient's vasopressor and inotropic requirements, thus describing the total amount of cardiovascular support. For example, a 100 kg patient on 10 µg/min epinephrine, 10 µg/min norepinephrine and 0.5µg/kg/min milrinone calculates to a vasoactive inotropic score of 25. (Supplementary Appendix 2) Intra-aortic balloon pump (IABP) was not included in the definition of PCCS.

Secondary endpoints include the identification of patients most at risk of PCCS in patients with ICM and NICM, evaluation of their postoperative outcomes, and longitudinal follow up of their left ventricular ejection fraction.

Data Analysis

All statistical analyses were performed using SAS statistical software and R software version 3.3.2. Categorical data are summarized by frequencies and percentages and compared using the chi-squared test. Continuous variables are summarized by mean ± standard deviation, or with equivalent 15^{th}, 50^{th} (median), and 85^{th} percentiles where data were skewed. For continuous variables, comparisons were made using the Wilcoxon rank sum test. Parametric estimates are accompanied by an asymmetric 68% confidence interval, comparable to ±1 standard error.

Random Forests

Random forest classification (randomForestsSRC) for imbalanced data was performed to assess possible nonlinear and interacting relationships between likelihood of PCCS and patient characteristics.[9] We used 5,000 trees and with 8 random variables at each split. All variables listed in Supplementary Appendix 3 were included in the analysis, without variable selection. Missing data were imputed using "on the fly" random forest imputation.[10] Variable importance was used to rank relative importance of these variables,[11] and their relationship with PCCS visualized using risk-adjusted partial-dependency plots.[12]

Longitudinal Data Analysis

The continuous repeated measurements of left ventricular EF were analyzed longitudinally across time. Nonlinear mixed-model regression (SAS PROC NLMIXED) was used to resolve a number of time phases to form a temporal decomposition model to describe the temporal trend of mean estimated left ventricular EF over time.[13] Two time-varying temporal phases were identified, an early phase and a late phase both modulating the entire longitudinal curve.

RESULTS

Population Characteristics

Mean age in the ICM and NICM groups were 66 ± 10 and 62 ± 13 years (P=.045) (Table 1). More patients with a history of myocardial infarction were in the ICM vs NICM group (64% vs 27%, P<.0001) as were patients with a history of peripheral artery disease (20% vs 10%, P=.027). History of prior cardiac operation was higher in the NICM vs ICM group (29% vs 5.6%, P<.0001). Various comorbidities were similar between groups, like history of congestive

heart failure, renal dialysis and prior stroke. Predicted risk of operative mortality for cases for which a Society of Thoracic Surgeons model is available (ICM: n=97 [78%] NICM: n=45 [40%]), was similar for ICM and NICM groups (median 4.0% vs 3.0%, respectively, *P*=.29) (Supplementary Figure 1)

Preoperative echocardiographic details

Overall mean EF was 24.6%, which was approximately normally distributed (skewness was -0.28). Mean EF in the ICM group was 24 ± 4%, and 25 ± 4% in the NICM group (*P*=.013). (Table 1) Mean preoperative left ventricular end diastolic inner diameter was 5.9 ± 0.79 cm in the ICM group and 6.1 ± 1.0 cm in the NICM group (*P*=.09). Preoperative left ventricular end diastolic inner diameter was greater than 6.5 cm in 20% (23/113) of ICM patients and 32% (33/104) of NICM patients.

Surgical components

Of 125 patients with ICM, 72 underwent isolated CABG, 31 CABG plus mitral valve surgery, 5 CABG plus tricuspid valve surgery, and 17 CABG plus mitral and tricuspid valve surgery. (Table 2) In the NICM group, CABG was performed in 34% of the 113 patients, however coronary artery disease was not the primary driver of their cardiomyopathy. The other components of surgery in the NICM group were aortic valve surgery (69%), mitral valve surgery (49%), tricuspid valve surgery (31%), aortic surgery (23%), and atrial fibrillation surgery (16%). (Table 3)

Surgical Details

Mean myocardial ischemic time was 100 ± 36 minutes and 100 ± 48 minutes in the ICM and NICM groups, respectively (*P*=.56). Mean total cardiopulmonary bypass time was 126 ± 45

minutes and 132 ± 63 minutes in the ICM and NICM groups, respectively (*P*=.85). There were 3 cases in the NICM group that underwent circulatory arrest, with a mean of 51 ± 25 minutes.

Post-cardiotomy cardiogenic shock

PCCS occurred in 35 (28%) patients in the ICM group and 30 (27%) in the NICM group (Table 4). In the ICM group, ECMO was placed in 3 patients postoperatively. In the NICM group, ECMO was placed in one patient intraoperatively and in 2 patients postoperatively. An Impella was placed in 30 patients, 18 in the ICM group and 12 in the NICM group. Eighteen patients in the ICM group and 18 in the NICM group had a post-operative vasoactive inotropic score of ≥25. Of these 36 patients, 7 met multiple criteria for fulfilling our definition of PCCS. (Figure 1) The distribution of the STS predicted risk of mortality score and development of PCCS for ICM and NICM was similar, (ICM PCCS vs non-PCCS, p=.34; NICM PCCS vs non-PCCS, p=.21) (Supplementary Figure 2).

Mechanical circulatory support

Of the 30 Impella devices used, 6 were Impella 5.5, 21 were Impella 5.0, 2 were Impella CP and 1 was an Impella LD. Twenty-eight were placed via the right axillary artery, 1 Impella 5.5 was placed via the left axillary artery, and the Impella LD was placed through a 10 mm graft off the aorta. Duration of Impella support was a median of 5.9 days (15th percentile: 3.0 days, 85th percentile 15.0 days).

70 patients with ICM and 37 patients with NICM were evaluated for temporary MCS backup preoperatively and Impella equipment was made available intraoperatively ahead of time (MCS Backup group). For the ICM group, PCCS occurred in 22/70 (31%) of those in the MCS backup group and 13/55 (24%) not in the backup group (*P*=.34). For the NICM group, PCCS

occurred in 20/37 (54%) patients in the backup group and 10/76 (13%) not in the backup group (*P*<.0001). For those in the backup group, 18/70 patients with ICM and 12/37 with NICM patients received an Impella.

In the operating room, when the cardiac index was <2.0 $L^{-1}m^{-2}$ despite high doses of inotropic support, Impella was used. However, when it was preserved but inotropic support was still high, IABP was sometimes used, particularly in patients with poor coronary artery targets. In the ICM and NICM groups, 14 patients and 7 patients had an IABP preoperatively, of which 9 and 5 were continued postoperatively; 30 patients (13%) had an IABP placed in surgery, 20 in the ICM group and 10 in the NICM group. (Table 4) Of the 30 patients with IABP placed intraoperatively, 15 met criteria for PCCS. Of the 15 patients that did not meet criteria for PCCS that had an IABP placed, 11 were in ICM patients and 4 were in NICM.

Postoperative Outcomes

Median (with 15th and 85th percentile) postoperative vasoactive inotropic score was 10 (4.7 and 25) and 12 (4.2 and 26) in the ICM and NICM groups, respectively. Median ICU length of stay was 4.2 (2.0 and 11) days in the ICM group and 4.8 (1.8 and 14) days in the NICM group. Postoperative length of stay was 11 (6.9 and 21) days in the ICM group, and 12 (7 and 25) days in the NICM group. Operative mortality was 1.7% (4/237); 1 patient in the ICM group and 3 patients in the NICM group.(Table 4) Three of the four deaths were patients who developed PCCS. Other secondary outcomes and MCS characteristics are shown in Table 4.

Predictors of Post-cardiotomy cardiogenic shock

Ischemic Cardiomyopathy Group

In the ICM group, the two most important factors predictive of PCCS were lower pulmonary artery pulsatility index (PAPi) particularly when less than 3.5, and higher pulmonary capillary wedge pressure (PCWP) above 19 mmHg. (Figure 2) The other most important factors predictive of PCCS were higher central venous pressure particularly above 8 mmHg, having tricuspid valve surgery as a surgical component of the operation, greater left ventricular mass index particularly when above 100, and higher pulmonary artery systolic pressure particularly above 45 mmHg. (Figure 2) Scar score was the 10th highest in variable importance, and was a weak negative predictor of PCCS.

Non-Ischemic Cardiomyopathy Group

In the NICM group, the two most important factors predictive of PCCS were lower preoperative cardiac index particularly when less than 2.3 $L \cdot min^{-1} \cdot m^{-2}$, and higher pulmonary capillary wedge pressure (PCWP) particularly when greater than 21 mmHg (Figure 3). The other most important factors predictive of PCCS were lower sodium particularly when less than 135 mmol/L, greater left ventricular mass index particularly when greater than 150 g/m^2, lower aortic valve peak gradient particularly when less than 10 mmHg, and higher bilirubin particularly when greater than 1 mg/dL.

