# RESEARCH

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# Evaluation of hemolysis in patients supported with Impella 5.5: a single center experience



## Abstract

**Background** Hemolysis, variably defined in mechanical circulatory support (MCS), is understudied in percutaneous left ventricular assist devices. We characterize hemolytic sequelae of Impella 5.5-supported patients in the largest series to date.

**Methods** All Impella 5.5 patients at our center from 2020 to 2023 were identified (n = 169) and retrospectively reviewed. Patients with a plasma free hemoglobin (PfHb) recorded (and not previously elevated) were included (n = 123). The top (high hemolysis [HH], n = 26) and bottom (low hemolysis [LH], n = 25) quintiles were categorized based on PfHb levels. Analysis between groups identified factors associated with hemolysis.

**Results** HH patients had higher admission SCAI stages (p = 0.008), more Impella 5.5 days (23.5 v 10.0, p = 0.001), more additional MCS (16/26 [61.5%] v 6/25 [24.0%], p = 0.015), and more transfusions of packed red blood cells (12.5 v 4.0, p = 0.001), fresh frozen plasma (2.5 v 0.0, p = 0.033), and platelets (3.0 v 0.0, p = 0.002). Logistic regression identified additional MCS (OR 10.82, p = 0.004) and more Impella days (OR 1.13 p = 0.006) as hemolysis risk factors. Eleven (44%) LH and 19/26 (73%) HH patients died, with no significant differences between postoperative complications. Compared with those who died, HH survivors had fewer platelet transfusions (2.0 vs. 5.0, p = 0.01) and less PfHb elevation days (3.0 v 6.0, p = 0.007).

**Conclusions** Hemolysis in this high-risk cohort has a poor prognosis. HH patients spent more days on Impella 5.5, needed more MCS, and required more blood product transfusions.

Keywords Hemolysis, Percutaneous LVAD, Blood transfusions, Mechanical circulatory support, Impella 5.5

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## Background

Hemolysis, defined as the lysis of circulating red blood cells (RBCs), is associated with mortality and poor outcomes [1, 2]. A low level of hemolysis exists by default in patients on mechanical circulatory support (MCS) when mechanical injury is incurred to RBCs [1], with causative factors comprised of shear stress, flow acceleration, and RBC contact with device surfaces [2]. There is no universally accepted algorithm or definition to establish clinically significant hemolysis in the setting of MCS [1]. Furthermore, hemolysis is particularly understudied in percutaneous left ventricular assist devices (LVADs).

Studies and guidelines have previously used various laboratory markers in attempts to define hemolysis, which include plasma free hemoglobin (PfHb), lactate dehydrogenase (LDH), haptoglobin, bilirubin, and hemoglobinuria. Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) guidelines have suggested that PfHb > 20 and LDH > 2.5 times the normal value are indicative of hemolysis [1, 3]. Other studies have suggested that a slightly higher level of PfHb (>40), with the addition of either LDH>2.5 times normal, hemoglobinuria, or clinical signs such as anemia in the absence of active bleeding or renal failure would appropriately define hemolysis on MCS [4-8]. Of note, LDH, also an inflammatory marker, is known to be nonspecific and has been thought to be an unreliable definer of hemolysis [2, 9].

In recent years, certain characteristics that could contribute to hemolytic events in percutaneous devices have been recognized, for example pump malfunction or thrombosis, positional problems (triggering "suction alarms"), and insufficient preload [2, 3, 6, 10]. A consensus statement of the MCS academic research consortium published in 2020 categorized hemolytic events into "major" and "minor," using some of these abovementioned mechanical characteristics but still employing the previous INTERMACS reported PfHb level > 20 or LDH > 2.5x normal as a qualifying criteria for an "adverse event." [3].

One study, with hemolysis defined as PfHb > 40, aimed to examine the predictive value of these INTER-MACS markers among cardiogenic shock patients receiving an Impella device (a percutaneous LVAD manufactured by Abiomed, Danvers, MA) and found that while an increase in delta PfHb was highly predictive of hemolysis, an increase in delta LDH was not [9]. Of note, US Food and Drug Administration (FDA)approved study protocol definitions of hemolysis for percutaneous MCS devices have specifically required PfHb > 40 to be recorded at two different points in time [7, 8, 11–13]. Notably, medical device companies benchmark test products on an FDA-approved model that does not utilize PfHb as there is no way to incorporate a kidney into the testing circuit (Figure S1) [14, 15]. This model employs Modified Index of Hemolysis (MIH), which represents rate of blood damage over time, as an alternative (Figure S2) [14, 15]. This imperfection of the device approval model makes a theoretical PfHb "cut-off value" for hemolysis difficult to ascertain.

Despite poor consensus on the definition of clinically significant hemolysis in MCS, we aim to study this complication in a real-world, clinically relevant manner in a series of patients supported with the Impella 5.5 percutaneous LVAD (Abiomed; Danvers, MA), which, to our knowledge, has not yet been reported. In the largest series to date, we characterize hemolytic sequelae of Impella 5.5-supported patients.

## Methods

This study was approved by the Institutional Review Board of the University of Southern California (IRB # HS-23-00521).

## Study design and patients

All consecutive Impella 5.5 patients at our center from 2020 to 2023 were identified (n = 169) and retrospectively reviewed. Any patient with a PfHb recorded during the Impella 5.5 run (and not elevated prior to device placement) was included (n = 123). From a practical standpoint, we were challenged by the fact that the bottom-most range of lab values for PfHb was "<30," and therefore we do not have the actual value for a significant number of patients but know that the value is < 30. Each patient's highest recorded PfHb while on Impella 5.5 (Fig. 1) was used to categorize the cohort into top (high hemolysis [HH], n = 26) and bottom (low hemolysis [LH], n = 25) quintiles (Fig. 2).

Analysis between groups was performed to identify factors associated with hemolysis. The HH group was then analyzed for factors associated with death versus survival. Outcomes of interest included days on Impella 5.5, blood transfusion, stroke, vascular complication (defined as operative vascular intervention), new renal replacement therapy (RRT), intensive care unit (ICU) days, admission outcomes, and 30-day mortality.

## Statistical analysis

Categorical variables are summarized as count (percent) and compared using Chi-square or Fisher's exact tests. Numerical variables are summarized as median (interquartile range) and compared using Wilcoxon rank-sum tests. Multivariable logistic regression identified risk factors for hemolysis. The Kaplan-Meier



Highest Plasma Free Hemoglobin (PfHb) of Included Patients

**Fig. 1** Violin plot depicting distribution of highest plasma free hemoglobin (PfHb) of included patients. The box plot within shows the median (60, solid middle line) and interquartile range (30–100, box ends) as well as outliers (black dots). For purposes of creating the figure, all values of "<30" were converted to 30

method was used to estimate survival. Statistical significance was prespecified at alpha level < 0.05. Analysis was performed in R version 4.2.3 (R studio version 1.1.456).

## Results

## **Preoperative characteristics**

Baseline characteristics of included patients are summarized in Table 1. The cohort was 82.4% (42/51) male and the median age was 61.0 (50.0–67.0). There was no significant difference in etiology of heart failure between HH and LH patients (p = 1.00). HH patients presented with significantly higher admission SCAI stages (p = 0.008). Otherwise, there was no significant difference in preoperative risk factors between groups. Six patients (11.8%) had an Impella 5.5 placed at an outside hospital prior to transfer to our center.

## Postoperative factors and complications

The majority of patients in both groups had the device placed in the right axillary artery (LH [84.0% (21/25)] versus HH [92.3% (24/26)], p = 0.103). HH patients had significantly more Impella 5.5 days (23.5 versus 10.0, p = 0.001) and significantly more additional MCS

(defined as concurrent extracorporeal membrane oxygenation or percutaneous right ventricular assist device) in place (16/26 [61.5%] versus 6/25 [24.0%], p = 0.015). The six LH patients who required additional MCS were on VA ECMO. The breakdown of additional MCS for HH patients is as follows: VA ECMO (5/26 [19.2%]), percutaneous OxyRVAD (6/26 [23.1%]), VA ECMO converted to OxyRVAD (3/26 [11.5%]), and Impella RP (2/26 [7.7%]). Furthermore, the HH cohort spent significantly more days on additional MCS (4.00 [0.00, 15.25]) than the LH cohort (0.00 [ (0.00, 2.00]) (p = 0.005). HH patients additionally had significantly more transfusions of packed RBCs (12.5 versus 4.0, p = 0.001), fresh frozen plasma (2.5 versus 0.0, p = 0.033), and platelets (3.0 versus 0.0, p = 0.002). There was no significant difference between groups regarding new RRT, operative vascular complications, or strokes. Because incidence of death was high and because many patients did not require any RRT, the number to report for renal recovery (including those on preoperative RRT and those newly on postoperative RRT) is low. The renal recovery rate (if applicable) in each group was 12.5% (1/8) in the LH cohort and 11.1% (2/18) in the HH cohort. Multivariable logistic



Fig. 2 Allocation of high hemolysis (HH) and low hemolysis (LH) groups

regression identified the presence of additional MCS (OR 10.82, p = 0.004) and increased Impella days (OR 1.13 p = 0.006) as risk factors for hemolysis.

