ORIGINAL ARTICLE

Outcomes of extracorporeal membrane oxygenation use in postcardiotomy shock at a single center

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Objective. *The primary objective of this study was to describe the outcomes of patients who underwent extracorporeal membrane oxygenation (ECMO) following postcardiotomy shock at a single center.* ***Material.*** *In this retrospective study, we reviewed the records of patients who had received postcardiotomy ECMO therapy from July 1, 2015 to December 31, 2019. The demographic characteristics and perioperative conditions were described.* ***Results.*** *We included 31 patients, 51.6% female. The median age of 26 years (IQR 12-54.5). Postcardiotomy venoarterial ECMO was used in 1.2% of all operations. Congenital procedures were the type of surgical procedure most associated with using ECMO (61.3%). The most common complication was renal failure (35.4%). The median duration of therapy in patients with successful and unsuccessful withdrawals was 5 and 6 days, respectively. Successful ECMO withdrawal was achieved in 38.7% of patients and 29.1 % at hospital discharge. Cardiogenic shock was the most prevalent cause of death (54.8%).* ***Conclusions.*** *ECMO contributes to improved outcomes in cases where alternative supportive measures are inadequate. The results from our center are similar to published reports supporting the use of postcardiotomy ECMO therapy as a feasible option for critically ill patients.*

Key words: Extracorporeal membrane oxygenation; Postcardiotomy shock; Congenital heart disease.

Objetivo. *El objetivo principal de este estudio fue describir los resultados de los pacientes que se sometieron a oxigenación por membrana extracorpórea (ECMO) en choque posterior a cirugía cardíaca en un solo centro.* ***Material.*** *Es este estudio retrospectivo, revisamos los expedientes de los pacientes que habían recibido terapia ECMO posquirúrgica desde el 1 de julio de 2015 hasta el 31 de diciembre de 2019. Se describieron las características demográficas y las condiciones perioperatorias.* ***Resultados.*** *Se incluyeron 31 pacientes, 51.6% fueron mujeres. La mediana de edad fue de 26 años (RIC 12-54.5). La terapia ECMO postcardiotomía se utilizó en el 1.2% de todas las cirugías. Los procedimientos congénitos se asociaron con más frecuencia en el uso de ECMO (61.3%). La complicación más común fue la insuficiencia renal (35.4%). La mediana de duración de la terapia en pacientes con retiro exitoso y no exitoso fue de 5 y 6 días, respectivamente. Se retiro el ECMO con éxito en 38.7% de los pacientes y 29.1% fue dado de alta. El choque cardiogénico fue la causa de muerte más frecuente de muerte (54.8%).* ***Conclusiones.*** *La terapia ECMO contribuye a mejorar los resultados en los casos en que las medidas de apoyo alternativas resultan inadecuadas. Los resultados de nuestro centro son similares a informes publicados, lo que respalda el uso de la terapia ECMO postcardiotomía como una opción factible para pacientes en estado crítico.*

Palabras clave: Oxigenación por membrana extracorpórea; Choque postcardiotomía; Cardiopatias congénitas.

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Postcardiotomy shock is a complication of cardiac surgery with an incidence of 0.5% to 6% and is associated with a poor prognosis. It is characterized by the inability to wean from cardiopulmonary bypass in the operating room or deterioration of myocardial function during the initial postoperative days and is a life-threatening complication associated with mortality rates ranging from 50% to 80%. After cardiac surgery, VA (venoarterial) ECMO (extracorporeal membrane oxygenation) is initiated in approximately 0.6% to 2.9% of patients [1].

However, despite postcardiotomy VA ECMO support, the in-hospital mortality rate ranges from 53% to 84% and is influenced by patient characteristics and the surgical case mix [1]. Approximately 3.2%–8.4% of children undergoing cardiac surgery may require circulatory support with ECMO owing to cardiogenic shock refractory to optimal medical treatment [2,3]. VA ECMO is intended to completely replace

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cardiac and pulmonary function, maintain continuous tissue perfusion, and allow the heart to recover. When recovery of cardiac function does not occur, VA ECMO can serve as a bridge to a left ventricular assist device, total artificial heart, or heart transplant [1]. In the United States and other developed countries, tertiary care hospitals have extensive experience using this therapy. However, its use in Mexico is relatively recent, considering it was established in 2013 [4,5].