Postoperative cardiac recovery

For the ICM group, left ventricular EF at 1 month, 6 months and 1 year was 32%, 36%, and 39%; in the NICM group it was 31%, 34% and 37%. For ICM and NICM, the left ventricular EF was not significantly different in early hazard phase (*P*=.74) or late phase (*P*=.77). (Figure 4). In the ICM group, for those that did and did not develop PCCS, there was a similar

increase in left ventricular EF after surgery (*P*=.48 early hazard phase and *P*=.10 late hazard phase). (Supplementary Figure 3) . In the NICM group, for those that did and did not develop PCCS, EF was higher in the late phase for the no PCCS group (*P*=.14 early hazard phase and *P*=.04 late hazard phase). (Supplementary Figure 4)

Three patients received a durable left ventricular assist device (LVAD), at 8.9, 13 and 38 months from initial operation. No patient received a heart transplant after the initial operation.

Discussion

Principal Findings

Prevalence of PCCS in our cohort of patients with low ejection fraction was high; however, a low operative mortality can be achieved with the use of early and planned MCS deployment. In the ischemic cardiomyopathy subgroup, right heart dysfunction with lower pulmonary artery pulsatility index was the most predictive of PCCS; whereas degree of heart failure decompensation measured by lower cardiac index and higher pulmonary capillary wedge pressure were the most predictive of PCCS in the non-ischemic cardiomyopathy subgroup.

Ischemic Cardiomyopathy

PAPi, an indicator of right heart function, was the most important predictor of PCCS in the ICM group at a value below 3.5. PAPi has been studied in the context of inferior wall myocardial infarction, postoperative LVADs requiring right ventricular assist device placement, primary pulmonary hypertension, and other heart failure populations.[14–18] In the Evaluation Study of Congestive Heart Failure and Pulmonary Artery Catheterization Effectiveness (ESCAPE) trial, the authors reported that PAPi was a significant predictor of death or hospitalization at 6 months, with a cutoff PAPi of 3.65.[17] Another study looking at patients with

primary pulmonary hypertension found that patients in the lowest quartile for PAPi (PAPi <3.7) had significantly lower 5 year survival.[18] These cutoff values for PAPi are close to our rapid change in probability for PAPi predicting increased risk of PCCS, but much higher than what is described in the LVAD population (1.5-2) as a predictor of needing right ventricular assist device. One reason for the difference is that in LVAD surgery, the decrease in left sided pressures is immediate whereas in patients undergoing conventional surgery, the decrease in left sided pressures can take many days. PAPi was a much better predictor of PCCS than the reported right ventricular function on echo. As the right ventricle is thin walled, the right ventricular EF is much more preload and afterload sensitive than the left ventricle. Therefore, in the setting of left ventricular dysfunction and venous pulmonary hypertension, the right ventricular contraction appearance on echocardiography is a poor indication of right ventricular function.

Non-ischemic cardiomyopathy

In the NICM group, cardiac index and PCWP were the most predictive of PCCS; right heart catheterization is routinely used in our practice prior to surgery for patients with cardiomyopathy. In patients with clinical evidence of decompensated heart failure, we tend to delay surgery in favor of Swan-directed medical treatment with diuretics and afterload reduction to optimize patients prior to surgery. In patients who would not tolerate diuretics and afterload reduction yet still have decompensated heart failure, preoperative use of IABP, Impella, and rarely ECMO may be useful. In patients who cannot achieve adequate fluid removal with diuresis, temporary MCS may be required intra-operatively.

Mechanical Circulatory Support

The goal is to be able to identify patients preoperatively at highest risk of PCCS and use these criteria for including patients in any future MCS protocols. We do not have a formal

inclusion criteria for a MCS backup protocol yet, however if a patient has the top 2 predictive factors in their respective group (eg. NICM patient with high PCWP and low CI), they will be highly considered for MCS backup.

With respect to IABP use, we do not typically place an IABP prophylactically if the patient is doing well on low dose inotropic support. Patients receiving an IABP who did not meet criteria for PCCS may have been on the margin for meeting criteria for PCCS or had poor coronary target quality.

Postoperative cardiac recovery

Longitudinal evaluation of EF after cardiac surgery showed a gradual improvement in function, suggesting that this group of patients can have substantial benefit when surgery is offered. The majority of patients in this study had a substantial degree of myocardial viability, given that 66/82 with viability studies had scar score ≤3; therefore, it would be expected to see post-operative improvement in EF. Despite there being some patients with a higher scar score, this was not shown to be an important predictor of PCCS. Our results suggest that the effect of viability on PCCS is of lower importance among this set of factors. Similar conclusions regarding the role of myocardial viability and survival were shown in a sub-study of the STICH (Surgical Treatment for Ischemic Heart Failure) trial.[19,20]

Limitations

This study is limited by its observational nature. Patients in this study underwent techniques such as the Impella back up strategy that may not be available at all hospitals performing cardiac surgery. Also, we used a new definition for PCCS, which limits comparison to other studies utilizing a different definition (Supplementary Appendix 4). IABP support alone

was not used as inclusion criteria for PCCS. This study is also limited by its short- to midterm follow up.

Conclusion

In patients with low ejection fraction, preoperative right heart function in ischemic cardiomyopathy patients, measured by PAPi, seemed to be the most predictive of PCCS. In the non-ischemic cardiomyopathy patients, high pulmonary capillary wedge pressure and low index were most predictive of PCCS, suggesting that the degree of preoperative cardiac decompensation is most important. Preoperative right heart catheterization should be obtained in patients with low ejection fraction in order to identify patients at higher risk of PCCS and plan for early use of temporary mechanical circulatory support.

Acknowledgements:

MT, ES, and EB have disclosures with the company Abiomed, which produces the Impella, discussed in this manuscript. We have minimized the bias given that the study design is observational and the conclusions are representative of the data and reported outcomes.

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Tables

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460 **Table 1: Baseline and Surgical Characteristics of the Ischemic and Non-Ischemic**

461 **Cardiomyopathy Subgroups.**

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	ICM (n=125)		NICM (n=113)		
Patient Characteristics	**N[a]**	**No. (%) or Mean ± SD**	**N[a]**	**No. (%) or Mean ± SD**	**P**
Demography					
Patient age (years)	125	66 ± 10	113	62 ± 13	.045
Male	125	111 (89)	113	89 (79)	.035
Symptoms (Preop NYHA Class)	102				.26
NYHA 1		4(3.9)		4(4.4)	
NYHA 2		42(41)		25(28)	
NYHA 3		41(40)		47(52)	
NYHA 4		15(15)	90	14(16)	
Cardiac Comorbidity					
Emergency surgery	125	1(0.80)	113	1(0.88)	.94
History of Myocardial Infarction	125	80(64)	113	31(27)	<.0001
Preop Ventricular Tachycardia or Fibrillation	125	7(5.6)	113	16(14)	.026
Prior Cardiac Operation	125	7 (5.6)	113	33 (29)	<.0001
History of chronic heart failure	125	112(90)	113	101(89)	.96
Non-cardiac comorbidity					
Endocarditis	125	0(0)	113	17(15)	<.0001
Peripheral Arterial Disease	125	25(20)	113	11(9.7)	.027
Chronic obstructive pulmonary disease	125	41(33)	113	53(47)	.026
Prior Renal Dialysis	125	5(4.0)	113	10(8.8)	.12
Prior Stroke	125	11(8.8)	113	15(13)	.27
Intubated	125	3(2.4)	113	5(4.4)	.39
STS PROM (%)[c]	97	1.0/4.0/8.0	45	1.0/3.0/7.0	.29
Preoperative Location					

Home	125	30(24)	113	38(34)	.1
Hospital Non-ICU	125	76(61)	113	59(52)	.18
ICU	125	19(15)	113	16(14)	.82
Preoperative vasopressors or inotropes					
On vasopressors prior to surgery (within 24 hours)	125	3(2.4)	113	3(2.7)	.9
On inotropes prior to surgery (within 24 hours)	125	0(0)	113	2(1.8)	.14
Echo data					
Preop left ventricular ejection fraction (%)	125	24 ± 4.4	113	25 ± 4.4	.013
Preop LVEDD (cm)	113	5.9 ± 0.79	104	6.1 ± 1.0	.088
Right Heart Catheterization					
Cardiac Index: Fick method ($L/min/m^2$)[c]	72	1.8/2.2/2.9	59	1.8/2.3/2.9	.75
Pulmonary artery Systolic Pressure (mmHg)	73	45 ± 15	62	46 ± 16	.61
Pulmonary artery Diastolic Pressure (mmHg)	73	21 ± 8.7	62	23 ± 8.6	.25
Central venous pressure (mmHg)	72	8.7 ± 5.6	62	8.5 ± 4.8	.97
Pulmonary artery pulsatility index	72	4.0 ± 3.4	62	3.8 ± 3.1	.64
Pulmonary capillary wedge pressure (mmHg)	73	19 ± 9.1	61	22 ± 7.5	.013
Surgical Characteristics					
MCS Back up Protocol	125	70(56)	113	37(33)	.00030
Impella Placed in Surgery	125	18(14)	113	12(11)	.38
Number of Surgical Components[b]	125		113		<.0001
1		63(50)		26(23)	
2		40(32)		48(42)	
3		20(16)		27(24)	
4		2(1.6)		11(9.7)	
5		0(0)		1(0.88)	

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Key: ICM: Ischemic cardiomyopathy, ICU: Intensive care unit, LVEDD: Left ventricular end diastolic diameter, MCS: mechanical circulatory support; NICM: Non-Ischemic Cardiomyopathy, NYHA: New York Heart Association, PCCS: post-cardiotomy cardiogenic shock, SD: standard deviation, STS PROM: Society of Thoracic Surgeons Predicted risk of mortality

a. Patients with data available.

b: Surgical Components contributing to the count: 1) atrial fibrillation surgery, 2) any major left ventricular procedure, 3) aortic valve repair/replacement, 4) aortic root replacement/aortic root surgery, 5) coronary artery bypass, 6) mitral valve repair/replacement, 7) tricuspid valve repair/replacement

c: 15th/50th/85th percentiles.