## **Outcomes and survival**

There was no statistically significant difference between HH and LH duration (days) of survival after Impella 5.5 placement (30.5 [14.5, 82.8] and 47 [12, 416] respectively) or 30-day survival (42.3% [11/26] and 44.0% [11/25] respectively). With regard to cardiac outcomes, 11/25 (44.0%) LH patients and 19/26 (73.1%) HH patients died, two (8.0%) LH patients transitioned to durable VAD, five patients were transplanted from each cohort (LH [20.0%] versus HH [19.2%]), and 7/25 (28.0%) LH patients recovered. There was no statistically significant difference between cohorts across these outcomes (p = 0.075). More LH patients (14/25 [56.0%]) than HH patients (7/26 [26.9%]) survived the admission, showing a trend toward significance (p = 0.068).

The Kaplan-Meier survival estimate (95% CI) at 1 month for HH versus LH groups was 50.0% (34.0 – 73.4%) and 60.0% (43.6 -82.6%) respectively, and 26.4% (13.8 – 50.6%) and 60.0% (43.6 -82.6%) respectively at 6 months (p = 0.1, Fig. 3).

## High hemolysis sub-analysis

Finally, the HH group was analyzed for factors associated with death versus survival (Table 2). Median Impella 5.5 days to peak PfHb in this cohort was 8.5 (1.25, 19.25) with no significant difference between survivors and those who died. HH group survivors were found to have significantly fewer platelet transfusions (2.0 vs. 5.0, p = 0.01), lower bilirubin (1.20 vs. 5.40, p = 0.003) and less days of PfHb elevation (defined as PfHb > 30, 3.0 v 6.0, p = 0.007), compared to those who died.

## Discussion

We aimed to better characterize the complex complication of hemolysis in a real-world series of patients supported with the Impella 5.5 percutaneous LVAD, which is unprecedented.

To provide insight into MCS and hemolysis management at our center, it is our practice to determine ECMO and Impella flows based on body surface area for a cardiac index of 2.2–2.4, unless a lower level of support is clinically indicated. In someone with suspected hemolysis, there was a step-wise protocol for troubleshooting. Device position was checked using radiography and echocardiogram (TTE or TEE if necessary), and would be promptly adjusted if found to be malpositioned, resulting in an improvement of

