Impact of Initial Operative Urgency on Short-Term Outcomes in Patients Treated with ECMO Due to Postcardiotomy Cardiogenic Shock

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Abstract: The outcomes of patients with PCS and following ECMO therapy are associated with several preoperative risk factors. Our aim was to compare clinical presentation, ECMO-related data and in-hospital outcomes of patients treated with ECMO due to PCS after cardiac surgery, in regard to elective or emergent cardiac surgery procedures. Between April 2006 and October 2016, 164 consecutive patients that received VA-ECMO therapy due to PCS were identified and included in this retrospective cohort study. The patients were divided into groups based on the urgency of the initial procedures performed: elective group (ELG; n = 95) and an emergency group (EMG; n = 69). To compare the unequal patient groups, a propensity score-based matching (PSM) was applied (ELG, n = 56 vs. EMG, n = 56). The EMG primarily received ECMO intraoperatively (p ≤ 0.001). In contrast, the ELG were needed ECMO support more frequently postoperatively (p < 0.001). In-hospital mortality accounted for 71% (n = 40) in the ELG and 76% (n = 43) in the EMG (p = 0.518). Outcome data showed no major differences in the (abdominal ischemia (p = 0.371); septic shock (p = 0.393); rhythm disturbances (p = 0.575); emergency re-thoracotomy (p = 0.418)) between the groups. The urgency of the initial procedures performed is secondary in patients suffering PCS and following ECMO. In this regard, PCS itself seems to trigger outcomes in cardiac surgery ECMO patients substantially.

Keywords: ECMO; cardiogenic shock; cardiac surgery; elective; emergent

1. Introduction

A patient’s preoperative hemodynamic state significantly impacts their mortality rates and outcomes after performed cardiac surgery. Elective coronary artery bypass graft surgery (CABG) is associated with a perioperative/hospital-mortality rate of approximately 3% [1,2], whereas CABG in acute myocardial infarction (MI) showed mortality rates up to 30% [3,4]. Similar differentiation is described in aortic valve surgery [5,6]. In this regard, the perioperative risk is highly depending on co-morbidities, postoperative complications, the hospital volume of specific procedures and the expertise of the involved physicians [7,8].

Alongside the impact of elective or emergent surgical procedures, postcardiotomy cardiogenic shock (PCS) is a complication associated with high mortality rates, especially in patients who require mechanical circulatory support (MCS) with extracorporeal membrane oxygenation (ECMO) [9,10]. However, refractory PCS requiring ECMO is described by an incidence of 0.5–1.5% [11,12].
Veno-arterial extracorporeal membrane oxygenation (VA-ECMO) is an increasingly used method for circulatory support [13]. VA-ECMO in postcardiotomy cardiogenic shock facilitates the improvement of hemodynamic status and significant increase in tissue perfusion [14]. Despite ongoing research, survival following VA-ECMO therapy remains low [14,15].

In the context of known distinctions of elective and emergent cardiac surgery procedures and their impact on perioperative results, the question arises whether outcomes of patients that require VA-ECMO support differ depending on the degree of emergency of the procedures performed. Therefore, the objective of this study was to compare clinical presentation, VA-ECMO-related data and in-hospital outcomes of patients treated with VA-ECMO due to PCS after cardiac surgery in regard to elective or emergent cardiac surgery.

2. Materials and Methods

The study was designed as a retrospective single center cohort analysis. Between April 2006 and October 2016, 164 consecutive patients with veno-arterial ECMO therapy due to PCS were identified and included in this study. To analyse the impact of urgency, patients were divided regarding the urgency of procedures performed in an elective group (ELG, n = 95) and an emergency group (EMG, n = 69). ECMO indications for both groups were: left ventricular (LV) failure, right ventricular (RV) failure, combined heart and lung failure, and cardiopulmonary resuscitation (CPR) (Figure 1). To compare the unequal patient groups a propensity score-based matching (PSM) was applied (Figure 2).

Figure 1. Flow chart illustrating patient selection and ECMO indication. ECMO: extracorporeal membrane oxygenation.

Figure 2. Study population of patients after VA-ECMO implantation. PSM: propensity score matching; ELG: elective group; EMG: emergency group.
2.1. ECMO-Center Protocol

VA-ECMO support (Rotaflow, Maquet, Rastatt, Germany) was established in the case of inefficient weaning from cardio-pulmonary bypass (CPB) or as an ultima-ratio therapeutic option in the case of therapy refractory postcardiotomy cardiogenic shock after performed cardiac surgery procedures. Central VA-ECMO implantation was performed by switching inserted CPB cannulas from the right atrium and ascending aorta into the ECMO system. The thorax was packed and left opened. In case of already closed-chest, peripheral VA-ECMO was implanted through groin vessels using the percutaneous Seldinger’s technique.