Surgical Components	N[a]	#(% of n)
Ischemic Cardiomyopathy group	125	
CABG only		72 (58)
CABG+MV surgery		31 (25)
CABG+TV surgery		5 (4.0)
CABG+MV+TV surgery		17 (14)
Echocardiography Evaluation	125	
Myocardial Function in LAD Territory	122	# (% of N)
Mild-moderate hypokinesia		4(3.3)
Moderately severe – severe hypokinesia		54(44)
Akinetic		61(50)
Dyskinetic		3(2.5)
Myocardial Function in LCX Territory	122	
Mild-moderate hypokinesia		11(9)
Moderately severe – severe hypokinesia		58(48)
Akinetic		51(42)
Dyskinetic		2(1.6)
Myocardial Function in RCA Territory	122	
Mild-moderate hypokinesia		7(5.7)
Moderately severe – severe hypokinesia		50(41)
Akinetic		63(52)
Dyskinetic		2(1.6)
Right heart dysfunction	124	
None		47(38)
Low Normal		15(12)
Mild		34(27)
Moderate		18(15)
Moderate-severe		8(6.5)
Severe		1(0.81)
Not documented		1(0.81)
Scar Score	**125**	**#(% of n)**
Availability of Preop MRI with Gadolinium		13 (10)

Availability of Preop cardiac PET		71 (57)
Total patients in the CABG primary procedure group with a viability study		82 (66)
Total Scar Score [b]	82	
0		25(30)
1		10(12)
2		23(28)
3		8(9.8)
4		6(7.3)
5		7(8.5)
6		3(3.7)
Coronary Angiography Data	125	**#(% of n)**
Coronary Dominance	123	
Right		104(85)
Left		12(9.8)
Co-dominant		7(5.7)
Target Vessel Evaluation in LAD Territory	123	
Optimal		77(63)
Suboptimal		36(29)
Poor		6(4.9)
Territory without significant stenosis (or patent bypass graft present)		4(3.3)
Target Vessel Evaluation in LCX Territory	123	
Optimal		75(61)
Suboptimal		28(23)
Poor		7(5.7)
Territory without significant stenosis (or patent bypass graft present)		13(11)
Target Vessel Evaluation in RCA Territory	123	
Optimal		56(46)
Suboptimal		42(34)
Poor		18(15)
Territory without significant stenosis (or patent bypass graft present)	122	7(5.7)
Complete Revascularization (all significant stenotic territories have been revascularized)		112(92)

Table 2: Surgical Components and preoperative evaluation of the Ischemic Cardiomyopathy Group

Demonstrates the main surgical components of the Ischemic Cardiomyopathy group. Also shows the evaluation of the Ischemic Cardiomyopathy group, which includes echocardiography, scar score, and coronary angiography.

Key: AV: aortic valve, CABG: coronary artery bypass graft, MV: mitral valve, TV: tricuspid valve

a: Patients with data available.

*b: Total Scar score = (LAD scar score*2) + LCX Scar score + RCA Scar score*

Table 3: Surgical Components of Non-Ischemic Cardiomyopathy Group.

Surgical Components of NICM group	113	#(% of n)
AV Surgery + CABG		17(15)
AV Surgery + Aortic		14(12)
AV Surgery		14(12)
MV surgery		11(10)
MV surgery + TV Surgery		10(8.8)
AV Surgery + MV surgery + TV surgery		7(6.2)
AV Surgery + MV surgery		6(5.3)
CABG + MV surgery +TV surgery		5(4.4)
CABG + aortic		4(3.5)
CABG + AV Surgery + MV surgery		4(3.5)
CABG + AV Surgery + MV surgery + TV surgery		4(3.5)
AV Surgery + Aortic + MV surgery		4(3.5)
AV Surgery + MV surgery + TV surgery + Aortic		4(3.5)
TV Surgery		2(1.8)
AV surgery + TV surgery		1(0.9)
AV surgery + TV surgery + Aortic		1(0.9)
AV surgery + CABG + Aortic		1(0.9)
Pericardiectomy + AV surgery + CABG		1(0.9)
Reconstruction of LV free wall rupture		1(0.9)
AV Surgery + CABG + LV aneurysm repair		1(0.9)
AV Surgery + CABG + VSD closure		1(0.9)
CABG only		0
CABG + MV surgery		0
CABG + TV surgery		0

Demonstrates the main surgical components of the Non-Ischemic Cardiomyopathy group. Surgical components that may have been performed but are not included in this list are: surgical ablation, epicardial lead placement, closure of patent foramen ovale, left atrial appendage ligation, and reoperative sternotomy

520 Key: AV: Aortic valve, CABG: coronary artery bypass grafting, LV: left ventricle, MV: mitral valve, NICM: Non-

521 Ischemic Cardiomyopathy, TV: tricuspid valve, VSD: ventricular septal defect

Table 4: Primary and Secondary Outcomes, Complications, and Mechanical Circulatory Support Characteristics

	ICM		NICM		
Complications and Outcomes	**N[a]**	**No. (%)**	**N[a]**	**No. (%)**	**P**
Primary Outcome	125		113		
Post cardiotomy cardiogenic shock (PCCS)		35(28)		30(27)	.80
VIS (Vasoactive Inotropic Score) greater than 25		18(14)		18(16)	.74
Placement of ECMO in surgery		0(0)		1(0.88)	.29
Placement of ECMO after surgery		3(2.4)		2(1.8)	.74
Placement of Impella in surgery		18(14)		12(11)	.38
Need for durable LVAD within 30 days from surgery		0 (0)		0 (0)	
Secondary Outcomes					
Stroke permanent	125	2(1.6)	113	5(4.4)	.20
Reop for bleed/tamponade	125	10(8)	113	4(3.5)	.14
Other non-cardiac reop	125	23(18)	113	18(16)	.61
Cardiac reop excluding Valve dysfunction/graft occlusion	125	2(1.6)	113	2(1.8)	.92
Renal failure requiring dialysis	120	4(3.3)	103	5(4.9)	.57
Prolonged ventilation >24 hour	125	30(24)	113	40(35)	.054
Hospital Death	125	1(0.8)	113	3(2.7)	.27
Operative mortality (in-hospital or <=30 days since procedure)	124	1(0.81)	113	3(2.7)	.27
MCS Characteristics	**N[a]**	**No. (%)**	**N[a]**	**No. (%)**	**P**
IABP					
Preop IABP Support	125	14(11)	113	7(6.2)	.17
Preop IABP continued postoperatively	14	9(64)	7	5(71)	.74
Placement of IABP in surgery	125	20(16)	113	10(8.8)	.097
ECMO					
Preop ECMO support	125	1(0.8)	113	1(0.88)	.94
Preop ECMO continued postoperatively	1	0(0)	1	0(0)	
Placement of ECMO in surgery	125	0(0)	113	1(0.88)	.29
Placement of ECMO after initial surgery	125	3(2.4)	113	2(1.8)	.74
Impella					
Preop Impella support	125	1(0.8)	113	0(0)	.34
Placement of Impella in surgery	125	18(14)	113	12(11)	.38
Placement of Impella after surgery	125	0 (0)	113	0 (0)	
Durable LVAD or Transplant					
Need for durable LVAD <6 months after index operation	125	0 (0)	113	0 (0)	

Need for durable LVAD >6 months after index operation?	125	1(0.8)	113	2(1.8)	.50
Heart Transplant after index operation?	125	0(0)	113	0 (0)	

a: Patients with data available.

Key: ECMO: extracorporeal membrane oxygenation, IABP: intra-aortic balloon pump, ICM: ischemic cardiomyopathy, LVAD: left ventricular assist device, NICM: non-ischemic cardiomyopathy, PCCS: post-cardiotomy cardiogenic shock, VIS: vasoactive inotropic score

Figure Legends

Figure 1: Predictors of Post-Cardiotomy Cardiogenic Shock in Ischemic and Non-Ischemic Cardiomyopathy. In this cohort of low ejection fraction patients, the primary outcome was post-cardiotomy cardiogenic shock (PCCS). Predictors of PCCS in ischemic and non-ischemic cardiomyopathy were found based on random forest analysis. Pulmonary artery pulsatility index was the most significant predictor of post-cardiotomy cardiogenic shock (PCCS) in the ischemic cardiomyopathy group, whereas cardiac index was the most significant predictor in the non-ischemic cardiopathy group.