## Table 1 Preoperative and postoperative comparison of high hemolysis and low hemolysis cohorts

Patient Characteristics   set of the se		Total (N=51)	LH Group (Bottom 20%, N=25)	HH Group (Top 20%, <i>N</i> = 26)	<i>p</i> value
Age (mode)64.00 (%0.00, %0.00)88.0 (\$0.50, 63.75)0.508Gender (%)9(17.6)5 (20.0)4 (15.4)98.0Male42 (82.4)20 (80.0)22 (44.0)0.8373Body Surface Area (med)an (10R)1.85 (18.3.2.09)1.95 (18.3.2.09)1.95 (18.3.2.09)1.95 (18.3.2.09)History of moloing (%)1.85 (18.3.2.09)1.45 (5.0)1.45 (5.0)1.45 (5.0)Body Surface Area (med)an (10R)1.85 (18.3.2.09)1.45 (5.0)1.45 (5.0)1.45 (5.0)Body Surface Area (med)an (10R)2.85 (5.0)1.45 (5.0)1.45 (5.0)1.45 (5.0)Body Surface Area (med)an (10R)28 (45.1)1.46 (5.0)1.45 (5.0)1.25 (5.0)Non-Schemic28 (45.1)1.46 (5.0)1.41 (5.0)1.41 (5.0)1.41 (5.0)Amission SCA15age (%)1.41 (4.0)1.45 (5.0)1.45 (5.0)1.45 (5.0)1.45 (5.0)Amission SCA15age (%)1.41 (4.7,5)8.13 (5.0)7.20 (7.7,7)1.5 (5.1) (7.2,0)0.01 (5.0, 27.0)1.45 (5.0)0.01 (5.0, 27.0)1.45 (5.0)0.01 (5.0, 27.0)1.45 (5.0)0.01 (5.0, 27.0)1.45 (5.0)0.01 (5.0, 27.0)1.45 (5.0)0.02 (5.0, 27.0)1.65 (1.2, 20.0) (5.0, 27.0)1.65 (1.2, 20.0) (5.0, 27.0)1.65 (1.2, 20.0) (5.0, 27.0)1.65 (1.2, 20.0) (5.0, 27.0)1.65 (1.2, 20.0) (5.0, 27.0)1.65 (5.0, 20.0)0.23 (5.0, 20.0)1.23 (5.0)1.23 (5.0)1.23 (5.0)1.23 (5.0)1.23 (5.0)1.23 (5.0)1.23 (5.0)1.23 (5.0)1.23 (5.0)1.23 (5.0)1.23 (5.0)1.23 (5.0)1.23 (5.0)<	Patient Characteristics				
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Non-lischemic23 (45.1)11 (44.0)12 (46.2)0.701Impella S.S placed at OSH (%)6 (11.8)2 (8.0)2 (15.4)0.701Admission SCAI Stage (%)3 (5.9)0 (0.0)3 (11.5)5B6 (11.8)4 (16.0)7 (26.9)1.72C20 (9.2)1 3 (52.0)7 (26.9)1.72D1 4 (27.5)8 (32.0)8 (30.8)1.72Preoperative election fraction (%) (median [0.8])1.50 (9.4)1.10 (0.85, 1.45)1.65 (1.12, 2.40)Preoperative election fraction (%) (median [0.8])2.00 (15.0, 300.0)2.000 (15.0, 300.0)9.00 (50.0, 1.20)Preoperative election fraction (%) (median [0.8])3.23 (37.6, 5.77)4.10 (8.90, 76.00)9.00 (50.0, 1.42)3.72Central venopus pressure9.00 (50.0, 1.100)7.00 (50.0, 0.100)7.00 (50.0, 0.120)7.00 (50.0, 0.11	Ischemic	28 (54.9)	14 (56.0)	14 (53.8)	
Impella SS placed at OSH (%)6(11.8)2(80)4(15.4)0.701Admission SCAI Stage (%)5(5.9)0(0.0)3 (11.5)5A5(5.9)0(0.0)3 (15.7)5B6(11.8)4 (16.0)2 (7.7)5C13 (52.0)13 (52.0)6 (23.1)5Preoperative Ref (%)15 (23.4)4 (16.0)11 (4.2.3)0.079Preoperative lector factor (%) (median IIQR)2000 (15.00, 20.00)20.00 (15.00, 27.73)22.50 (15.00, 30.00)0.333Final preoperative lector factor (%) (median IIQR)7.300 (65.00, 78.00)7.000 (64.00, 82.00)0.700Preoperative lector factor (%) (median IIQR)7.000 (50.0, 17.00)7.000 (64.00, 82.00)0.700Preoperative lector factor (%) (median IIQR)7.000 (50.0, 17.00)7.000 (64.00, 82.00)0.700Preoperative lector (median IIQR)4.03 (37.6, 5.77)4.16 (37.0, 5.92)4.27 (38.0, 5.27)0.700Impella S5 Indication15 (27.4)8 (32.0)7 (26.9)1.5001.500Post-Cardiotomy10 (19.6)5 (20.00)7 (26.9)1.5001.500Post-Cardiotomy10 (19.6)2 (8.0)0.0001.5001.500Post-Cardiotomy10 (19.6)2 (8.0)0.0001.5001.500Post-Cardiotomy2 (3.9)2 (8.0)0.0001.5001.500Post-Cardiotomy2 (3.9)0.000,0.000.000,0.001.5000.500Post-Cardiotomy2 (3.9)0.000,0.000.000,0.000.000,0.000.	Non-ischemic	23 (45.1)	11 (44.0)	12 (46.2)	
Admission SCAI Stage (%)   0.000   3 (15.9)   0 (0.0)   3 (11.5)   8     A   3 (5.9)   0 (0.0)   3 (11.5)   3 (11.5)   5     B   20 (39.2)   13 (52.0)   7 (26.9)   5     D   14 (27.5)   8 (32.0)   6 (23.1)   5     F   8 (15.7)   0 (0.0)   8 (30.8)   5     Preoperative ejection fraction (%) (median [10,8)   1.20 (1.00.2.00)   1.10 (0.55.1.45)   1.65 (1.12.2.40)   0.033     Final preoperative lactate (median [10,8)   1.20 (1.00.2.00)   7.400 (69.00.76.00)   7.000 (64.00.82.00)   0.750     Gentral venous pressure   900 (5.00, 74.00   7.000 (54.00, 75.00)   9.00 (6.00, 14.25)   0.325     Cardiac output   1.5 (29.4)   8 (32.0)   7 (26.9)   0.228     Prior Impella Camplication   10 (19.6)   5 (20.0)   7 (26.9)   0.00     Cardiac output   1.5 (29.4)   8 (32.0)   7 (26.9)   0.00     Chif Exacerbation   1.0 (19.6)   5 (20.0)   7 (26.9)   1.20     Posta Cardiotomy   0 (19	Impella 5.5 placed at OSH (%)	6 (11.8)	2 (8.0)	4 (15.4)	0.701
A   3 (5.9)   0 (0.0)   3 (11.5)     B   6 (11.8)   4 (16.0)   2 (7.7)     C   20 (39.2)   13 (52.0)   7 (26.9)     D   14 (27.5)   8 (32.0)   6 (23.1)     F   8 (15.7)   0 (0.0)   8 (30.8)     Preoperative election fraction (%) (median (IQR))   20.00 (15.00, 30.00)   20.00 (15.00, 27.75)   22.50 (15.00, 30.00)   0.353     Final preoperative hemodynamics (median (IQR))   20.00 (15.00, 74.00)   7.00 (64.	Admission SCAI Stage (%)				0.008
B   6 (11.8)   4 (16.0)   2 (7.7)     C   20 (39.2)   13 (52.0)   7 (26.9)     D   14 (27.5)   8 (32.0)   6 (32.1)     Preoperative RRT (%)   8 (15.7)   0 (0.0)   8 (36.8)     Preoperative ejection fraction (%) (median (IQR))   1.20 (1.00, 2.00)   1.10 (0.85, 1.45)   1.65 (1.12, 2.40)   0.353     Final preoperative lactate (median (IQR))   1.20 (1.00, 2.00)   7.400 (69.00, 76:00)   7.000 (64.00, 82.00)   0.750     Gentral venous pressure   9.00 (5.00, 11.00)   7.00 (5.00, 75.00)   9.00 (6.00, 14.25)   0.325     Cardiac output   4.23 (3.76, 5.77)   4.16 (3.70, 5.92)   4.27 (3.80, 5.27)   0.750     Cardiac output   15 (29.4)   8 (32.0)   7 (26.9)   0.228     Cardiaction   13 (25.5)   6 (20.0)   7 (26.9)   1.010     Post-Cardiotomy   9 (17.6)   2 (8.0)   0 (0.0)   2.27.7     Postagrative Factors, Complication, and Outcomes   1.400 (6.00, 15.00)   2.35 (6.5.0)   0.017     Acter MI   13 (25.9)   0 (0.0)   2.27.7   1.28 (1.0)<	A	3 (5.9)	0 (0.0)	3 (11.5)	
C   20 (39.2)   13 (52.0)   7 (26.9)     D   14 (27.5)   8 (32.0)   6 (23.1)     Feoperative elaction (%0) (median [IOR))   15 (29.4)   4 (16.0)   11 (42.3)   0.079     Preoperative elaction (%0) (median [IOR))   20.00 (15.00, 30.00   20.00 (15.00, 27.50)   25.50 (15.00, 30.00   0.333     Final preoperative lactatic (median [IOR))   1.20 (1.00, 2.00)   1.10 (0.85, 1.45)   1.65 (1.12, 2.40)   0.333     Final preoperative lactatic (median [IOR))   2.00 (15.00, 17.00)   7.00.0 (64.00, 82.00)   0.70.0 (50.0, 11.00)   7.00.0 (60.0, 42.00)   0.70.0 (50.0, 11.00)   7.00.0 (64.00, 82.00)   0.70.0 (50.0, 11.00)   7.00.0 (64.00, 82.00)   0.70.0 (50.0, 11.00)   7.00.0 (64.00, 82.00)   0.70.0 (50.0, 11.00)   7.00.0 (64.00, 82.00)   0.70.0 (50.0, 11.00)   7.00.0 (64.00, 82.00)   0.70.0 (50.0, 11.00)   7.00.0 (64.00, 82.00)   0.75.0 (50.0, 11.00)   7.00.0 (64.00, 82.00)   0.75.0 (50.0, 11.00)   7.00.0 (64.00, 82.00)   7.00.0 (64.00, 82.00)   7.00.0 (64.00, 82.00)   7.00.0 (64.00, 82.00)   7.00.0 (64.00, 82.00)   7.00.0 (64.00, 82.00)   7.00.0 (64.00, 82.00)   7.00.0 (50.0, 11.00)   7.00.0 (60.0, 15.00)   7.00.0 (60.0, 15.00)   7.00.0 (60.0	В	6 (11.8)	4 (16.0)	2 (7.7)	
D   14 (27.5)   8 (32.0)   6 (23.1)     E   8 (15.7)   0 (0.0)   8 (30.8)     Preoperative RRT (%)   15 (29.4)   4 (6.0)   11 (42.3)   0.035     Final preoperative lactate (median [IQR)   1.20 (1.00, 30.00)   2.000 (15.00, 27.75)   2.50 (15.00, 30.00)   0.353     Final preoperative lactate (median [IQR)   1.20 (1.00, 2.00)   1.10 (0.85, 1.45]   1.65 [1.12, 2.40]   0.025     Final preoperative hemodynamics (median [IQR)   7.00 (65.00, 78.00)   7.400 (69.00, 76.00)   7.000 (64.00, 82.00)   0.750     Gardiac output   7.300 (55.00, 78.00)   7.400 (69.00, 76.00)   7.000 (64.00, 82.00)   0.750     Cardiac output   7.300 (55.00, 78.00)   7.400 (69.00, 76.00)   7.000 (64.00, 82.00)   0.750     Cardiac output   7.300 (55.00, 78.00)   7.400 (69.00, 76.00)   7.000 (64.00, 82.00)   0.375     Cardiac output   7.300 (55.00, 78.00)   7.400 (69.00, 76.00)   7.400 (69.00, 76.00)   7.000 (64.00, 82.00)   0.375     Impelia S.5 Indication   7.300 (55.00, 78.00)   7.400 (69.00, 76.00)   7.200 (50.00   0.700   1.201     <	C	20 (39.2)	13 (52.0)	7 (26.9)	