Our anticoagulant protocol aimed towards an activated clotting time (ACT) 160–180 s and activated partial thromboplastin time (aPTT), 60–80 s after intravenous infusion of unfractionated heparin, to avoid potential thromboembolic events. Following this, echocardiography, laboratory parameters and chest X-rays were performed to evaluate the hemodynamic stability and possible weaning ability. Moreover, heart function was evaluated daily using transesophageal echocardiography (TEE).

VA-ECMO weaning was initialized after haemodynamic stabilization. The ECMO flow rate was decreased, 100–200 mL/h. Moreover, lactate and urine outputs were assessed hourly. ECMO removal was feasible when TEE showed partial or full recovery under 2.0 L/min ECMO support, without increasing lactate concentration in the blood and decreasing urine output. All patients assumed to be suitable for weaning underwent surgical explanation of ECMO cannulas.

2.2. Data Collection

All relevant data were analyzed retrospectively, after extraction from our institutional database. The variables evaluated included:

- patients’ demographic characteristics (age, body mass index (BMI), sex, European System for Cardiac Operative Risk Evaluation (EuroSCORE II), Society of Thoracic Surgeons (STS Score));
- patients’ status before ECMO support (renal insufficiency with dialysis, previous heart surgery, catecholamine therapy, left-ventricular ejection fraction (LV-EF));
- laboratory parameter (creatine kinases (CK), creatine kinases muscle brain (CK-MB), glutamate-oxalacetate transaminase (GOT), glutamate-oxalacetate transaminase (GLT), bilirubin);
- implantation data (ECMO duration, ECMO complications, concomitant intra-aortic balloon pump (IABP) implantation, ECMO weaning);
- early outcome data (in-hospital all-cause mortality, intensive care unit (ICU)- and hospital stay, renal failure requiring dialysis, disabling cerebrovascular events, septic shock, emergency re-thoracotomy, abdominal ischemia, rhythm disturbances, tracheotomy and red blood cell transfusion rate).

2.3. Endpoints of the Study

The primary endpoint was in-hospital all-cause mortality. The secondary outcome parameters were: in-hospital stay, renal failure requiring dialysis (glomerular filtration rate (GFR) < 15 mL/min, life-threatening hyperkalemia, refractory acidosis and hypervolemia causing end-organ complications), disabling cerebrovascular events (ischemic stroke or hemorrhagic stroke), septic shock (persistent hypotension requiring vasopressors to maintain mean arterial pressure of 65 mm Hg or higher and a serum lactate level greater than 2 mmol/L despite adequate volume resuscitation), emergency re-thoracotomy (blood loss with a hemoglobin decrease of greater than 3 g/dL or any hemoglobin decrease of greater than 4 g/dL), abdominal ischemia (detected with computed tomography (CT) angiography), rhythm disturbances, tracheotomy and red blood cell transfusion rate. Early outcomes were analyzed for both cohorts (ELG and EMG).
2.4. Ethics

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The Ethics Committee of the Medical Faculty of the University of Cologne stated that we are exempted from applying for ethical approval as no separate ethics application or statement of ethical approval by the local ethics committee are required for performing purely retrospective clinical studies under German law.

2.5. Statistical Analysis

Statistical analysis was performed using the Statistical Package for Social Sciences, version 23.0 (SPSS IBM, Chicago, IL, USA). All data were presented as continuous or categorical variables. Categorical data were expressed as total numbers and percentages. Continuous data were evaluated for normality using a one-sample Kolmogorov-Smirnov test and were expressed as the mean ± standard deviation (SD) in cases of normally distributed, or median (interquartile range) in cases of non-normally distributed continuous variables. Univariate analysis was performed using either a Student t or a Mann-Whitney U test for normally and non-normally distributed continuous variables, respectively. Pearson’s $\chi^2$ or Fisher exact tests were used for the comparison of categorical data, depending on the minimum expected count in each cross-tab. Logistical regression was conducted in order to create the predicted variable. A rigorous 1:1 nearest neighbor-matching algorithm, without replacement, was used with a 0.2 caliper set. Standardized-mean-differences (d-values) were calculated, and absolute d-values under 0.2 were considered to be an indicator of adequate balance and sufficient reduction of bias; $p$ values < 0.05 were considered statistically significant.

3. Results

3.1. Preoperative Profile Differences Depending on Urgency before and after PSM

The preoperative characteristics of the study population are presented in Table 1. Both groups differed in several preoperative characteristics. Congruent to the preoperative co-morbidity profile, the EUROSCORE II ($p < 0.001$ before PSM and $p < 0.001$ after PSM) and the STS score ($p = 0.001$ before PSM and $p < 0.001$ after PSM) were significantly higher in the EMG. Preoperative catecholamine therapy ($p < 0.001$ before PSM $p < 0.001$ after PSM) was significantly higher in the EMG compared to the ELG. Similarly, duration of mechanical ventilation ($p < 0.001$ before PSM $p < 0.001$ after PSM) was significantly higher in the EMG.