Key: AV: aortic valve, EF: ejection fraction, ICM: Ischemic Cardiomyopathy, LV: left ventricle, LVEDD: left ventricular end diastolic diameter, NICM: Non-ischemic cardiomyopathy, PCCS: post-cardiotomy cardiogenic shock, TV: tricuspid valve

Figure 2: Predictors of Post-Cardiotomy Cardiogenic Shock in Patients with Ischemic Cardiomyopathy. Panel A shows the variable importance from random forest analysis of predictive factors, with pulmonary artery pulsatility index (PAPi) and pulmonary capillary wedge pressure (PCWP) as the most predictive. The random forest partial dependency plots for this analysis is shown for the top variables: B) PAPi, C) PCWP, D) central venous pressure, E) tricuspid valve (TV) surgery, F) left ventricle (LV) mass index, and G) pulmonary systolic pressure. Right heart function, as indicated by PAPi, seems to be most predictive of post-cardiotomy cardiogenic shock in patients with ischemic cardiomyopathy.

Figure 3: Predictors of Post-Cardiotomy Cardiogenic Shock in Patients with Non-Ischemic Cardiomyopathy. Panel A shows the variable importance from random forest analysis of predictive factors, with cardiac index and pulmonary capillary wedge pressure (PCWP) as the most predictive. The random forest partial dependency plots of this analysis are shown for the

top variables: B) cardiac index, C) PCWP, D) sodium, E) left ventricle (LV) mass index, F) aortic valve (AV) peak gradient, and G) bilirubin. Variables showing decompensated heart failure seem to be most predictive of post-cardiotomy cardiogenic shock in patients with non-ischemic cardiomyopathy.

Figure 4: Progression of Ejection Fraction in Patients with Ischemic and Non-Ischemic Cardiomyopathy. The lines represent unadjusted estimates of temporal trend of postoperative LV EF from available echocardiography in the ICM (blue) and NICM (green) groups, with vertical bars showing 68% confidence interval. Number of EF records and patients at risk is reported below. Ejection fraction in the ICM group at preoperative, 3 months, 6 months, 12 months, and 24 months was 24%, 34%, 36%, 39%, and 39%, respectively. Ejection fraction in the NICM group at pre-surgery, 3 months, 6 months, 12 months, and 24 months was 25%, 32%, 34%, 37%, and 40%, respectively. For both ICM and NICM, there is no overlap of the upper confidence interval of preoperative LVEF with the lower confidence interval of the postoperative LVEF, therefore we can say LVEF significantly increased ($p < .05$).

Key: EF: Ejection fraction, ICM: Ischemic cardiomyopathy, LV: Left ventricle, NICM: Non-ischemic cardiomyopathy

Supplementary Figure 1: Society of Thoracic Surgeons Predicted Risk of Mortality for Ischemic and Non-ischemic cardiomyopathy groups. This shows the cumulative distribution function of the Society of Thoracic Surgeons predicted risk of mortality stratified by ischemic cardiomyopathy (ICM) in blue and non-ischemic cardiomyopathy (NICM) in green. In the ICM group, 50% had lower than a 3.5% score. In the NICM group, 50% had lower than a 3.4% score.

Key: ICM: ischemic cardiomyopathy, NICM: non-ischemic cardiomyopathy, STS PROM: Society of Thoracic Surgeons predicted risk of mortality

Supplementary Figure 2: Society of Thoracic Surgeons Predicted risk of Mortality and Development of Post-cardiotomy Cardiogenic Shock. This is a scatter plot of the available STS PROM scores and whether the patients developed post-cardiotomy cardiogenic shock. Panel A shows the data for the ischemic cardiomyopathy patients, and panel B shows the data for the non-ischemic cardiomyopathy patients.

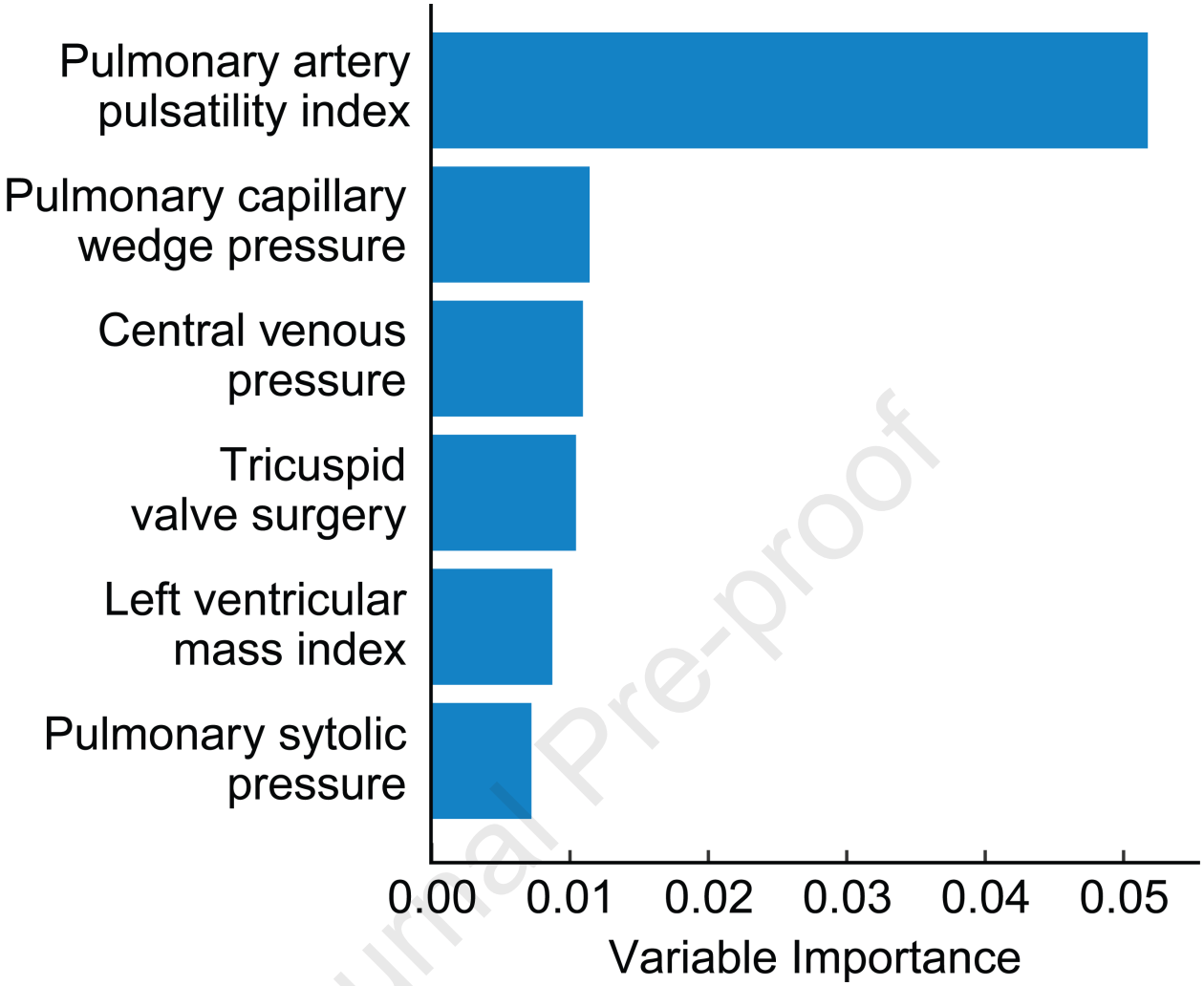
Key: ICM: ischemic cardiomyopathy, NICM: non-ischemic cardiomyopathy, PCCS: Post-cardiotomy cardiogenic shock, STS PROM: Society of Thoracic Surgeons predicted risk of mortality

Supplementary Figure 3: Progression of Ejection Fraction in patients with Ischemic Cardiomyopathy in setting of PCCS. The lines represent unadjusted estimates of temporal trend of postoperative LV EF from available echocardiography in ICM patients with no PCCS (black) and with PCCS (red) groups, with vertical bars showing 68% confidence interval. Number of EF records and patients at risk is reported below. In the ICM patients that did have PCCS, ejection fraction at pre-surgery, 3 months, 6 months, 12 months, and 24 months was 23%, 33%, 34%, 36%, and 42%, respectively. In the ICM patients that did not have PCCS, ejection fraction at pre-surgery, 3 months, 6 months, 12 months, and 24 months was 24%, 34%, 37%, 39%, and 40%, respectively. For both ICM with and without PCCS, there is no overlap of the upper confidence interval of preoperative LVEF with the lower confidence interval of the postoperative LVEF, therefore we can say LVEF significantly increased ($p < .05$).

Key: EF: Ejection fraction, ICM: Ischemic cardiomyopathy, LV: Left ventricle, PCCS: Post-cardiotomy cardiogenic shock

Supplementary Figure 4: Progression of Ejection Fraction in patients with Non-ischemic Cardiomyopathy in setting of PCCS. The lines represent unadjusted estimates of temporal trend of postoperative LV EF from available echocardiography in NICM patients with no PCCS (black) and with PCCS (red) groups, with vertical bars showing 68% confidence interval. Number of EF records and patients at risk is reported below. In the NICM patients that did have PCCS, ejection fraction at pre-surgery, 3 months, 6 months, 12 months, and 24 months was 24%, 28%, 30%, 34%, and 35%, respectively. In the NICM patients that did not have PCCS, ejection fraction at pre-surgery, 3 months, 6 months, 12 months, and 24 months was 25%, 34%, 35%, 38%, and 41%, respectively. For both NICM with and without PCCS, there is no overlap of the upper confidence interval of preoperative LVEF with the lower confidence interval of the postoperative LVEF, therefore we can say LVEF significantly increased ($p < .05$).