E   8 (15.7)   0 (0.0)   8 (30.8)     Preoperative RIT (%)   15 (29.4)   4 (16.0)   11 (42.3)   0.79     Preoperative ejection fraction (%) (median [10R))   2000 (15.00, 30.00)   2030 (15.00, 27.75]   2250 (15.00, 30.00)   0.333     Final preoperative lactate (median [10R))   1.20 (1.00, 2.00)   1.10 (69.00, 76.00)   7.000 (64.00, 82.00)   0.750     Central venous pressure   9.00 (55.00, 78.00)   7.000 (69.00, 76.00)   9.00 (50.0, 11.00)   9.00 (50.0, 11.00)   9.00 (50.0, 11.00)   9.00 (50.0, 11.00)   9.00 (50.0, 11.00)   9.00 (50.0, 11.00)   9.00 (50.0, 11.00)   9.00 (50.0, 11.00)   9.00 (50.0, 11.00)   9.00 (50.0, 11.00)   9.00 (50.0, 11.00)   9.00 (50.0, 11.00)   9.00 (50.0, 12.0)   0.323     Cardiac output   4.23 (3.76, 5.77)   4.16 (3.70, 5.92)   4.27 (38.0, 5.27)   0.792     Impella S5 Indication   15 (29.4)   8 (32.0)   7 (26.9)	P	14 (27.5)	8 (32.0)	6 (23.1)	
Preoperative election fraction (%) (median [IQR))   15 (29.4)   4 (16.0)   11 (42.3)   0.079     Preoperative election fraction (%) (median [IQR))   2.000 (15.00, 30.00)   2.000 (15.00, 27.75)   22.50 (15.00, 30.00)   0.333     Final preoperative lactate (median [IQR))   1.00 (1.00, 2.00)   1.10 (0.85, 1.45)   1.65 (1.12, 2.40)   0.025     Final preoperative hemodynamics (median [IQR))   7.00 (50.00, 78.00)   74.00 (69.00, 76.00)   70.00 (64.00, 82.00)   0.750     Central venous pressure   9.00 (50.0, 11.00)   7.00 (50.0, 11.00)   9.00 (6.00, 42.51)   0.325     Cardiac output   1.5 (29.4)   8 (32.0)   7 (26.9)	E	8 (15.7)	0 (0.0)	8 (30.8)	
Preoperative ejection fraction (%) (median [IQR))   2000 [15.00, 30.00]   20.00 [15.00, 27.75]   22.50 [15.00, 30.00]   0.033     Final preoperative lactate (median [IQR))   1.20 [1.00, 2.00]   1.10 [0.85, 1.45]   1.65 [1.12, 2.40]   0.025     Final preoperative hemodynamics (median [IQR))   73.00 [65.00, 78.00]   74.00 [69.00, 76.00]   90.00 [60.0, 14.25]   0.335     Mean arterial pressure   90.00 [50.0, 11.00]   7.00 [64.00, 82.00]   0.750     Central venous pressure   90.00 [50.0, 11.00]   7.00 [50.0, 11.00]   90.00 [60.0, 14.25]   0.325     Gardia cutput   42.33 [37, 5.77]   41.61 37.05 592   42.73 [38.52.7]   0.750     Polla Complication   13 (25.5)   6 (24.00   7 (26.9)   22.80     Post-Cardiotomy   0 (19.6)   5 (20.0)   5 (19.2)   22.80     Proof Impelia Complication   9 (17.6)   2 (8.0)   0 (0.0)   2 (7.7)     Patter gard   3 (5.9)   3 (12.0)   0 (0.0)   2 (7.7)     Right axillary   2 (3.9)   2 (8.0)   2 (4 (2.3)   0 (16.15)   0.011     Additional MCS Days (median [IQR))	Preoperative RRT (%)	15 (29.4)	4 (16.0)	11 (42.3)	0.079
Inal propertive lactate (median [IQR])   I.20 [1.0.0.2.00]   I.10 [0.85, 1.45]   I.65 [1.1, 2.40]   0.025     Final preoperative hemodynamics (median [IQR])   74.00 [69.00, 76.00]   70.00 [64.00, 82.00]   0.750     Central venous pressure   900 [5.00, 11.00]   7.00 [5.00, 11.00]   9.00 [6.00, 14.25]   0.325     Cardiac output   4.23 [3.76, 5.77]   4.16 [3.70, 5.92]   4.27 [3.80, 52.7]   0.792     Impella 5.5 Indication   5 (29.4)   7 (26.9)   5 (29.0)   7 (26.9)     Post-Cardiotomy   10 (19.6)   5 (20.0)   5 (19.2)   10 (19.6)   7 (26.9)     Post-Cardiotomy   10 (19.6)   2 (8.0)   0 (0.0)   10 (9.0)   7 (26.9)     Post-Cardiotomy   0 (19.6)   2 (8.0)   0 (0.0)   10 (9.0)   10 (9.0)     Postpartum   2 (3.9)   2 (8.0)   0 (0.0)   10 (9.0)   10 (9.0)     Left axillary   2 (3.9)   3 (12.0)   0 (0.0)   10 (9.0)   10 (9.0)     Left axillary   2 (3.9)   3 (12.0)   10 (0.0)   0.00   10 (9.0)   10 (9.0)   10 (9.0)   10	Preoperative ejection fraction (%) (median [IOR])	20.00 [15.00, 30.00]	20.00 [15.00, 27.75]	22.50 [15.00, 30.00]	0.353
Final preoperative hemodynamics (median [IQR])   International median (IQR)   International median (IQR)     Mean arterial pressure   73.00 (65.00, 78.00)   74.00 (69.00, 76.00)   70.00 (64.00, 82.00)   0.750     Central venous pressure   9.00 (50.0, 11.00)   7.00 (50.0, 14.25)   0.325     Cardiac output   4.23 (3.76, 5.77)   4.16 (37.0, 5.92)   4.27 (3.80, 5.27)   0.792     Impella 5.5 Indication   5 (29.4)   8 (32.0)   7 (26.9)   -   0.228     Actrd MI   15 (29.4)   8 (32.0)   7 (26.9)   -   -   0.229     Prior Impella Complication   10 (19.6)   2 (8.0)   7 (26.9)   -	Final preoperative lactate (median [IOR])	1.20 [1.00, 2.00]	1.10 [0.85, 1.45]	1.65 [1.12, 2.40]	0.025
Mean atterial pressure   73.00 (65.00, 78.00)   74.00 (69.00, 76.00)   70.00 (64.00, 82.00)   0.750     Central venous pressure   9.00 (5.00, 11.00)   7.00 (5.00, 11.00)   9.00 (5.00, 11.20)   9.00 (5.00, 11.20)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.20)   9.00 (5.00, 11.20)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.00 (5.00, 11.00)   9.028     Impella 5.1 dictation   13 (25.5)   6 (24.0)   7 (26.9)   7 (26.9)   7 (26.9)     Prior Impella Complication   9 (17.6)   2 (8.0)   0 (0.0)   7 (26.9)   7 (26.9)     Arrhythmia   2 (3.9)   2 (8.0)   0 (0.0)   7 (26.9)   7 (26.9)     Aortic graft   3 (5.9)   3 (12.0)   0 (0.0)   7 (27.7)   1 (1.01 (6.50, 25.00)   1 (0.00 (6.00, 15.00)   2 (9.2)     Total graft   3 (5.9)   3 (12.0)   0 (0.00, 15.25]   0.005   7 (7.7)   1 (1.01 (6.6, 0.5,	Final preoperative hemodynamics (median [IOR])				
Instruction   POD [500, 11.00]   7.00 [5.00, 11.00]   9.00 [6.00, 14.25]   0.325     Cardiac output   4.23 [3.76, 5.77]   4.16 [3.70, 5.92]   4.27 [3.80, 5.27]   0.792     Impella 5.5 Indication	Mean arterial pressure	73.00 [65.00, 78.00]	74.00 [69.00, 76.00]	70.00 [64.00, 82.00]	0.750
Cardiac output   4.23 (3.76, 5.77)   4.16 (3.70, 5.92)   4.27 (3.80, 5.27)   0.792     Impella 5.5 Indication   5.5 (2.0, 2.0, 2.0, 2.0, 2.0, 2.0, 2.0, 2.0,	Central venous pressure	9.00 [5.00, 11.00]	7.00 [5.00, 11.00]	9.00 [6.00, 14,25]	0.325
Instrict of optical stress   Instrict of optical stress   Outpical stress   Outpical stress     Acute MI   15 (29.4)   8 (32.0)   7 (26.9)   -     CHF Exacerbation   13 (25.5)   6 (24.0)   7 (26.9)   -     Post-Cardiotomy   10 (19.6)   5 (20.0)   5 (19.2)   -     Prior Impella Complication   9 (17.6)   2 (8.0)   0 (0.0)   -     Post-Cardiotomy   2 (3.9)   2 (8.0)   0 (0.0)   -     Postparture   Factors, Complications, and Outcomes   -   -   -     Impella 5.5 days (median [IQR)   3 (5.9)   3 (12.0)   0 (0.0)   -   -     Left axillary   2 (3.9)   0 (0.0)   2 (7.7)   -	Cardiac output	4 23 [3 76 5 77]	4 16 [3 70 5 92]	4 27 [3 80 5 27]	0.792
Acute MI   15 (29.4)   8 (32.0)   7 (26.9)     CHF Exacerbation   13 (25.5)   6 (24.0)   7 (26.9)     Prior Impella Complication   9 (17.6)   5 (20.0)   5 (19.2)     Prior Impella Complication   9 (17.6)   2 (8.0)   7 (26.9)     Arrhythmia   2 (3.9)   2 (8.0)   0 (0.0)     Postoperative Factors, Complications, and Outcomes   0.02   0.000   0.000     Postoperative Factors, Complications, and Outcomes   0.00   0.000   0.000     Left axillary   2 (3.9)   3 (12.0)   0 (0.0)   0.001     Actite graft   3 (5.9)   3 (12.0)   2 (92.3)   0.001     Additional MCS with Impella 5.5 (%)   22 (83.0)   10.00 (6.00, 15.00]   2.50 (9.00, 41.00]   0.001     Additional MCS pays (median [IQR])   14.00 [6.50, 25.00]   0.000 [0.00, 6.50]   0.00 [0.00, 6.50]   0.00 [0.00, 6.50]   0.001     Additional MCS bays (median [IQR])   0.00 [0.00, 6.50]   0.000 [0.00, 2.00]   3.50 [0.00, 7.00]   0.03     Packed red blood cells   8.00 [3.00, 17.00]   4.00 [2.00, 9.00]   1.55 (6.50, 28	Impella 5.5 Indication			1.2, [3,00, 3,2,7]	0.228