### Table 1. Preoperative characteristics of patients with PCS and ECMO-therapy before and after PSM.

| Preoperative Characteristics                       | Elective (n = 95) | Emergency (n = 69) | p-Value | Elective (n = 56) | Emergency (n = 56) | p-Value |
|----------------------------------------------------|-------------------|-------------------|---------|-------------------|-------------------|---------|
| Age, years, mean (min/max)                         | 69 (58/73)        | 61 (54/68)        | 0.001   | 62 (58/66)        | 62 (59/64)        | 0.981   |
| Body mass index, kg/m², mean (min/max)             | 27 (25/32)        | 26 (24/29)        | 0.321   | 28 (26/45)        | 26 (25/27)        | 0.139   |
| Female gender, (n) %                               | 31 (33)           | 14 (20)           | 0.080   | 19 (33.9)         | 10 (17.9)         | 0.052   |
| Chronic lung disease, (n) %                         | 11 (12)           | 8 (12)            | 0.063   | 4 (7.1)           | 7 (12.5)          | 0.341   |
| Pulmonary hypertension, (n) %                      | 24 (25)           | 2 (2.9)           | <0.001  | 4 (7.1)           | 2 (3.6)           | 0.679   |
| Renal insufficiency, (n) %                         | 32 (34)           | 12 (1.4)          | 0.024   | 13 (23.2)         | 12 (21.4)         | 0.820   |
| Renal insufficiency, (n) %                         | 5 (5.3)           | 2 (2.9)           | 0.701   | 3 (5.4)           | 2 (3.6)           | 0.647   |
| Hypertension, (n) %                                | 71 (75)           | 43 (62)           | 0.147   | 40 (71.4)         | 36 (64.3)         | 0.418   |
| Diabetes mellitus, (n) %                           | 33 (35)           | 17 (25)           | 0.204   | 17 (32.1)         | 15 (26.8)         | 0.534   |
| Peripheral vascular disease, (n) %                 | 15 (16)           | 14 (20)           | 0.404   | 5 (8.9)           | 12 (21.4)         | 0.065   |
| Atrial fibrillation, (n) %                         | 35 (37)           | 8 (12)            | <0.001  | 12 (21.4)         | 8 (14.3)          | 0.324   |
| Catecholamine therapy, (n) %                       | 0 (0.0)           | 45 (65)           | <0.001  | 0 (0.0)           | 36 (65.5)         | <0.001  |
| Mechanical ventilation, (n) %                      | 0 (0.0)           | 38 (55)           | <0.001  | 0 (0.0)           | 31 (55.4)         | <0.001  |
| Left-ventricular ejection-fraction, mean (min/max) | 50(39/60)         | 35(20/50)         | <0.001  | 50 (45/55)        | 33 (28/38)        | <0.001  |
Table 1. Cont.

| Preoperative Characteristics | Before PSM | After PSM | p-Value |
|-----------------------------|------------|-----------|---------|
|                             | Elective   | Emergency |         |
|                             | (n = 95)   | (n = 69)  |         |
| Lactate, mmol/L, mean (min/max) | 7.4(4.7/13.1) | 10.8(5.4/14.8) | 0.025  |
| EuroSCORE II, %, mean (min/max) | 7.0(4.8/9.0) | 12.9(11.0/15.0) | <0.001 |
| STS Score, mean (min/max)    | 3.7(1.5/6.5) | 17.7(5.9/28.4) | 0.001  |

Data is expressed as median (range) or percentage (counts) as indicated. IABP = intra-aortic balloon pump, ECMO = extracorporeal membrane oxygenation, CK = creatine kinases, CK-MB = creatine kinases muscle-brain.

3.2. Time Point and Indication of ECMO Therapy as Major Characteristics of Urgency Procedures after PSM

The ECMO-related parameters are summarized in Table 2. The EMG primarily received ECMO intraoperatively (ELG n = 21 (38%) vs. EMG n = 45 (80%), p ≤ 0.001). In contrast, the ELG required ECMO support more frequently postoperatively (ELG n = 35 (62%) vs. EMG n = 11 (20%), p < 0.001). The type of ECMO support, central (ELG n = 14 (25%) vs. EMG n = 8 (14%), p = 0.154) or peripheral (ELG n = 42 (75%) vs. EMG n = 48 (86%), p = 0.234), did not differ between the groups.