Key: EF: Ejection fraction, LV: Left ventricle, NICM: Non-ischemic cardiomyopathy, PCCS: Post-cardiotomy cardiogenic shock



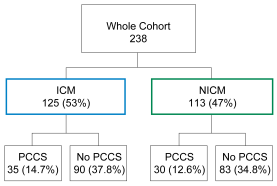
Predictors of Post-Cardiotomy Cardiogenic Shock in Ischemic and Non-Ischemic Cardiomyopathy

Methods & Results

January 2017 - 2020

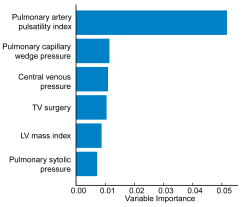
Cohort 238 patients
- EF <30% (209)
- EF <35% with at least moderately severe MR (32)

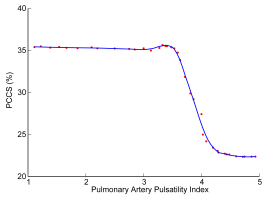
Primary outcome was PCCS, defined as need for Impella, extracorporeal membrane oxygenation, or vasoactive-inotropic score >25.



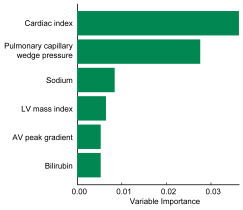
Random Forest analysis was used to identify predictors of PCCS