The primary objective of this study was to describe the outcomes of patients who underwent ECMO following postcardiotomy shock at a single center.

MATERIAL

The local institutional review board approved the study, waving the need for patient consent. We conducted a descriptive and cross-sectional study to review the results of VA ECMO use in patients with postcardiotomy shock. We reviewed the records of patients who had received this therapy and met the inclusion criteria between July 1, 2015, and December 31, 2019. The inclusion criteria encompassed the presence of postcardiotomy shock and the use of ECMO for circulatory support. Patients whose clinical records did not include information essential for this study were excluded.

Statistical analysis

We used descriptive statistics for continuous variables, with measures of central tendency (mean, median, and mode), standard deviation, and range. Distributions were evaluated using the Shapiro–Wilk test. Asymmetric data were measured with Fisher's coefficient, and the degree of concentration or Kurtosis was determined. We evaluated quartiles and percentiles. For categorical variables, frequency distributions were shown using box-and-whisker plots. The data were visualized using bar graphs and histograms. The software used was SPSS version 24.0, SPSS Inc., Chicago, IL.

RESULTS

A total of 31 patients were included, 16 (51.6%) female and 15 (48.4%) males. Four patients were excluded because of incomplete records (**Table 1**). The median age was 26 years (IQR 12 - 54.5). The youngest patient was 4 years, while the oldest was 66 years. The mean body mass index was 22.5 kg/m2 (SD 5.5]; the most frequent body mass index was 29.3 kg/m2, with a minimum of 13.6 kg/m2 and a maximum of 32 kg/m2. The mean weight was 54.7 kg (SD 23.5); the most frequently reported was 64 kg, with a minimum of 16 kg and a maximum of 95 kg. The median height was 157 cm (IQR 145–168), ranging between 100 cm and 180 cm. The mean body surface area was 1.5 m2 (SD 0.4); the most frequent was 1.4 m2, with a minimum of 0.67 m2 and a maximum of 2.1 m2 (**Fig. 1**). The expected mortality for the different types of surgical procedures was established using the Comprehensive Aristotle Risk Score for congenital procedures. The mean score was 8.5 points (SD 2.7), yielding a surgical risk level of 3 (out of 4); 7.0 points was the most frequent score, with a minimum of 3.0 and a maximum of 13.0 points. For non-congenital surgical procedures, the EuroSCORE II risk scale was used. The median score was 2.5 points (IQR 1.4–7.0), indicating a low surgical risk (<5 points). The lowest patient score was 0.6, and the highest was 12.5. We evaluated cardiac function on initiation of ECMO using four echocardiographic parameters. The median left ventricular ejection fraction was 21% (IQR 15.0–21.0), ranging from 5% to 60%. The median tricuspid annular plane systolic excursion was 5 mm (IQR 15–26.5), ranging from 2 mm to 10 mm. The median aortic velocity-time integral was 4.7 cm (IQR 4.1–5.6), ranging from 1.9 cm to 16 cm. The median cardiac output on initiation of ECMO was 1.8 l/min (IQR 1.7–2.5), ranging between 1.50 l/min and 3.1 l/min. Most patients, 30 (96.8%), were not diagnosed with diabetes mellitus or systemic arterial hypertension 26 (80.6%). Among the included patients, 10 (32.2%) had previous cardiac surgery.