Table 2. ECMO-related data after PSM.

| ECMO Related Data                          | Elective (n = 56) | Emergency (n = 56) | p-Value |
|-------------------------------------------|-------------------|--------------------|---------|
| ECMO implantation intraoperative, (n) %    | 21 (38)           | 45 (80)            | <0.001  |
| ECMO implantation postoperative, (n) %     | 35 (62)           | 11 (20)            | <0.001  |
| central ECMO, (n) %                       | 14 (25)           | 8 (14)             | 0.154   |
| peripheral ECMO, (n) %                    | 42 (75)           | 48 (86)            | 0.234   |
| ECMO indication                           |                   |                    |         |
| Left ventricular failure, (n) %           | 23 (41)           | 31 (55)            | 0.185   |
| Right ventricular failure, (n) %          | 12 (22)           | 15 (27)            | 0.658   |
| Combined heart and lung failure, (n) %     | 6 (10)            | 4 (8)              | 0.740   |
| Cardiopulmonary resuscitation, (n) %      | 15 (27)           | 6 (10)             | 0.052   |
| ECMO outcome                              |                   |                    |         |
| Duration, hours, mean (min/max)           | 81 (64/97)        | 91 (72/109)        | 0.408   |
| ECMO complication, (n) %                  | 36 (64.3)         | 32 (57)            | 0.439   |
| ECMO local complication, (n) %            | 10 (17.9)         | 13 (23)            | 0.320   |
| IABP implantation, (n) %                  | 45 (80.4)         | 48 (85)            | 0.308   |
| ECMO weaning, (n) %                       | 32 (57.1)         | 26 (46.4)          | 0.257   |

Data is expressed as median (range) or percentage (counts) as indicated. ECMO = extracorporeal membrane oxygenation, IABP = intra-aortic balloon pump.

3.3. Intra- and Postoperative Outcomes of Patients with PCS and ECMO Therapy after PSM

Intraoperative and postoperative data, before and after PSM, is presented in Table 3. CABG was performed significantly more often in the EMG (ELG n = 39 (69%) vs. EMG n = 49 (87%); p = 0.037). In-hospital mortality accounted for 71% (n = 40) in the ELG and 76% (n = 43) in EMG (p = 0.518). The outcome data showed no major differences (abdominal ischemia (p = 0.371); septic shock (p = 0.393); rhythm disturbances (p = 0.575); emergency re-thoracotomy (p = 0.418) between the groups.
Table 3. Intra- and postoperative outcomes of patients with postcardiotomy cardiogenic shock and ECMO-therapy after PSM.

| Intra- and Postoperative Outcomes                        | Elective (n = 56) | Emergency (n = 56) | p-Value |
|----------------------------------------------------------|-------------------|-------------------|---------|
| CABG, (n) %                                              | 39 (69)           | 49 (87)           | 0.037   |
| CABG, isolated, (n) %                                    | 22 (39)           | 39 (69)           | 0.002   |
| Aortic valve replacement, isolated, (n) %                | 5 (8.9)           | 1 (1.8)           | 0.206   |
| Other valve surgery, (n) %                               | 2 (3.6)           | 0 (0.0)           | 0.495   |
| Cardiopulmonary bypass time, minutes, mean (min/max)    | 176 (149/203)     | 176 (145/187)     | 0.345   |
| Aortic cross-clamp time, minutes, mean (min/max)         | 78 (64/92)        | 60 (47/68)        | 0.057   |
| In hospital all-cause mortality, (n) %                   | 40 (71)           | 43 (76)           | 0.518   |
| Disabling cerebrovascular events, (n) %                  | 12 (21)           | 15 (26)           | 0.330   |
| Abdominal ischemia, (n) %                                | 11 (19)           | 15 (26)           | 0.371   |
| -Emergency laparotomy, (n) %                             | 4 (7.1)           | 4 (7.1)           | 0.642   |
| Septic shock, (n) %                                      | 8 (15)            | 12 (21)           | 0.393   |
| Rhythm disturbances, (n) %                               | 29 (51)           | 29 (51)           | 0.575   |
| Emergency re-thoracotomy, (n) %                          | 40 (71)           | 36 (64)           | 0.418   |
| Dialysis, (n) %                                          | 35 (63)           | 36 (66)           | 0.448   |
| Mechanical ventilation, days                             | 10 (8/12)         | 16 (12/18)        | 0.056   |
| Tracheotomy, (n) %                                       | 13 (23.2)         | 24 (42.9)         | 0.022   |
| Red blood cell transfusion, units, mean (min/max)        | 33 (27/38)        | 32 (22/49)        | 0.093   |
| Length of ICU stay, days, mean (min/max)                 | 11 (8/13)         | 20 (11/29)        | 0.051   |
| Discharge out of hospital, (n) %                         | 13 (23.2)         | 16 (28.6)         | 0.518   |
| Postoperative laboratory parameters                      |                   |                   |         |
| CK maximum, U/L, mean (min/max)                          | 1740 (1007/2473)  | 2361 (1644/3078)  | 0.227   |
| CK-MB maximum, U/L, mean (min/max)                       | 168 (96/240)      | 267 (179/355)     | 0.083   |
| Bilirubin, mg/dL, mean (min/max)                         | 3.2 (2.8/5.3)     | 6.2 (3.1/7.9)     | 0.178   |
| GOT maximum, U/L, mean (min/max)                         | 752 (252/1898)    | 1088 (315/3785)   | 0.071   |
| GPT maximum, U/L, mean (min/max)                         | 295 (125/590)     | 596 (225/1875)    | 0.338   |