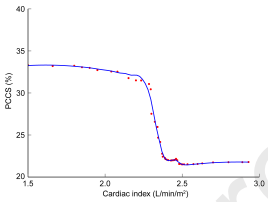
Ischemic Cardiomyopathy





Non-Ischemic Cardiomyopathy

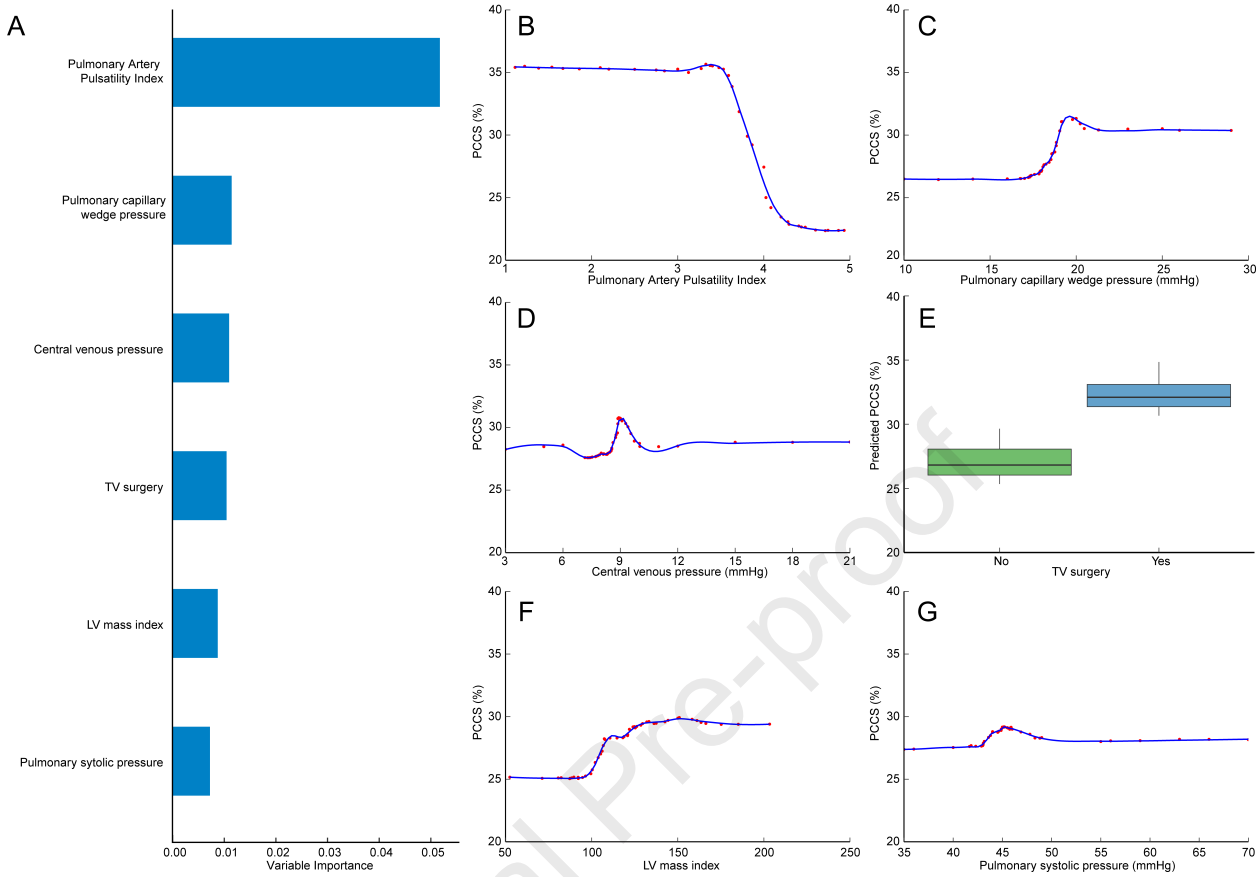


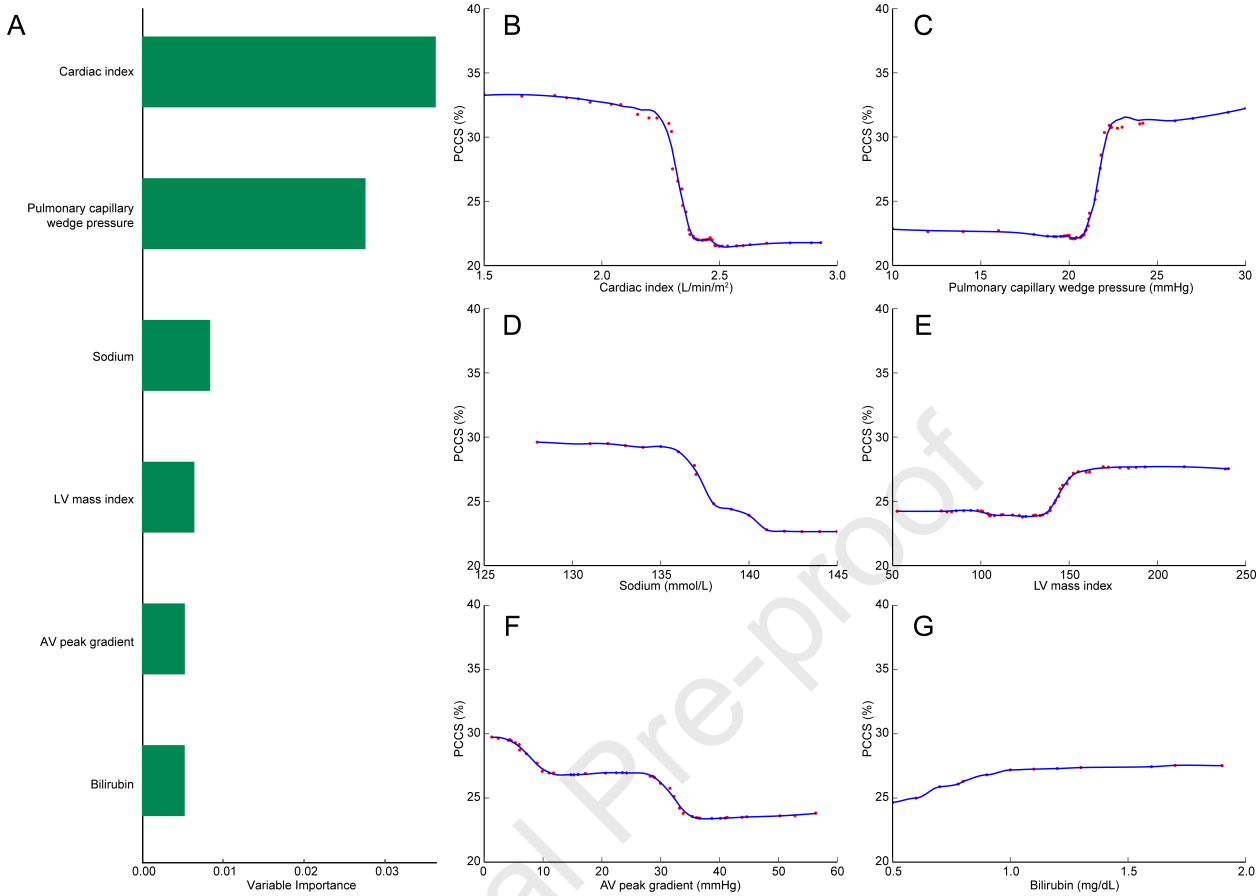


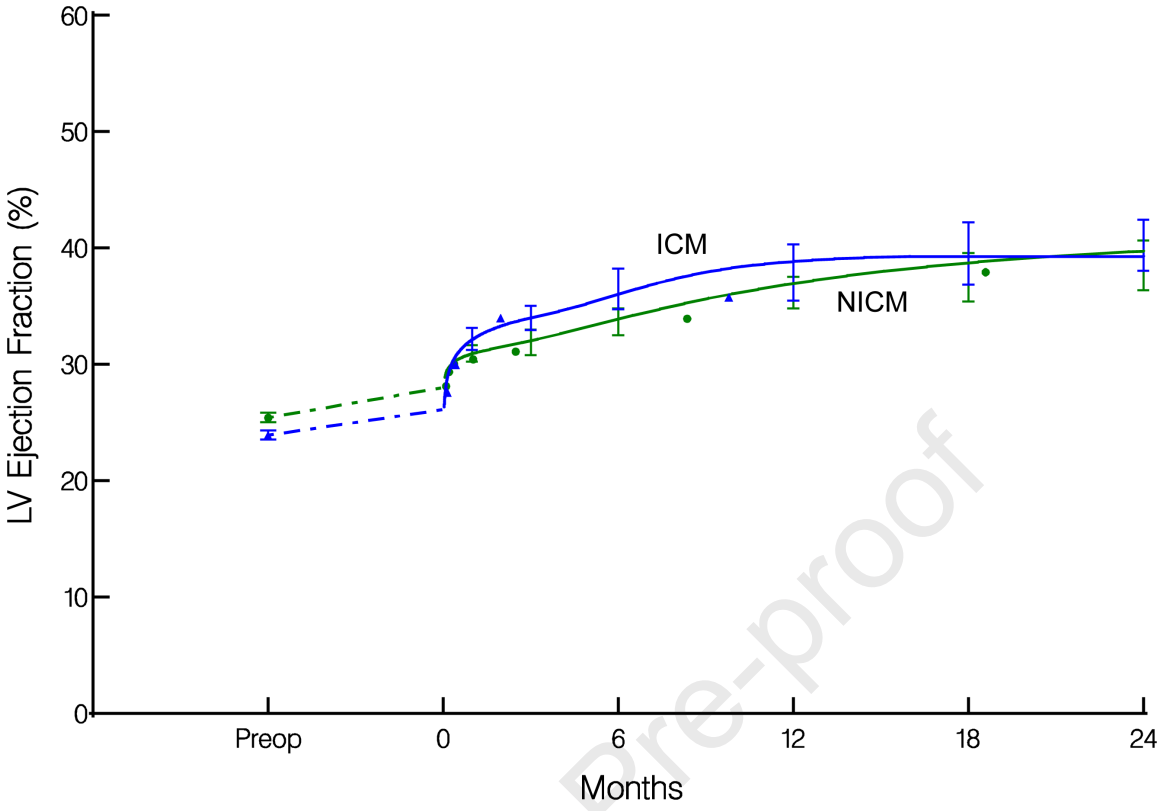
Implications

Right heart function, measure by PAPi, is most predictive of PCCS in ICM, whereas degree of cardiac decompensation is most predictive of PCCS in NICM. This knowledge will help guide early use of mechanical circulatory support in high risk low ejection fraction patients.

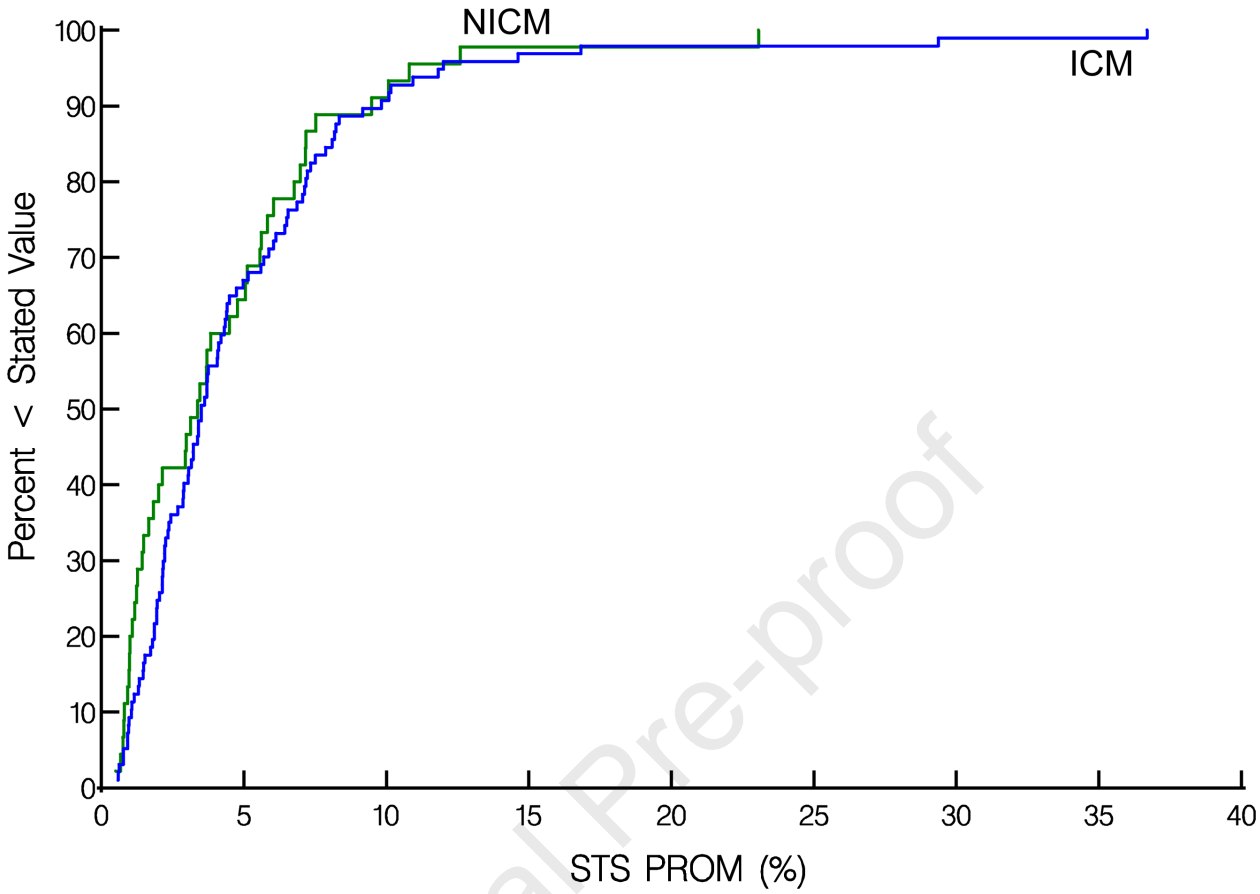
AV: aortic valve, EF: Ejection fraction, ICM: Ischemic cardiomyopathy, LV: left ventricle, MR: Mitral regurgitation, NICM: Non-ischemic cardiomyopathy, PAPi: Pulmonary artery pulsatility index, PCCS: Post-cardiotomy cardiogenic shock, TV: Tricuspid valve