Table 1. Overall patient characteristics

Age (years)	Gender	BSA (kg/m2)	SAH	DM	Reoperation[a]	Aristotle[b]	EuroScore II
11	F	0.86	No	No	Yes	8.5	-
13	F	1.25	No	No	Yes	7.5	-
13	M	1.64	No	No	No	7	-
11	F	1.08	No	No	No	11	-
66	M	1.70	Yes	No	No	-	6.9
13	F	1.40	No	No	No	9	-
12	M	1.37	No	No	Yes	7	-
66	F	1.54	Yes	No	Yes	-	11
40	F	1.67	Yes	No	No	10	-
33	F	1.57	No	No	Yes	-	2
06	F	0.68	No	No	No	3	-
14	F	1.39	No	No	No	12	-
54	M	1.98	No	No	No	-	0.8
58	F	1.49	Yes	No	No	-	4.9
17	M	1.35	No	No	Yes	10	-
57	M	1.93	No	No	No	-	0.67
29	F	1.68	No	No	No	10	-
12	M	1.40	No	No	Yes	11	-
55	M	1.89	No	No	Yes	-	3.09
35	M	2.18	No	No	No	-	12.5
04	F	0.67	No	No	No	3	.
35	M	2.00	Yes	No	No	13	-
57	F	1.58	No	No	No	-	0.9
56	M	2.00	Yes	No	No	-	1.59
59	M	2.07	No	Yes	No	-	1.73
31	F	1.47	No	No	No	6	-
14	F	1.29	No	No	Yes	11	-
07	M	0.73	No	No	No	7.5	-
26	M	1.99	No	No	No	-	7.5
09	F	0.79	No	No	Yes	8	-
12	M	1.74	No	No	No	7	-

BSA: body surface area; DM: diabetes mellitus; F: female; M: male; SAH: systemic arterial hypertension. [a]History of cardiac surgery with a conventional sternotomy approach. [b]Comprehensive Aristotle Score.

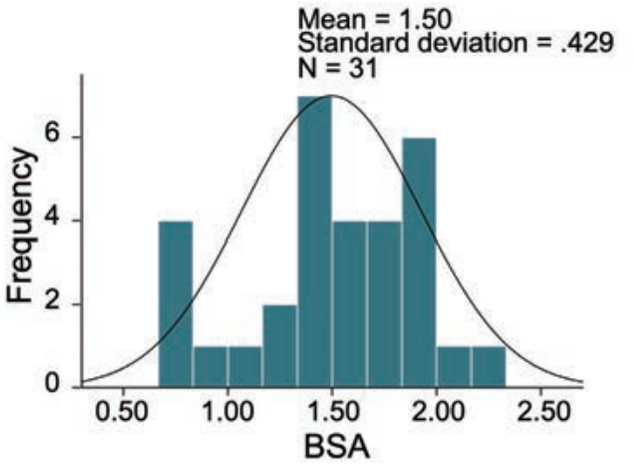

Figure 1. Frequency distribution intervals in comparison with normal distribution. BSA: body surface area.

74.1% of patients were treated using Cardiohelp (Getinge AB, Rastatt, Germany) and 25.9% with Sorin SCP (LivaNova PLC, Mirandola, Italy) systems; the latter used Dideco Membranes (LivaNova PLC, Mirandola, Italy). Congenital procedures were the type of surgical procedure most associated with using ECMO; the therapy was used in 19 (61.3%) patients. Other types of procedures included were isolated valve surgery 7 (22.6%), isolated myocardial revascularization 2 (6.5%), and other procedures 2 (6.5%). Only one patient (3.2%) with a mixed procedure (valve surgery and coronary artery bypass graft) required circulatory support (**Fig. 2**).

Peripheral cannulation was the most frequently used 14 (45.1%). A central approach and hybrid cannulation were used in 12 (38.7%) and 5 (16.1%). The most used left ventricular venting method was double inotropic therapy in 10 (32.3%), followed by surgical atrioseptostomy 6 (19.4%) and drainage catheter in the right superior pulmonary vein was used in 6 (19.4%). No venting method was used in 4 (12.9%); intra-aortic balloon pump was used in 2 (6.5%). The mixed form (surgical atrioseptostomy plus drainage catheter in the right superior pulmonary vein) was used in 2 (6.5%), and only one patient underwent percutaneous atrioseptostomy (3.2%).

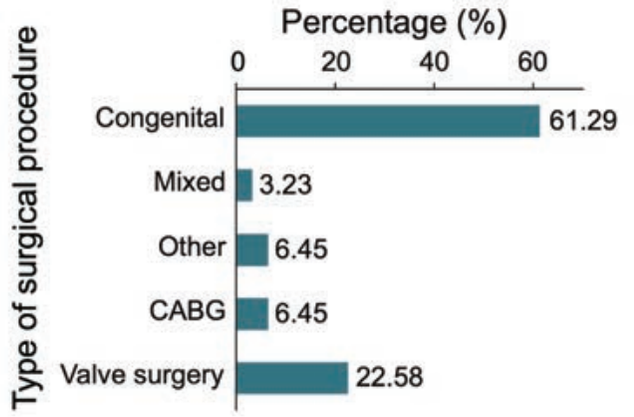

Figure 2. Surgery to treat congenital heart disease is noteworthy for its greater use of circulatory therapy. Mixed indicates valve surgery plus CABG. CABG: coronary artery bypass graft.