Data is expressed as median (range) or percentage (counts) as indicated. CABG = coronary artery bypass grafting, CK = creatine kinases, CK-MB = creatine kinases muscle-brain, ICU = intensive care unit, GOT = glutamate-oxaloacetate transaminase, GPT = glutamate-pyruvate transaminase.

4. Discussion

The analysis performed clearly showed that the preoperative risk profile significantly differed between the compared patient cohorts, as expected. While the electively operated patients were treated with ECMO after surgery, the emergently operated patients showed a failure to be weaned from cardio-pulmonary bypass more frequently and required ECMO support intraoperatively. Despite significant distinctions in the preoperative, intraoperative and ECMO-related parameters, the outcome data were comparable, resulting in high mortality (70–80%) in both groups.

4.1. Risk Stratification of Urgency in Treatment Strategies

In general, urgency is known to impact the outcomes of patients [16]. Several studies have conducted comparative investigations in regard to elective or emergent surgical procedures performed [17–19]. De Rango and colleagues, in their retrospective analysis of 141 patients, showed that in-hospital mortality was strongly associated with urgency in thoracic aortic endovascular repair [20]. The results from other disciplines are not generalizable for cardiac surgery patients. Kabahizi and colleagues provided recent data of 1157 patients, indicating that urgent transcatheter aortic valve replacement (TAVR) might be performed at a similar risk to elective TAVR [21]. Singh and colleagues postulated that
the emergent use of mechanical circulatory support during TAVR is associated with high short- and long-term mortality in comparison to the elective application [22]. In particular, specific analysis of cardiac surgery procedures regarding urgency is scarce, particularly in terms of ECMO support [23–25]. Data in this specific field is lacking and our analysis is one of the first to investigate the impact of urgency on outcomes after ECMO therapy due to PCS [26–28].

4.2. Urgency Is Secondary in Cardiac Surgery ECMO Patients

In our analysis, the direct comparison between patients divided into groups based on urgency showed that in-hospital mortality rates were comparable between the groups. Despite a significantly higher EUROSCORE II and STS score, the outcomes were not different. This fact clearly indicates that PCS after cardiac surgery diminishes the presumed beneficial outcomes of patients that have had elective cardiac surgery in comparison to emergency procedures [23]. Independently of several risk factors, the leading cause of limited survival in cardiac surgery ECMO patients might be substantially triggered by PCS itself [29–33]. Badulak corroborates this postulate, suggesting that increased morbidity and mortality following ECMO insertion is independent to preoperative co-morbidities [34]. In fact, both mortality rates from our analysis (78% ELG vs. 71% EMG; \( p = 0.315 \)) match the mortality described in the current literature [35]. Therefore, therapeutic strategies in ECMO patients may not be influenced by the initial procedure [36].

4.3. Operative Characteristics in ECMO Patients Depending on Urgency

As acute CABG procedures present a significant proportion of emergent cardiac surgery procedures, it is not surprising that CABG was performed significantly more often in the EMG in our analysis. Moreover, emergent procedure patients showed higher cardiopulmonary bypass and cross clamp time, necessitating a higher number of patients in need of ECMO support intraoperatively, in comparison to elective procedure patients. The fact that patients in the EMG were provided long-term assist devices systems significantly more often remains unclear from our data and might be the focus of further investigation.

4.4. Study Limitations

The retrospective non-randomized design and analysis of a limited number of patients from a single center reduces the statistical power of the study. Therefore, the presented data should be taken with caution. However, the present report focused on short-term outcomes and did not evaluate long-term results and quality of life measures. Moreover, the collection of data was restricted to the variables that were available in electronic or written patient notes and flowcharts.

5. Conclusions

Urgency impacts the incidence of PCS and subsequent ECMO therapy in cardiac surgery patients, however, urgency itself is secondary in patients suffering PCS and following ECMO therapy, according to our data. In this regard, PCS itself seems to trigger outcomes in cardiac surgery ECMO patients substantially. In communication with relatives, this fact might help physicians to evaluate, categorize and predict outcomes among patients with PCS and consecutive ECMO therapy.