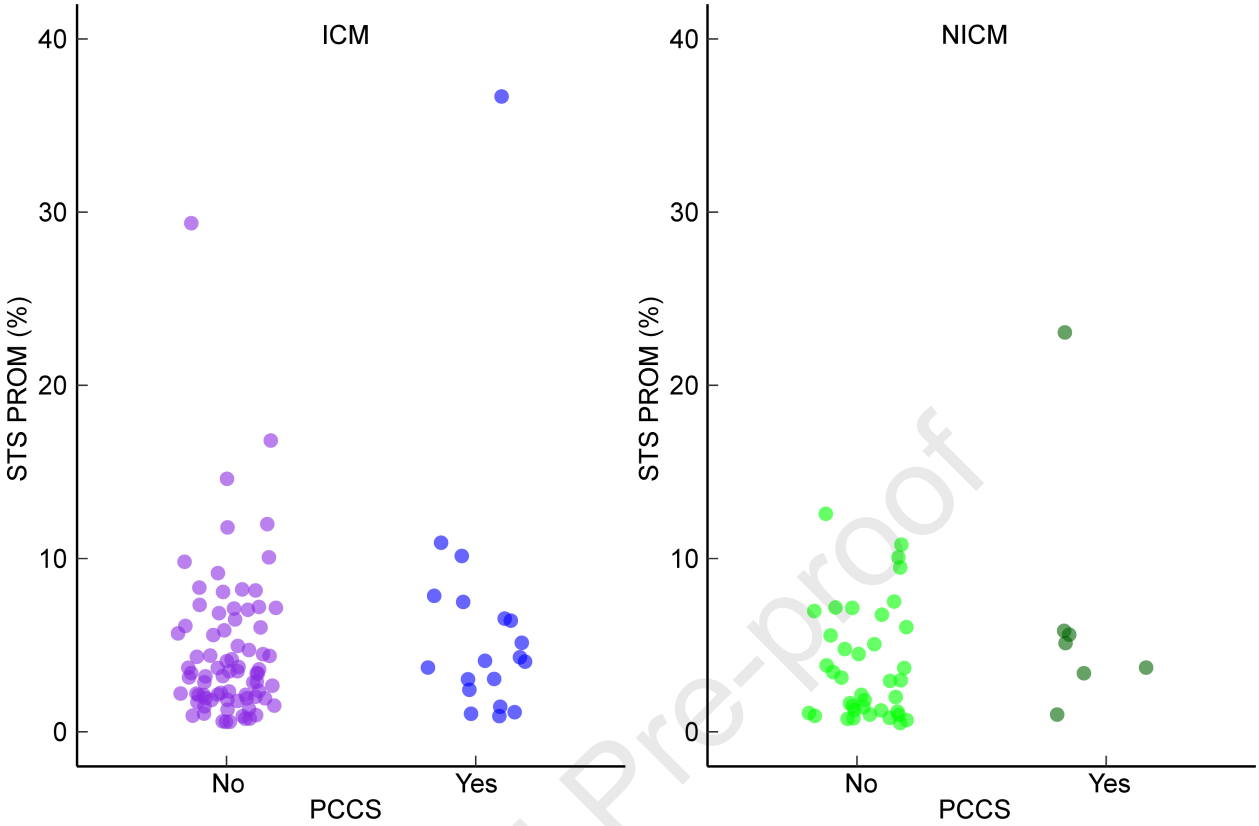


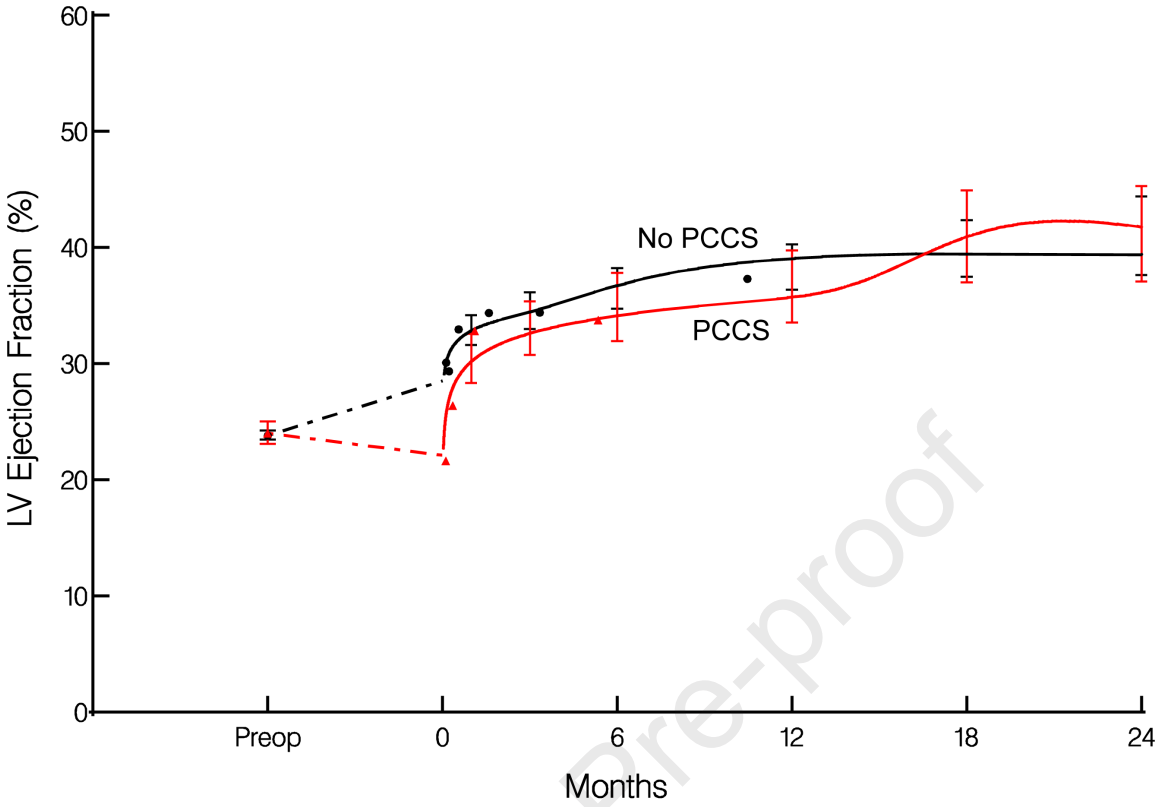




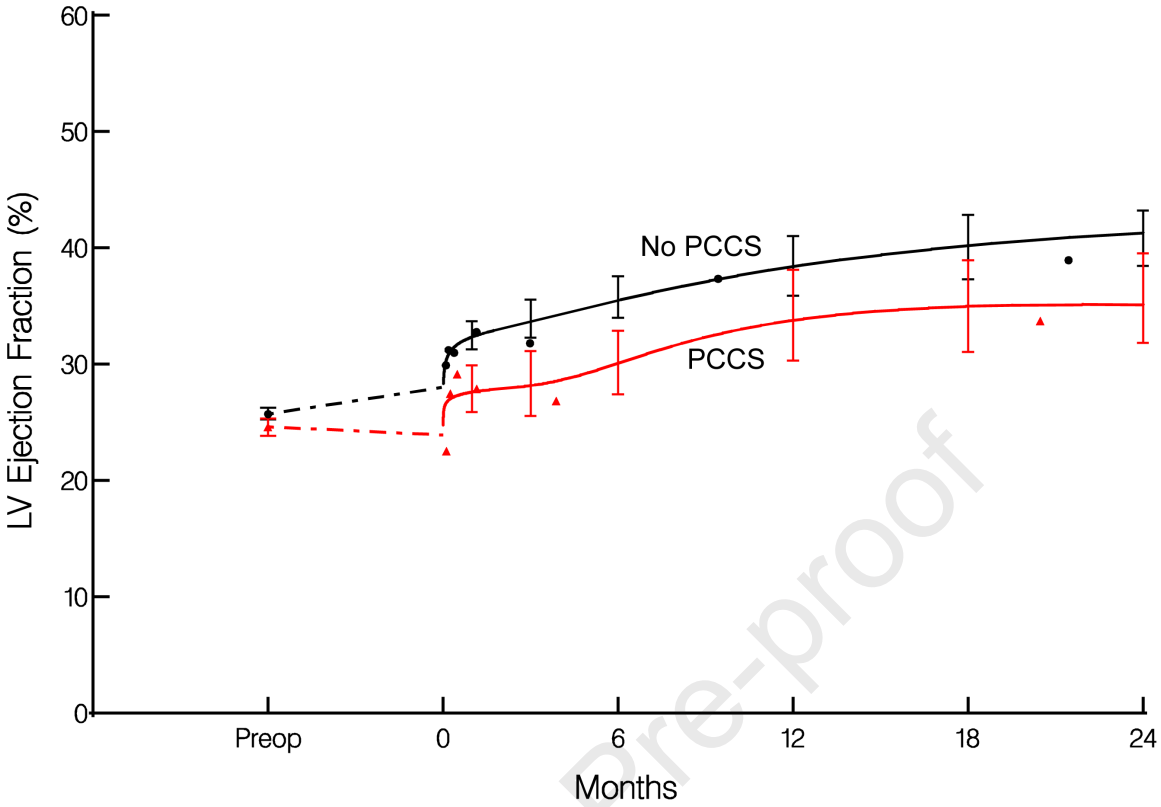
ICM	LVEF records		279		31		22		21		72
	Patients	125		60		53		47		40	
NICM	LVEF records		225		36		18		20		50
	Patients	113		52		44		40		31	







PCCS	LVEF records		90		9		7		6			13
	Patients	35		18		17		13		9		
No PCCS	LVEF records		189		22		15		15			59
	Patients	90		42		36		34		31		



PCCS	LVEF records		71		14		5		6		10
	Patients	30		17		14		12		8	
No PCCS	LVEF records		154		22		13		14		40
	Patients	83		35		30		28		23	

Supplementary Appendix

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Appendix 1: Preoperative Heart disease Evaluation

Right heart catheterization

Cardiac index (Fick method), pulmonary artery systolic and diastolic pressure, central venous pressure, and pulmonary capillary wedge pressure (PCWP) were collected if available. Pulmonary artery pulsatility index (PAPi) was calculated from the following equation:

Pulmonary pulsatility index (PAPi) = (pulmonary artery systolic pressure – pulmonary artery diastolic pressure) / Central venous pressure

Ischemic Heart Disease Evaluation

Echocardiography was used to assess the regional function of the heart. We defined the territories according to the coronary anatomy of majority of patients – right dominant circulation. The left anterior descending (LAD) territory included all anterior, anteroseptal and apex segments. The circumflex territory included all anterolateral and inferolateral segments. The right coronary artery (RCA) territory included all inferior and inferoseptal segments. The scores were as follows: 0 for normal function, 1 for mild or moderate hypokinetic, 2 for moderately severe to severely hypokinetic, 3 for akinetic, and 4 for dyskinetic. The scores were taken from the echo reports of staff cardiologist interpretations.