Chef Exacerbation   13 (25)   6 (24.0)   7 (26.9)     Post-Cardiotomy   10 (19.6)   5 (20.0)   5 (19.2)     Prior Impella Complication   9 (17.6)   2 (8.0)   7 (26.9)     Arrhythmia   2 (3.9)   2 (8.0)   0 (0.0)     Postpartum   2 (3.9)   2 (8.0)   0 (0.0)     Postpartive Factors, Complications, and Outcomes    0.079     Postpartive Factors, Complications, and Outcomes    0.001   2 (3.9)     Postpartive Factors, Complications, and Outcomes    0.077   0.000     Postpartive Factors, Complications, and Outcomes    0.001   2 (3.9)   0 (0.0)   2 (7.7)     Right axillary   2 (3.9)   0 (0.0)   2 (3.9)   0 (0.0)   2 (3.9)   0.001     Additional MCS with Impella 5.5 (%)   22 (43.1)   6 (24.0)   16 (61.5)   0.015     Additional MCS Days (median [IQR])   0.00 [0.00, 5.00]   0.00 [0.00, 2.00]   2.50 [0.00, 7.00]   0.30     Packed red blood cells   8.00 [3.00, 17.00]   4.00 [0.00, 2.00]   2.50 [0.00, 7.00]   0.001	Acute MI	15 (29 4)	8 (32 0)	7 (26 9)	0.220
Characterization   Council   Council   Council     Post-Cardiotomy   10 (19.6)   5 (20.0)   5 (19.2)     Prior Impella Complication   9 (17.6)   2 (8.0)   7 (26.9)     Arrhythmia   2 (3.9)   2 (8.0)   0 (0.0)     Post-Cardiotomy   2 (3.9)   0 (0.0)   2 (7.7)     Aortic graft   3 (5.9)   3 (12.0)   0 (0.0)   2 (9.3)     Total Impella 5.5 days (median [IQR])   14.00 [6.50, 25.00]   10.00 [6.00, 15.00]   23.50 [9.00, 41.00]   0.001     Additional MCS bays (median [IQR])   14.00 [6.50, 25.00]   10.00 [0.00, 2.00]   4.00 [0.00, 15.5]   0.015     Additional MCS bays (median [IQR])   14.00 [6.50, 15.00]   0.00 [0.00, 2.00]   2.50 [0.00, 7.00]   0.033     Platelets   0.00 [0.00, 5.00]   0.00 [0.00, 2.00]   2.50 [0.00, 7.00]   0.033     Platelets   1.00 [0.00, 0.4.50]	CHE Exacerbation	13 (25 5)	6 (24 0)	7 (26.9)	
Trice Readed with y in the Rest of Pice (N)   Constraint of Pice (N)   Constraint of Pice (N)     Prior Impella Complication   9 (7.6)   2 (8.0)   0 (0.0)     Postpartum   2 (3.9)   2 (8.0)   0 (0.0)     Postpartur   2 (3.9)   2 (8.0)   0 (0.0)     Postpartur   2 (3.9)   2 (8.0)   0 (0.0)     Postpartur Factors, Complications, and Outcomes	Post-Cardiotomy	10 (196)	5 (20.0)	5 (19 2)	
Interface   Interface   Interface   Interface     Arrhythmia   2 (3.9)   2 (8.0)   0 (0.0)     Postoperative Factors, Complications, and Outcomes	Prior Impella Complication	9 (17 6)	2 (8 0)	7 (26.9)	
Prostpartum   2 (3.9)   2 (8.9)   0 (0.0)     Postpartum   2 (3.9)   2 (8.0)   0 (0.0)     Postpartive Factors, Complications, and Outcomes	Arrhythmia	2 (3 9)	2 (8.0)	0 (0 0)	
Postoperative Factors, Complications, and Outcomes   Items	Postpartum	2 (3.9)	2 (8.0)	0 (0.0)	
Impella Site of Placement (%)   0.079     Aortic graft   3 (5.9)   3 (12.0)   0 (0.0)     Left axillary   2 (3.9)   0 (0.0)   2 (7.7)     Right axillary   46 (90.2)   22 (88.0)   24 (92.3)     Total Impella 5.5 days (median [IQR])   14.00 [6.50, 25.00]   10.00 [6.00, 15.00]   23.50 [9.00, 41.00]   0.001     Additional MCS with Impella 5.5 (%)   22 (43.1)   6 (24.0)   16 (61.5)   0.015     Additional MCS Days (median [IQR])   0.00 [0.00, 6.50]   0.00 [0.00, 2.00]   4.00 [0.00, 15.25]   0.005     Transfusions on Impella 5.5 (median [IQR])   0.00 [0.00, 5.00]   0.00 [0.00, 2.00]   2.50 [0.00, 7.00]   0.033     Placked red blood cells   8.00 [3.00, 17.00]   4.00 [2.00, 9.00]   12.50 [6.50, 28.00]   0.001     Fresh Frozen Plasma   0.00 [0.00, 4.50]   0.00 [0.00, 2.00]   3.00 [1.00, 6.75]   0.002     Complications (%)   1   1.00 [0.00, 4.50]   0.00 [0.00, 2.00]   3.00 [1.00, 6.75]   0.002     Complications (%)   1   12 (23.5)   6 (24.0)   6 (23.1)   1.000     Stroke	Postoperative Factors Complications and Outcomes	2 (3.7)	2 (0.0)	0 (0.0)	
Anotic graft 3 (5.9) 3 (12.0) 0 (0.0)   Left axillary 2 (3.9) 0 (0.0) 2 (7.7)   Right axillary 46 (90.2) 22 (88.0) 24 (92.3)   Total Impella 5.5 days (median [IQR]) 14.00 [6.50, 25.00] 10.00 [6.00, 15.00] 23.50 [9.00, 41.00] 0.001   Additional MCS with Impella 5.5 (%) 22 (43.1) 6 (24.0) 16 (61.5) 0.015   Additional MCS Days (median [IQR]) 0.00 [0.00, 6.50] 0.00 [0.00, 2.00] 4.00 [0.00, 15.25] 0.005   Transfusions on Impella 5.5 (median [IQR]) 0.00 [0.00, 5.00] 0.00 [0.00, 2.00] 12.50 [6.50, 28.00] 0.001   Fresh Frozen Plasma 0.00 [0.00, 5.00] 0.00 [0.00, 2.00] 2.50 [0.00, 7.00] 0.033   Platelets 1.00 [0.00, 4.50] 0.00 [0.00, 2.00] 3.00 [1.00, 6.75] 0.002   Complications (%)    1.000 2 (2.5) 1.000 2.500 [1.400, 34.00] 2.750 [16.50, 61.50] 0.270   Stroke 7 (13.7) 4 (16.0) 3 (11.5) 0.955 1.000 2.500 [1.400, 34.00] 2.750 [16.50, 61.50] 0.270   LOS (median [IQR]) 2.00 (21.00, 53.30)	Impella Site of Placement (%)				0.079
Left axillary 2 (3.9) 0 (0.0) 2 (7.7)   Right axillary 46 (90.2) 22 (88.0) 24 (92.3)   Total Impella 5.5 days (median [IQR]) 14.00 [6.50, 25.00] 10.00 [6.00, 15.00] 23.50 [9.00, 41.00] 0.001   Additional MCS with Impella 5.5 (%) 22 (43.1) 6 (24.0) 16 (61.5) 0.015   Additional MCS Days (median [IQR]) 0.00 [0.00, 6.50] 0.00 [0.00, 2.00] 4.00 [0.00, 15.25] 0.005   Transfusions on Impella 5.5 (median [IQR]) 8.00 [3.00, 17.00] 4.00 [2.00, 9.00] 12.50 [6.50, 28.00] 0.001   Packed red blood cells 8.00 [3.00, 17.00] 4.00 [2.00, 9.00] 12.50 [6.50, 28.00] 0.001   Fresh Frozen Plasma 0.00 [0.00, 4.50] 0.00 [0.00, 2.00] 2.50 [0.00, 7.00] 0.033   Platelets 1.00 [0.00, 4.50] 0.00 [0.00, 2.00] 2.50 [0.00, 7.00] 0.033   Complications (%) 12 (23.5) 6 (24.0) 6 (23.1) 1.000   New RRT 12 (23.5) 6 (24.0) 2 (7.7) 1.000   Stroke 7 (13.7) 4 (16.0) 3 (11.5) 0.955   ICU days (median [IQR]) 32.00 [1.00, 53.00] 41.00 [22.00,	Aortic graft	3 (5 9)	3 (12 0)	0 (0 0)	0.07 9
Right axillary 46 (90.2) 22 (88.0) 24 (92.3)   Total Impella 5.5 days (median [IQR]) 14.00 [6.50, 25.00] 10.00 [6.00, 15.00] 23.50 [9.00, 41.00] 0.001   Additional MCS with Impella 5.5 (%) 22 (43.1) 6 (24.0) 16 (61.5) 0.015   Additional MCS Days (median [IQR]) 0.00 [0.00, 6.50] 0.00 [0.00, 2.00] 4.00 [0.00, 15.25] 0.005   Transfusions on Impella 5.5 (median [IQR]) 8.00 [3.00, 17.00] 4.00 [2.00, 9.00] 12.50 [6.50, 28.00] 0.001   Packed red blood cells 8.00 [0.00, 5.00] 0.00 [0.00, 2.00] 3.00 [1.00, 6.75] 0.002   Complications (%) 12 (23.5) 6 (24.0) 6 (23.1) 1.000   New RRT 12 (23.5) 6 (24.0) 6 (23.1) 1.000   Operative vascular complication 4 (7.8) 2 (8.0) 2 (7.7) 1.000   Stroke 7 (13.7) 4 (16.0) 3 (11.5) 0.955   ICU days (median [IQR]) 20.00 [1.00, 53.00] 41.00 [22.00, 49.00] 27.50 [16.50, 61.50] 0.270   LOS (median [IQR]) 20.00 [15.00, 40.50] 25.00 [14.00, 34.00] 27.50 [16.50, 61.50] 0.270   LOS (median [IQR]) <td>l eft avillary</td> <td>2 (3.9)</td> <td>0 (0 0)</td> <td>2 (7 7)</td> <td></td>	l eft avillary	2 (3.9)	0 (0 0)	2 (7 7)	
Total Impella 5.5 days (median [IQR]) 14.00 [6.50, 25.00] 10.00 [6.00, 15.00] 23.50 [9.00, 41.00] 0.001   Additional MCS with Impella 5.5 (%) 22 (43.1) 6 (24.0) 16 (61.5) 0.015   Additional MCS Days (median [IQR]) 0.00 [0.00, 6.50] 0.00 [0.00, 2.00] 4.00 [0.00, 15.25] 0.005   Transfusions on Impella 5.5 (median [IQR]) 0.00 [0.00, 5.00] 0.00 [0.00, 2.00] 12.50 [6.50, 28.00] 0.001   Fresh Frozen Plasma 0.00 [0.00, 5.00] 0.00 [0.00, 2.00] 2.50 [0.00, 7.00] 0.033   Platelets 1.00 [0.00, 4.50] 0.00 [0.00, 2.00] 3.00 [1.00, 6.75] 0.002   Complications (%) New RRT 12 (23.5) 6 (24.0) 6 (23.1) 1.000   Operative vascular complication 4 (7.8) 2 (8.0) 2 (7.7) 1.000   Stroke 7 (13.7) 4 (16.0) 3 (11.5) 0.955   ICU days (median [IQR]) 32.00 [21.00, 53.00] 41.00 [22.00, 49.00] 27.50 [0.25, 62.25] 0.917   Days survived after Impella 5.5 placed (median [IQR]) 37.00 [12.50, 333.50] 47.00 [12.00, 416.00] 30.50 [14.50, 82.75] 0.509   30-day mortality (%) 24 (47.1)	Bight axillary	46 (90 2)	22 (88 0)	2 (0.0)	