Among complications that occurred with the use of ECMO, the most frequent was renal failure 11 (35.4%); major bleeding with central cannulation 10 (32.2%); and infections 10 (32.2%), all respiratory origin; and two of the latter patients (6.4%) developed sepsis. Cardiac tamponade occurred in 5 (16.1%) cases, and injury to an artery or vein of the lower extremities occurred in 4 (12.9%). Cerebrovascular events during postcardiotomy VA ECMO occurred in 3 (9.6%), all of whom were hemorrhagic. Bleeding at the peripheral cannulation site was seen in 2 (6.4%) of patients. Hemolysis was observed in only two patients (6.4%).

The median duration of postcardiotomy VA ECMO in patients with successful and unsuccessful withdrawal was 5 days (IQR 3.5–9.0) and 6 days (IQR 3–12.5), respectively. The shortest duration of ECMO therapy was 3 days in the first group and one day in the second group, whereas the longest durations were 20 and 25 days, respectively (**Fig. 3**).

After ECMO withdrawal, echocardiographic parameters were as follows. The mean left ventricle ejection fraction was 51.6% (SD 12.1%); the most frequent value was 23%, with a minimum of 23% and a maximum of 68%. The mean tricuspid annular plane systolic excursion was 12.0 (SD 3.4) mm; the most frequently reported value was 11 mm, with a minimum of 7.5 mm and a maximum of 20 mm. The mean aortic velocity time integral was 18.2 (SD 5.1) cm; the most frequent value was 22 cm, with a minimum of 8.9 cm and a maximum of 25 cm. The median cardiac output was 4.5 l/min (IQR 4.4–5.2 l/min). The lowest cardiac output was 4.2 l/min, and the highest was 5.5 l/min.

Withdrawal of postcardiotomy VA ECMO was successful in 12 (38.7%) patients and 9 (29.1%) at hospital discharge. Regarding patients in whom ECMO was unsuccessful, the most frequently reported cause of mortality was cardiogenic shock 17 (54.8%). Two patients (6.4%) died of hypovolemic shock.

DISCUSSION

VA ECMO postcardiotomy shock has a reported success rate at hospital discharge of approximately 40% [4, 5]. Although still not optimal, the success rate at our hospital was acceptable (38.7% at withdrawal and 29% at hospital discharge). Furthermore, the number of cases with satisfactory outcomes has been increasing as the center acquires experience in patient selection, decision-making, cannulation techniques, and care of the patient during ECMO therapy. Throughout the study period, ECMO employment for postcardiotomy shock constituted 1.2% of all performed surgeries, consistent with global findings reported in other studies [1, 4].

Surgical treatment for congenital heart defects is highly complex, particularly when two or three-stage procedures must be performed. The patients in this study had a mean Comprehensive Aristotle Score of 8.5 points, representing greater complexi-