Coronary angiography was also examined for each patient that underwent a coronary artery bypass procedure. These studies were interpreted retrospectively by cardiothoracic surgery residents in order to assess the quality of targets for coronary artery bypass.

Again, we used the 3 main coronary artery territories (LAD, circumflex, and RCA) to break down the scores of the target vessel evaluation. For those patients that were left dominant, we designated the left posterior descending artery to correlate to the RCA territory grade, in order to keep consistency with the echo territory grading. The grades were as follows: 0 for optimal target, 1 for suboptimal target, 2 for poor target, and 3 for a territory without significant stenosis or that has a patent bypass graft present. An optimal target was a target that was adequate size with adequate runoff. A suboptimal target was defined as either a small target or a target with small area of myocardial distribution, but could still be grafted. A poor target was a defined as a target that was likely not graftable – due to a combination of being a small target and poor runoff. Complete revascularization was also noted for each case. This

was defined as all diseased territories with an artery >75% stenosis (left main >50%) having at least 1 bypass graft placed to that territory.

Viability testing

Viability testing consisted of cardiac positron emission tomography (PET) scans and cardiac magnetic resonance imaging (MRI) with gadolinium contrast. We did not include single photon emission computed tomography (SPECT), since this test cannot differentiate fixed perfusion defect from scar and hibernating myocardium. Significant scar was defined according to how the results were reported. Similar to the echocardiographic evaluation, viability was assessed according to the 3 main coronary territories – LAD, circumflex, and RCA. The scores were as follows: 0 for no scar, 1 for some scar but small, 2 for significant scar. Significant scar was defined as greater than 50% wall thickness seen on MRI, or greater than 20% scar in a territory on cardiac PET scan. Our grading system from 0-2 was used for both MRI and PET so that the data could be combined. When patients had both a PET scan and an MRI, we chose the MRI data over the PET data since MRI has better spatial resolution.[1,2] From the viability data in the 3 territories, we calculated a weighted total scar score that gave more importance to the LAD territory. The total scar score is as follows:

total scar score = (scar score in LAD territory x 2) + (scar score in the circumflex territory) + (scar score in the RCA territory).

LAD Scar Score	82	
No Scar (0)		51(62)
Small scar (1)		20(24)
Large scar (2)		11(13)
LCX Scar Score	82	
No Scar (0)		60(73)
Small scar (1)		17(21)
Large scar (2)		5(6.1)
RCA Scar Score	82	
No Scar (0)		51(62)
Small scar (1)		16(20)
Large scar (2)		15(18)

Supplementary Table 1: Scar Score by territory

Key: LAD: left anterior descending, LCx: left circumflex, RCA: right coronary artery

Appendix 2: Vasoactive inotropic score (VIS)

The VIS has been used in other studies, and it has been shown to predict morbidity and mortality after cardiac surgery.[3] The VIS formula used by many of these studies does not include phenylephrine, and so we used an expanded version of the formula that has been previously described.[3–5]

Vasoactive-Inotropic Score = dopamine dose (μg/kg/min) + dobutamine dose (μg/kg/min) + 100 x epinephrine dose (μg/ kg/ min) + 100 x norepinephrine dose (μg/kg/min) + 10 x milrinone dose (μg/kg/min) + 10,000 x vasopressin dose (U/kg/min) + 10 x phenylephrine dose (mcg/kg/min)

VIS was calculated preoperatively and immediately postoperatively. The preoperative VIS was calculated from the inotropic and vasopressor doses required in the hours before surgery. The postoperative VIS score was calculated from the vasopressor and inotropic doses during the first hour upon arrival to the cardiovascular intensive care unit.

A VIS of equal to or greater than 25 was used as the threshold for PCCS. This threshold was created after analyzing what value of VIS correctly portrayed the use of multiple moderate - high dose inotropes and vasopressors.

Appendix 3: Variables included in Random Forest analysis of imbalanced data.

Demographics

Age (years), Sex, Race (white, black, other), Body mass index (BMI, $kg \cdot m^{-2}$).

Symptoms

NYHA functional class, Myocardial infarction.

Ventricular Function.

Right ventricular systolic pressure (mmHg), LV systolic function, LV ejection fraction (%).

Valve Pathology

Presence of pulmonary regurgitation

Regurgitation grade in aortic, mitral, and tricuspid valve.

Presence of stenosis of aortic valve.

Aortic valve area (cm^2)

TV regurgitation velocity (cm/s)

LV structure

LV inner diameter in diastole (cm), LV end diastolic volume (mL).

LV Mass

Posterior wall thickness (cm), Intraventricular septal thickness (cm), LV relative wall thickness (cm), LV Mass Index (BSA) (g/m^2).

Cardiac Comorbidity

Atrial fibrillation/flutter, Ventricular tachycardia or fibrillation, Number of cardiac operations, Congestive heart failure.

Laboratory chemistries

Bilirubin (mg/dL), Creatinine (mg/dL), Blood urea nitrogen (mg/dL), Hematocrit (%), Sodium (mmol/L).

Hemodynamics

Cardiac Index ($L \cdot min^{-1} \cdot m^{-2}$) Fick method, Pulmonary diastolic pressure (mmHg), Pulmonary systolic pressure (mmHg), Central venous pressure (mmHg), Pulmonary artery pulsatility index (PAPi), Pulmonary capillary wedge pressure (mmHg).

Non-Cardiac Comorbidity

Peripheral artery disease, Hypertension, Diabetes (types-pharmacologically treated, insulin treated, non-insulin/diet treated), Chronic obstructive pulmonary disease, Smoking, Stroke.

Coronary Artery Disease

Coronary artery stenosis (left main trunk [LMT] >50%, left anterior descending system [LAD] > 50%, left circumflex system [LCX] > 50%, right coronary artery system [RCA] >50%), Total number of systems diseased greater than 50%.

Coronary Perfusion Territories

Myocardial function territory (LAD, LCX, RCA)

Target vessel evaluation territory (LAD, LCX, RCA)

Scar score

Scar score= (viab_lad*2) + viab_lcx + viab_rca
Where-

Maximum mri_lad or pet_lad, if both available take mri_lad (viab_lad)
Maximum mri_lcx or pet_lcx, if both available take mri_lcx (viab_lcx)
Maximum mri_rca or pet_rca, if both available take mri_rca (viab_rca)

Etiology (cardiomyopathy)

Ischemic cardiomyopathy

Concomitant Procedure

CABG only, Any ITA graft.

Aortic valve surgery, Mitral valve repair, Mitral valve replacement, Tricuspid valve surgery,

Atrial fibrillation surgery.

Number of surgical components, created with the following procedures:

1. Coronary artery bypass
2. Aortic valve repair or aortic valve replacement
3. Aortic root replacement/aortic root surgery
4. Mitral valve repair/replacement
5. Tricuspid valve repair/ Tricuspid valve replacement
6. Atrial fibrillation surgery
7. Any major left ventricular procedure

Preoperative support

No support, Intra-aortic balloon pump (IABP)

Preoperative location

Home, hospital floor, intensive care unit (ICU).

Experience

Date of Surgery

Appendix 4: Post-cardiotomy Cardiogenic Shock Definition

The definition of post-cardiotomy cardiogenic shock (PCCS) in the literature is quite variable, and terms such as low cardiac output syndrome and PCCS seem to be used interchangeably. Cardiogenic shock is traditionally defined as hypotension (systolic blood pressure <90 mmHg) despite adequate cardiac filling, with signs of hypoperfusion.[6–8] Studies have used this definition in defining post-cardiotomy cardiogenic shock (PCCS), with additional inclusion criteria such as the inability to wean from cardiopulmonary bypass despite maximal pharmacologic and IABP support.[9] Another definition of PCCS is the need for any mechanical circulatory support or inotropic support for greater than 30 minutes in the ICU.[10] Furthermore, refractory PCCS has been defined as hypoperfusion despite optimal volume loading, vasoactive medical support, and IABP.[6] Given the ambiguity of the definition of PCCS, we chose to define PCCS in a way that reflected the level of intensity of the pharmacologic and mechanical support. We chose to have one of the criteria for PCCS to be insertion of an Impella or ECMO since these are 2 of the highest levels of mechanical support, with the ability to either fully support the LV (Impella) or give biventricular support (ECMO). We did not include placement of an IABP in our definition of PCCS, as it only provides about 0.5 L/min of support, a fraction of what is provided by Impella and ECMO devices.[11] We also chose to use a vasoactive inotropic score threshold as an additional inclusion criteria for PCCS, which has not been described before to the authors' knowledge. We sought influence from prior definitions of PCCS that were characterized by the use of multiple high dose inotropes, or maximal pharmacologic support. We sought to quantify these prior definitions with a score that reflects the clinical situation appropriately. After analyzing the different vasoactive inotropic scores, we decided a

threshold of 25 properly reflected patients on multiple vasopressors and inotropes at moderate to high doses. 65 of the 66 patients that developed PCCS were on inotropic support; therefore, we felt that a high VIS was more likely to be reflective of a low cardiac output state rather than a vasoplegic state, especially in the context of this population's low preoperative ejection fraction.

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