Additional MCS with Impella 5.5 (%) 22 (43.1) 6 (24.0) 16 (61.5) 0.015   Additional MCS Days (median [IQR]) 0.00 [0.00, 6.50] 0.00 [0.00, 2.00] 4.00 [0.00, 15.25] 0.005   Transfusions on Impella 5.5 (median [IQR]) 8.00 [3.00, 17.00] 4.00 [2.00, 9.00] 12.50 [6.50, 28.00] 0.001   Packed red blood cells 8.00 [3.00, 17.00] 0.00 [0.00, 2.00] 2.50 [0.00, 7.00] 0.033   Platelets 1.00 [0.00, 4.50] 0.00 [0.00, 2.00] 3.00 [1.00, 6.75] 0.002   Complications (%) 12 (23.5) 6 (24.0) 6 (23.1) 1.000   Operative vascular complication 4 (7.8) 2 (8.0) 2 (7.7) 1.000   Stroke 7 (13.7) 4 (16.0) 3 (11.5) 0.955   ICU days (median [IQR]) 32.00 [21.00, 53.00] 41.00 [22.00, 49.00] 27.50 [16.50, 61.50] 0.270   LOS (median [IQR]) 32.00 [21.00, 53.00] 41.00 [22.00, 49.00] 27.50 [20.25, 62.25] 0.917   Days survived after Impella 5.5 placed (median [IQR]) 37.00 [12.50, 333.50] 47.00 [12.00, 416.00] 30.50 [14.50, 82.75] 0.509   30-day mortality (%) 24 (47.1) 14 (40.0) 13 (50.0	Total Impella 5 5 days (median [IOB])	14 00 [6 50 25 00]	10 00 [6 00 15 00]	23 50 [9 00 41 00]	0.001
Additional MCS Days (median [IQR]) 0.00 [0.00, 6.50] 0.00 [0.00, 2.00] 4.00 [0.00, 15.25] 0.005   Transfusions on Impella 5.5 (median [IQR]) 8.00 [3.00, 17.00] 4.00 [2.00, 9.00] 12.50 [6.50, 28.00] 0.001   Packed red blood cells 8.00 [3.00, 17.00] 0.00 [0.00, 2.00] 2.50 [0.00, 7.00] 0.033   Platelets 1.00 [0.00, 4.50] 0.00 [0.00, 2.00] 3.00 [1.00, 6.75] 0.002   Complications (%) 12 (23.5) 6 (24.0) 6 (23.1) 1.000   Operative vascular complication 4 (7.8) 2 (8.0) 2 (7.7) 1.000   Stroke 7 (13.7) 4 (16.0) 3 (11.5) 0.955   ICU days (median [IQR]) 26.00 [15.00, 40.50] 25.00 [14.00, 34.00] 27.50 [16.50, 61.50] 0.270   LOS (median [IQR]) 32.00 [21.00, 53.00] 41.00 [22.00, 49.00] 27.50 [16.50, 61.50] 0.509   30-day mortality (%) 24 (47.1) 11 (44.0) 13 (50.0) 0.882	Additional MCS with Impella 5.5 (%)	22 (43.1)	6 (24.0)	16 (61.5)	0.015
Transfusions on Impella 5.5 (median [IQR]) 8.00 [3.00, 17.00] 4.00 [2.00, 9.00] 12.50 [6.50, 28.00] 0.001   Fresh Frozen Plasma 0.00 [0.00, 5.00] 0.00 [0.00, 2.00] 2.50 [0.00, 7.00] 0.033   Platelets 1.00 [0.00, 4.50] 0.00 [0.00, 2.00] 3.00 [1.00, 6.75] 0.002   Complications (%) 12 (23.5) 6 (24.0) 6 (23.1) 1.000   Operative vascular complication 4 (7.8) 2 (8.0) 2 (7.7) 1.000   Stroke 7 (13.7) 4 (16.0) 3 (11.5) 0.955   ICU days (median [IQR]) 26.00 [15.00, 40.50] 25.00 [14.00, 34.00] 27.50 [0.50, 61.50] 0.270   LOS (median [IQR]) 32.00 [21.00, 53.00] 41.00 [22.00, 49.00] 27.50 [0.25, 62.25] 0.917   Days survived after Impella 5.5 placed (median [IQR]) 37.00 [12.50, 333.50] 47.00 [12.00, 416.00] 30.50 [14.50, 82.75] 0.509   30-day mortality (%) 24 (47.1) 11 (44.0) 13 (50.0) 0.882   Survived admission (%) 21 (41.2) 14 (56.0) 7 (26.9) 0.068	Additional MCS Days (median [IOB])	0.00 [0.00 6.50]	0.00 [0.00 2.00]	4.00 [0.00 15.25]	0.005
Packed red blood cells 8.00 [3.00, 17.00] 4.00 [2.00, 9.00] 12.50 [6.50, 28.00] 0.001   Fresh Frozen Plasma 0.00 [0.00, 5.00] 0.00 [0.00, 2.00] 2.50 [0.00, 7.00] 0.033   Platelets 1.00 [0.00, 4.50] 0.00 [0.00, 2.00] 3.00 [1.00, 6.75] 0.002   Complications (%)	Transfusions on Impella 5.5 (median [IOR])	0.00 [0.00, 0.50]	0100 [0100, 2100]	100 [0100, 10120]	0.005
Fresh Frozen Plasma 0.00 [0.00, 5.00] 0.00 [0.00, 2.00] 2.50 [0.00, 7.00] 0.033   Platelets 1.00 [0.00, 4.50] 0.00 [0.00, 2.00] 3.00 [1.00, 6.75] 0.002   Complications (%)	Packed red blood cells	8 00 [3 00 17 00]	4 00 [2 00 9 00]	12 50 [6 50 28 00]	0.001
Platelets   1.00 [0.00, 4.50]   0.00 [0.00, 2.00]   3.00 [1.00, 6.75]   0.002     Complications (%)	Fresh Frozen Plasma	0.00[0.00 5.00]	4.00 [2.00, 3.00] 0.00 [0.00, 2.00]	2 50 [0 00 7 00]	0.033
Number of [1000], 41.50] Excor [1000], 21.50]	Platelets		0.00 [0.00, 2.00]	3 00 [1 00 6 75]	0.000
New RRT   12 (23.5)   6 (24.0)   6 (23.1)   1.000     Operative vascular complication   4 (7.8)   2 (8.0)   2 (7.7)   1.000     Stroke   7 (13.7)   4 (16.0)   3 (11.5)   0.955     ICU days (median [IQR])   26.00 [15.00, 40.50]   25.00 [14.00, 34.00]   27.50 [16.50, 61.50]   0.270     LOS (median [IQR])   32.00 [21.00, 53.00]   41.00 [22.00, 49.00]   27.50 [20.25, 62.25]   0.917     Days survived after Impella 5.5 placed (median [IQR])   37.00 [12.50, 333.50]   47.00 [12.00, 416.00]   30.50 [14.50, 82.75]   0.509     30-day mortality (%)   24 (47.1)   11 (44.0)   13 (50.0)   0.882     Survived admission (%)   21 (41.2)   14 (56.0)   7 (26.9)   0.068	Complications (%)	1.00 [0.00, 4.00]	0.00 [0.00, 2.00]	5.00[1.00, 0.75]	0.002
New Intra 12 (25.5) 0 (24.0) 0 (24.0) 0 (25.1) 1.000   Operative vascular complication 4 (7.8) 2 (8.0) 2 (7.7) 1.000   Stroke 7 (13.7) 4 (16.0) 3 (11.5) 0.955   ICU days (median [IQR]) 26.00 [15.00, 40.50] 25.00 [14.00, 34.00] 27.50 [16.50, 61.50] 0.270   LOS (median [IQR]) 32.00 [21.00, 53.00] 41.00 [22.00, 49.00] 27.50 [20.25, 62.25] 0.917   Days survived after Impella 5.5 placed (median [IQR]) 37.00 [12.50, 333.50] 47.00 [12.00, 416.00] 30.50 [14.50, 82.75] 0.509   30-day mortality (%) 24 (47.1) 11 (44.0) 13 (50.0) 0.882   Survived admission (%) 21 (41.2) 14 (56.0) 7 (26.9) 0.068	New RRT	12 (23 5)	6 (24.0)	6 (23 1)	1 000
Stroke 7 (13.7) 4 (16.0) 3 (11.5) 0.955   ICU days (median [IQR]) 26.00 [15.00, 40.50] 25.00 [14.00, 34.00] 27.50 [16.50, 61.50] 0.270   LOS (median [IQR]) 32.00 [21.00, 53.00] 41.00 [22.00, 49.00] 27.50 [20.25, 62.25] 0.917   Days survived after Impella 5.5 placed (median [IQR]) 37.00 [12.50, 333.50] 47.00 [12.00, 416.00] 30.50 [14.50, 82.75] 0.509   30-day mortality (%) 24 (47.1) 11 (44.0) 13 (50.0) 0.882   Survived admission (%) 21 (41.2) 14 (56.0) 7 (26.9) 0.068	Operative vascular complication	12 (23.3)	2 (8 0)	0 (23.1) 2 (7.7)	1.000
ICU days (median [IQR]) 26.00 [15.00, 40.50] 25.00 [14.00, 34.00] 27.50 [16.50, 61.50] 0.270   LOS (median [IQR]) 32.00 [21.00, 53.00] 41.00 [22.00, 49.00] 27.50 [0.25, 62.25] 0.917   Days survived after Impella 5.5 placed (median [IQR]) 37.00 [12.50, 333.50] 47.00 [12.00, 416.00] 30.50 [14.50, 82.75] 0.509   30-day mortality (%) 24 (47.1) 11 (44.0) 13 (50.0) 0.882   Survived admission (%) 21 (41.2) 14 (56.0) 7 (26.9) 0.068	Stroko	7 (13 7)	2 (0.0)	2 (1.7)	0.055
LOS (median [IQR]) 22.00 [15.0, 40.50] 22.00 [14.0, 54.00] 27.00 [10.0, 01.50] 0.270   LOS (median [IQR]) 32.00 [21.00, 53.00] 41.00 [22.00, 49.00] 27.50 [20.25, 62.25] 0.917   Days survived after Impella 5.5 placed (median [IQR]) 37.00 [12.50, 333.50] 47.00 [12.00, 416.00] 30.50 [14.50, 82.75] 0.509   30-day mortality (%) 24 (47.1) 11 (44.0) 13 (50.0) 0.882   Survived admission (%) 21 (41.2) 14 (56.0) 7 (26.9) 0.068	ICL days (modian [IOP])	7 (15.7) 26.00 [15.00, 40.50]		27 50 [16 50 61 50]	0.935
Days survived after Impella 5.5 placed (median [IQR]) 37.00 [12.50, 333.50] 47.00 [12.00, 416.00] 30.50 [14.50, 82.75] 0.509   30-day mortality (%) 24 (47.1) 11 (44.0) 13 (50.0) 0.882   Survived admission (%) 21 (41.2) 14 (56.0) 7 (26.9) 0.068		20.00 [10.00, 40.00]		27.50 [10.50, 01.50]	0.270
30-day mortality (%) 24 (47.1) 11 (44.0) 13 (50.0) 0.882   Survived admission (%) 21 (41.2) 14 (56.0) 7 (26.9) 0.068	Days survived after Impella 5.5 placed (modian $I(OPI)$	37.00 [21.00, 33.00]	A7 00 [12 00 416 00]	27.50 [20.25, 02.25]	0.517
Survived admission (%)   21 (41.7)   11 (44.0)   15 (50.0)   0.682	30-day mortality (%)	эл.00 [12.30, 333.30] Эл (Л7 1)	11 (1/1 (1)	13 (50 0)	0.209
	Survived admission (%)	24 (47.1)	14 (56.0)	7 (26 9)	0.002