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References

1. Hannan, E.L.; Racz, M.J.; Walford, G.; Jones, R.H.; Ryan, T.J.; Bennett, E.; Culliford, A.T.; Isom, O.W.; Gold, J.P.; Rose, E.A.; et al. Long-term outcomes of coronary-artery bypass grafting versus stent implantation. N. Engl. J. Med. 2005, 352, 2174–2183. [CrossRef]

2. Lorusso, R.; Shekar, K.; MacLaren, G.; Schmidt, M.; Pellegrino, V.; Meyns, B.; Haft, J.; Vercaemst, L.; Pappalardo, F.; Bermudez, C.; et al. ELSO Interim Guidelines for Venoarterial Extracorporeal Membrane Oxygenation in Adult Cardiac Patients. ASAIO J. 2021, 67, 827–844. [CrossRef]

3. Spence, N.; Abbott, J.D. Coronary Revascularization in Cardiogenic Shock. Curr. Treat. Options Cardiovasc. Med. 2016, 18, 1. [CrossRef] [PubMed]

4. Koch, C.G.; Khandwala, F.; Nussmeier, N.; Blackstone, E.H. Gender and outcomes after coronary artery bypass grafting: A propensity-matched comparison. J. Thorac. Cardiovasc. Surg. 2003, 126, 2032–2043. [CrossRef]

5. Hernandez-Vaquero, D.; Diaz, R.; Alperi, A.; Almendarez, M.G.; Escalera, A.; Cubero-Gallego, H.; Avanzas, P.; Moris, C.; Pascual, I. Life expectancy of patients undergoing surgical aortic valve replacement compared with that of the general population. Interact. Cardiovasc. Thorac. Surg. 2020, 30, 394–399. [CrossRef]

6. Chaker, Z.; Badhwar, V.; Alqahtani, F.; Aljohani, S.; Zack, C.J.; Holmes, D.R.; Rihal, C.S.; Alkhouli, M. Sex Differences in the Utilization and Outcomes of Surgical Aortic Valve Replacement for Severe Aortic Stenosis. J. Am. Heart Assoc. 2017, 6, e006370. [CrossRef]

7. Birkmeyer, J.D.; Sievers, A.E.; Finlayson, E.V.A.; Stukel, T.A.; Lucas, F.L.; Batista, I.; Welch, H.G.; Wennberg, D.E. Hospital volume and surgical mortality in the United States. N. Engl. J. Med. 2002, 346, 1128–1137. [CrossRef] [PubMed]

8. Cram, P.; Rosenthal, G.E.; Vaughan-Sarrazin, M.S. Cardiac revascularization in specialty and general hospitals. N. Engl. J. Med. 2005, 352, 1454–1462. [CrossRef] [PubMed]

9. Mariscalco, G.; Salsano, A.; Fiore, A.; Dalén, M.; Ruggieri, VG.; Saeed, D.; Jönsson, K.; Gatti, G.; Zipfel, S.; Dell’Aquila, A.M.; et al. Peripheral versus central extracorporeal membrane oxygenation for postcardiotomy shock: Multicenter registry, systematic review, and meta-analysis. J. Thorac. Cardiovasc. Surg. 2020, 160, 1207–1216.e44. [CrossRef]

10. Chung, S.Y.; Sheu, J.J.; Lin, YJ.; Sun, C.K.; Chang, L.T.; Chen, Y.L.; Tsai, T.H.; Chen, C.J.; Yang, C.H.; Hang, C.L.; et al. Outcome of patients with profound cardiogenic shock after cardiopulmonary resuscitation and prompt extracorporeal membrane oxygenation support. A single-center observational study. Circ. J. 2012, 76, 1385–1392. [CrossRef]

11. Doll, N.; Kiaii, B.; Borger, M.; Buceriuss, J.; Krämer, K.; Schmitt, D.V.; Walther, T.; Mohr, F.W. Five-year results of 219 consecutive patients treated with extracorporeal membrane oxygenation for refractory postoperative cardiac shock. Ann. Thorac. Surg. 2004, 77, 151–157. [CrossRef]

12. Smedira, N.G.; Moazami, N.; Golding, C.M.; McCarthy, P.M.; Apperson-Hansen, C.; Blackstone, E.H.; Cosgrove, D.M. 3rd Clinical experience with 202 adults receiving extracorporeal membrane oxygenation for cardiac failure: Survival at five years. J. Thorac. Cardiovasc. Surg. 2001, 122, 92–102. [CrossRef] [PubMed]