## Table 1 (continued)

	Total (N=51)	LH Group (Bottom 20%, N=25)	HH Group (Top 20%, <i>N</i> =26)	<i>p</i> value
Survival outcome (%)				0.253
Durable LVAD	2 (3.9)	2 (14.3)	0 (0.0)	
Transplanted	10 (19.6)	5 (35.7)	5 (71.4)	
Recovered	9 (17.6)	7 (50.0)	2 (28.6)	

Abbreviations: High Hemolysis (HH), Low Hemolysis (LH), Outside Hospital (OSH), Renal Replacement Therapy (RRT) Society for Cardiovascular Angiography & Interventions (SCAI), Mechanical Circulatory Support (MCS), Intensive Care Unit (ICU), Length of Stay (LOS), Left Ventricular Assist Device (LVAD)



## Group – LH – HH

Fig. 3 Kaplan-Meier Survival of high hemolysis (HH) and low hemolysis (LH) cohorts

Analysis of Top Quintile (HH patients)	Total (N=26)	Died (N=19)	Survived (N=7)	<i>p</i> value
Total Impella 5.5 days (median [IQR])	23.50 [9.00, 41.00]	21.00 [8.00, 27.50]	44.00 [30.50, 60.50]	0.064
Impella 5.5 days to peak PfHb (median [IQR])	8.50 [1.25, 19.25]	9.00 [2.00, 20.00]	7.00 [1.00, 10.50]	0.323
Transfusions on Impella 5.5 (median [IQR])				
Packed red blood cells	12.50 [6.50, 28.00]	18.00 [7.00, 29.00]	8.00 [6.00, 9.50]	0.183
Fresh Frozen Plasma	2.50 [0.00, 7.00]	3.00 [0.00, 9.50]	1.00 [0.00, 3.50]	0.271
Platelets	3.00 [1.00, 6.75]	5.00 [2.50, 9.00]	1.00 [0.50, 1.50]	0.010
Labs at time of highest PfHb (median [IQR])				
PTT	43.00 [38.85, 48.75]	43.90 [38.10, 47.20]	42.10 [41.60, 52.55]	0.470
LDH	1073.50 [706.25, 1941.50]	1182.00 [978.50, 2196.50]	719.00 [516.50, 1080.50]	0.060
Bilirubin, Total	3.80 [1.65, 8.20]	5.40 [3.15, 11.60]	1.20 [0.85, 2.45]	0.003
Days of elevated PfHb (median [IQR])	6.00 [3.00, 7.75]	6.00 [5.00, 8.00]	3.00 [1.00, 4.50]	0.007

Abbreviations: High Hemolysis (HH), Plasma Free Hemoglobin (PfHb), Partial thromboplastin time (PTT), Lactate dehydrogenase (LDH)

symptoms. Additionally, purge pressures were checked for any issues. There was no standardized anticoagulation protocol for non-complicated patients, but in cases of continued hemolysis, as long as the patient had no clinical contraindications, the level of anticoagulation was increased either by increasing systemic heparin drip or adding heparin to the bicarbonate purge solution. Finally, in those patients who were judged to be able to tolerate a lower level of hemodynamic support, the revolutions per minute on the device were lowered. Ultimately, several Impella supported patients needed rescue therapy with ECMO if the above measures did not help.