13. Ostadal, P.; Roktya, R.; Kruger, A.; Vondráková, D.; Janotka, M.; Smid, O.; Smalova, J.; Hromadka, M.; Linhart, A.; Bělohlávek, J. Extra corporeal membrane oxygenation in the therapy of cardiogenic shock (ECMO-CS): Rationale and design of the multicenter randomized trial. Eur. J. Heart Fail. 2017, 19, 124–127. [CrossRef] [PubMed]

14. Gerfer, S.; Gaisendrees, C.; Djordjevic, I.; Ivanov, B.; Merkle, J; Eghbalzadeh, K; Schlachtenberger, G; Rustenbach, C; Sabashnikov, A; Kuhn-Régnier, F; et al. Gender-related propensity score match analysis of ECMO therapy in postcardiomyopathy cardiac shock in patients after myocardial revascularization. Perfusion 2022, 37, 470–476. [CrossRef] [PubMed]

15. Gaisendrees, C.; Djordjevic, I.; Sabashnikov, A.; Adler, C.; Eghbalzadeh, K.; Ivanov, B.; Walter, S.G.; Braumann, S.; Wörmann, J.; Suhr, L.; et al. Gender-related differences in treatment and outcome of extracorporeal cardiopulmonary resuscitation-patients. Artif. Organs 2021, 45, 488–494. [CrossRef] [PubMed]

16. Farnsworth, N.; Fagan, S.P.; Berger, D.H.; Awad, S.S. Child-Turcotte-Pugh versus MELD score as a predictor of outcome after elective and emergent surgery in cirrhotic patients. Am. J. Surg. 2004, 188, 580–583. [CrossRef] [PubMed]

17. Diaz, A.; Barmash, E.; Azap, R.; Paredes, A.Z.; Hyer, J.M.; Pawlik, T.M. Association of County-Level Social Vulnerability with Elective Versus Non-elective Colorectal Surgery. J. Gastrointest. Surg. 2021, 25, 786–794. [CrossRef] [PubMed]
18. Gadzhiev, N.K.; Akopyan, G.N.; Tursunova, F.I.; Afyouni, A.S.; Korolev, D.O.; Tsarichenko, D.G.; Rapoport, L.M.; Okhunov, Z.; Bhaskar, S.; Malkhasyan, V.A. Emergency versus elective ureteroscopy for the management of ureteral stones. *Urológia* 2022, 89, 79–84. [CrossRef]

19. Dick, F.; Hinder, D.; Imme, F.F.; Savolainen, H.; Do, D.D.; Carrel, T.P.; Schmidli, J. Thoracic endovascular aortic repair: Impact of urgency on outcome and quality of life. *Eur. J. Cardiothorac. Surg.* 2009, 35, 96–103. [CrossRef]

20. de Rango, F.; Isernia, G.; Simonte, G.; Cieri, E.; Marucchini, A.; Farchioni, L.; Verzini, F.; Lenti, M. Impact of age and urgency on survival after thoracic endovascular aortic repair. *J. Vasc. Surg.* 2016, 64, 25–32. [CrossRef]

21. Kabahizi, A.; Sheikh, A.S.; Williams, T.; Taneseo, K.; Myat, A.; Trivedi, U.; de Belder, A.; Cockburn, J.; Hildick-Smith, D. Elective versus urgent in-hospital transcatheter aortic valve implantation. *Catheter. Cardiovasc. Interv.* 2021, 98, 170–175. [CrossRef] [PubMed]

22. Singh, V.; Damluji, A.A.; Mendirichaga, R.; Alfonso, C.E.; Martinez, C.A.; Williams, D.; Heldman, A.W.; de Marchena, E.J.; O’Neill, W.W.; Cohen, M.G. Elective or Emergency Use of Mechanical Circulatory Support Devices During Transcatheter Aortic Valve Replacement. *J. Interv. Cardiol.* 2016, 29, 513–522. [CrossRef] [PubMed]

23. Khorsandi, M.; Treml, B.; Jadzic, D.; Breitkopf, R.; Oberleitner, C.; Krneta, M.P.; Bukumiric, Z. Extra-corpooreal membrane oxygenation for refractory cardiogenic shock after adult cardiac surgery: A systematic review and meta-analysis. *J. Cardiothorac. Surg.* 2017, 12, 55. [CrossRef]

24. Benseghir, Y.; Sebestyan, A.; Durand, M.; Benenni, F.; Bédague, D.; Chavanon, O. ECMO for post cardiotomy refractory cardiogenic shock: Experience of the cardiac surgery department of the Grenoble Alpes University Hospital. *Ann. Cardiol. Angeiol. (Paris)* 2021, 70, 63–67. [CrossRef]