Study limitations include its retrospective nature, relatively low sample size of both cohorts, and the lack of a consistent and well-established hemolysis definition in MCS. Because of this lack of a hemolysis definition, we are unable to prove with evidence that hemolysis is an independent risk factor for adverse events. Furthermore, and related to the retrospective nature of the study, this analysis is hampered by the fact that no consistent clinical protocol for sending hemolysis labs on patients in the postoperative period throughout the entirety of the study period was in place. This, in turn, affected the sample size as 39 patients of the original 169 had to be excluded as there was no PfHb drawn.

Further studies involving larger sample sizes, longer follow-up periods, and a protocolized manner of PfHb sampling will be necessary to further elucidate factors contributing to percutaneous LVAD-associated hemolysis and its sequelae.

## Conclusions

The authors appreciate that hemolysis is an indicator of an increased risk of poor outcomes, and as such should be aggressively tracked and minimized whenever possible using the approaches outlined above. The HH patients spent more days on Impella 5.5, were on additional MCS, and required more transfusions. HH patients who survived required fewer platelet transfusions, had lower bilirubin, and had less days of elevated PfHb.

Hemolysis in the field of MCS has historically been variably defined, and this assessment of a series of patients with a contemporary MCS device may add further insight into the characteristics of patients experiencing clinically significant hemolysis in the field.

## Abbreviations

FDA	U.S. Food & Drug Administration
HH	High Hemolysis
ICU	Intensive Care Unit
INTERMACS	Interagency Registry for Mechanically Assisted Circulatory
	Support
LDH	Lactate Dehydrogenase
LH	Low Hemolysis
LVAD	Left Ventricular Assist Device
MCS	Mechanical Circulatory Support
MIH	Modified Index of Hemolysis
PfHb	Plasma Free Hemoglobin
RBCs	Red Blood Cells
RRT	Renal Replacement Therapy
SCAI	Society for Cardiovascular Angiography and Interventions

## **Supplementary Information**

The online version contains supplementary material available at https://doi.or g/10.1186/s13019-025-03352-7.

Supplementary Material 1

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Not applicable.

## Author contributions

JC - writing and editing of manuscript, study design, acquisition of data, interpretation of data. SK- writing and editing of manuscript, study design, interpretation of data. LL - writing and editing of manuscript, acquisition of data. NR - writing and editing of manuscript, acquisition of data. MB writing and editing of manuscript, data analysis. JP- writing and editing of manuscript, study design, interpretation of data. MB - writing and editing of manuscript, study design. RL- writing and editing of manuscript, study design, interpretation of data.

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There was no funding for this study.

#### Data availability

No datasets were generated or analysed during the current study.

## Declarations

#### Ethics approval and consent to participate

This study was approved by the Institutional Review Board of the University of Southern California (IRB # HS-23-00521) and the need for consent was waived.

## **Consent for publication**

Not applicable.

## **Competing interests**

Dr Raymond Lee has received speaker honoraria from Abiomed, Abbott, and Edwards Lifesciences. The other authors declare they have no competing interests.

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#### References

- Papanastasiou CA, Kyriakoulis KG, Theochari CA, Kokkinidis DG, Karamitsos TD, Palaiodimos L. Comprehensive review of hemolysis in ventricular assist devices. World J Cardiol. 2020;26(7):334–41. https://doi.org/10.4330/wjc.v12.i 7.334
- Balthazar T, Bennett J, Adriaenssens T. Hemolysis during short-term mechanical circulatory support: from pathophysiology to diagnosis and treatment. Expert Rev Med Devices. 2022;19(6):477–88. https://doi.org/10.1080/1743444 0.2022.2108319
- Kormos RL, Antonides CFJ, Goldstein DJ, et al. Updated definitions of adverse events for trials and registries of mechanical circulatory support: a consensus statement of the mechanical circulatory support academic research consortium. J Heart Lung Transpl. 2020;39(8):735–50. https://doi.org/10.1016/j.healu n.2020.03.010
- Pagani FD, Miller LW, Russell SD, et al. Extended mechanical circulatory support with a continuous-flow rotary left ventricular assist device. J Am Coll Cardiol. 2009;21(4):312–21. https://doi.org/10.1016/j.jacc.2009.03.055
- Slaughter MS, Rogers JG, Milano CA, et al. Advanced heart failure treated with continuous-flow left ventricular assist device. N Engl J Med. 2009;03(23):2241–51. https://doi.org/10.1056/NEJMoa0909938
- Salas de Armas I, Bergeron A, Bhardwaj A, et al. Surgically implanted Impella device for patients on impella CP support experiencing refractory hemolysis. ASAIO J. 2022;01(12):e251–5. https://doi.org/10.1097/MAT.0000000000171 2

- Anderson MB, Goldstein J, Milano C, et al. Benefits of a novel percutaneous ventricular assist device for right heart failure: the prospective RECOVER RIGHT study of the Impella RP device. J Heart Lung Transpl. 2015;34(12):1549– 60. https://doi.org/10.1016/j.healun.2015.08.018
- Burkhoff D, Cohen H, Brunckhorst C, O'Neill WW, Group TI. A randomized multicenter clinical study to evaluate the safety and efficacy of the Tandem-Heart percutaneous ventricular assist device versus conventional therapy with intraaortic balloon pumping for treatment of cardiogenic shock. Am Heart J. 2006;152(3):e4691–8. https://doi.org/10.1016/j.ahj.2006.05.031
- Esposito ML, Morine KJ, Annamalai SK, et al. Increased plasma-free hemoglobin levels identify hemolysis in patients with cardiogenic shock and a trans valvular micro-axial flow pump. Artif Organs. 2019;43(2):125–31. https://doi.or g/10.1111/aor.13319
- Nakamura M, Imamura T, Hida Y, Kinugawa K. Pulmonary artery pulsatility index and hemolysis during Impella-incorporated mechanical circulatory support. J Clin Med. 2022;23(5). https://doi.org/10.3390/jcm11051206
- O'Neill WW, Kleiman NS, Moses J, et al. A prospective, randomized clinical trial of hemodynamic support with Impella 2.5 versus intra-aortic balloon pump in patients undergoing high-risk percutaneous coronary intervention: the PROTECT II study. Circulation. 2012;02(14):1717–27. https://doi.org/10.1161/C IRCULATIONAHA.112.098194

- 12. Kapur NK, Kim RJ, Moses JW, et al. Primary left ventricular unloading with delayed reperfusion in patients with anterior ST-elevation myocardial infarction: rationale and design of the STEMI-DTU randomized pivotal trial. Am Heart J. 2022;254:122–32. https://doi.org/10.1016/j.ahj.2022.08.011
- Griffith BP, Anderson MB, Samuels LE, Pae WE, Naka Y, Frazier OH. The RECOVER I: a multicenter prospective study of Impella 5.0/LD for postcardiotomy circulatory support. J Thorac Cardiovasc Surg. 2013;145(2):548–54. htt ps://doi.org/10.1016/j.jtcvs.2012.01.067
- Malinauskas R, Rinaldi J, Jamiolkowski M, Lu Q. In vitro dynamic hemolysis testing of blood pumps: updating the ASTM F1841 testing standard. 2021 FDA Science Forum: fda.gov; 2021.
- Roberts N, Chandrasekaran U, Das S, Qi Z, Corbett S. Hemolysis associated with Impella heart pump positioning: in vitro hemolysis testing and computational fluid dynamics modeling. Int J Artif Organs. 2020;04:391398820909843. https://doi.org/10.1177/0391398820909843

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