25. Brewer, J.M.; Tran, A.; Yu, J.; Ali, M.I.; Poulos, C.M.; Gates, J.; Gluck, J.; Underhill, D. ECMO after cardiac surgery: A single center study on survival and optimizing outcomes. *J. Cardiovasc. Surg.* 2021, 62, 264. [CrossRef] [PubMed]

26. Djordjevic, I.; Deppe, A.-C.; Sabashnikov, A.; Kuhn, E.; Eghbalzadeh, K.; Merkle, J.; Gerfer, S.; Gaisendrees, C.; Ivanov, B.; Moellenbeck, L.; et al. Concomitant ECMO And IABP Support in Postcardiomyopathy Cardiogenic Shock Patients. *Heart Lung Circ.* 2021, 30, 1533–1539. [CrossRef]

27. Djordjevic, I.; Eghbalzadeh, K.; Sabashnikov, A.; Deppe, A.-C.; Kuhn, E.; Merkle, J.; Weber, C.; Ivanov, B.; Ghodsi-zad, A.; Rustenbach, C.; et al. Central vs peripheral venoarterial ECMO in postcardiomyopathy cardiogenic shock. *J. Card. Surg.* 2020, 35, 1037–1042. [CrossRef] [PubMed]

28. Djordjevic, I.; Eghbalzadeh, K.; Sabashnikov, A.; Deppe, A.C.; Kuhn, E.W.; Seo, J.; Weber, C.; Merkle, J.; Adler, C.; Rahmanian, P.B.; et al. Single center experience with patients on veno arterial ECMO due to postcardiomyopathy right ventricular failure. *J. Card. Surg.* 2020, 35, 83–88. [CrossRef]

29. Ogami, T.; Takayama, H.; Melehy, A.; Witter, L.; Kaku, Y.; Fried, J.; Masoumi, A.; Brodie, D.; Takeda, K. A Standardized Approach Improves Outcomes of Extracorporeal Membrane Oxygenation for Postcardiomyopathy Shock. *ASAIO J.* 2021, 67, 1119–1124. [CrossRef]

30. Mariscalco, G.; El-Dean, Z.; Yusuff, H.; Fox, T.; Dell’Aquila, A.M.; Jónsson, K.; Ragnarsson, S.; Fiore, A.; Dalén, M.; di Perna, D.; et al. Duration of Venoarterial Extracorporeal Membrane Oxygenation and Mortality in Postcardiomyopathy Cardiogenic Shock. *J. Cardiothorac. Vasc. Anesth.* 2021, 35, 2662–2668. [CrossRef]

31. Raffa, G.M.; Kowalewski, M.; Brodie, D.; Ogin, M.; Whitman, G.; Meani, P.; Pilato, M.; Arcadipane, A.; Delnoij, T.; Natour, E.; et al. Meta-Analysis of Peripheral or Central Extracorporeal Membrane Oxygenation in Postcardiomyopathy and Non-Postcardiomyopathy Shock. *Ann. Thorac. Surg.* 2019, 107, 311–321. [CrossRef] [PubMed]

32. Huang, D.; Xu, A.; Guan, Q.; Qin, J.; Zhang, C. Venoarterial extracorporeal membrane oxygenation with intra-aortic balloon pump for postcardiomyopathy cardiogenic shock: A systematic review and meta-analysis. *Perfusion* 2021. [CrossRef] [PubMed]

33. Wang, L.; Wang, H.; Hou, X. Clinical Outcomes of Adult Patients Who Receive Extracorporeal Membrane Oxygenation for Postcardiomyopathy Cardiogenic Shock: A Systematic Review and Meta-Analysis. *J. Cardiovasc. Anesth.* 2018, 32, 2087–2093. [CrossRef]

34. Badulak, J.H.; Shinar, Z. Extracorporeal Membrane Oxygenation in the Emergency Department. *Emerg. Med. Clin. N. Am.* 2020, 38, 945–959. [CrossRef] [PubMed]

35. Rastan, A.J.; Dege, A.; Mohr, M.; Doll, N.; Falk, V.; Walther, T.; Mohr, F.W. Early and late outcomes of 517 consecutive adult patients treated with extracorporeal membrane oxygenation for refractory postcardiomyopathy cardiogenic shock. *J. Thorac. Cardiovasc. Surg.* 2010, 139, 302–311. [CrossRef] [PubMed]

36. Sabashnikov, A.; Djordjevic, I.; Deppe, A.; Kuhn, E.W.; Merkle, J.; Weber, C.; Sindhu, D.; Eghbalzadeh, K.; Zerouh, M.; Liakopoulos, O.J.; et al. Managing Traps and Pitfalls During Initial Steps of an ECMO Retrieval Program Using a Miniaturized Portable System: What Have We Learned From the First Two Years? *Artif. Organs* 2018, 42, 484–492. [CrossRef] [PubMed]