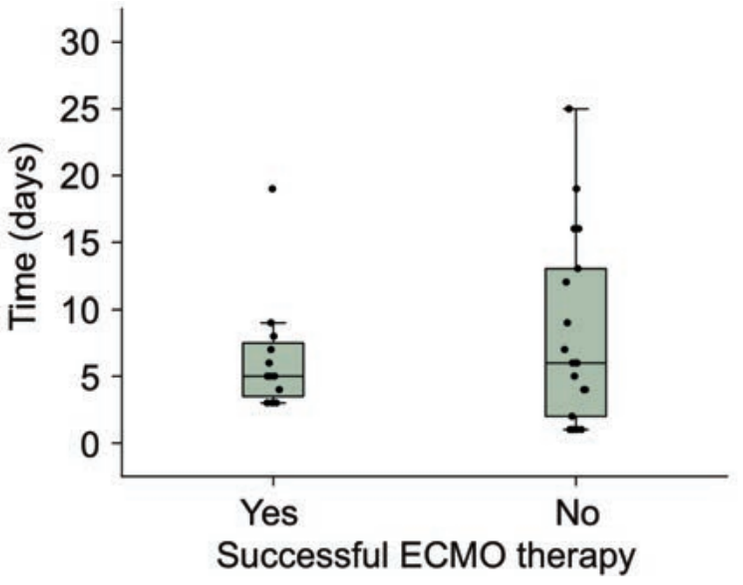

Figure 3. Box-and-whisker plots of the duration of ECMO therapy in successful and unsuccessful cases. ECMO: extracorporeal membrane oxygenation.

ty. This coincided with the greater use of ECMO therapy in these procedures [6,7].

The factors that most influence the prognosis of patients treated with ECMO are the timing of initiation and the parameters evaluated before cannulation [8-12]. We found that in our cases treated during 2015 and 2016, the optimal echocardiographic evaluation was not conducted, and the initiation of therapy was delayed in some cases. We also identified that a left ventricular venting technique was rarely used. The relationship between left ventricular venting and favorable outcomes is well-documented [13]. The Impella Device (Abiomed Inc, Danvers, MA) in ECMO is a good option for unloading the left ventricle but is very expensive for routine use. After the training of the ECMO team, we decided to use an unloading left ventricle method routinely. The best results were related to this strategy, among other modifications in the patient's care with ECMO. We generally use double inotropic therapy, surgical atrioseptostomy, or a drainage catheter in the right superior pulmonary vein. Our approach to surgical atrioseptostomy is distinctive. We place a purse in the right atrium with a polypropylene suture, then insert a 5 mm thoracoscopy trocar through the purse, ensuring a procedure is airtight all the time. Then a puncture of the oval fossa is performed, guided by reconstruction in 3D rendering of the atrial septum by transesophageal echocardiography. The benefit of this approach is reducing the risk of iatrogenic injuries to adjacent structures without needing catheterization to perform atrioseptostomy.

The duration of ECMO support has been correlated with the prognosis of patients. In VA ECMO, the ideal treatment duration is no longer than 3–5 days; survival after 10 days is very low [11, 14]. We showed that in most patients with successful outcomes, the duration of ECMO was between 3 and 9 days. Cardiogenic shock was the main cause of death among patients with unsuccessful ECMO. Two patients died of hypovolemic shock, a complication that is very difficult to treat in these patients and has been the subject of multiple recent studies [7, 11, 15].

Renal failure and bleeding at the cannulation site are the most common complications among patients receiving ECMO. Acute kidney failure is as high as 70% to 85%. Acute renal failure in ECMO is associated with higher mortality rates of up to 80% [16-19]. Bleeding is more common in postcardiotomy therapy, ranging between 10% and 30% [15,19]. Consistent with other reports, kidney failure and bleeding were the predominant complications observed at our center. Infectious complications are reported worldwide in approximately 13% of cases. Infection mainly originates in the respiratory and urinary systems and is often associated with sepsis [19, 20]. In our study, infection occurred in 32.2% of the patients. Among these, two patients developed sepsis. We showed that hemolysis was among the less common complications (6.4%). We believe this complication may be underdiagnosed because, at our hospital, there is no free hemoglobin in the plasma test [21, 22]. Limb ischemia complications were not frequent, which could be explained by the greater number of cases with central or hybrid cannulation and the routine use of distal perfusion cannula in the femoral artery in peripheral cannulation patients. Cerebrovascular events were also rare (9.6%), and they were all related to supra-anticoagulation, which resulted in hemorrhagic events.

Echocardiographic evaluation to decide on ECMO cannulation is very important. Past studies reported the need to assess left and right ventricular morphology and function, the dimension and volume of the right atrium, valve pathology, and other factors such as the presence of patent foramen ovale, aortic dissection or atheroma, and the Chiari network [12]. We collected data on left ventricle ejection fraction, tricuspid annular plane systolic excursion, aortic velocity time integral, and cardiac output. These parameters at the initiation of ECMO were as follows: median left ventricle ejection fraction was 21%, median tricuspid

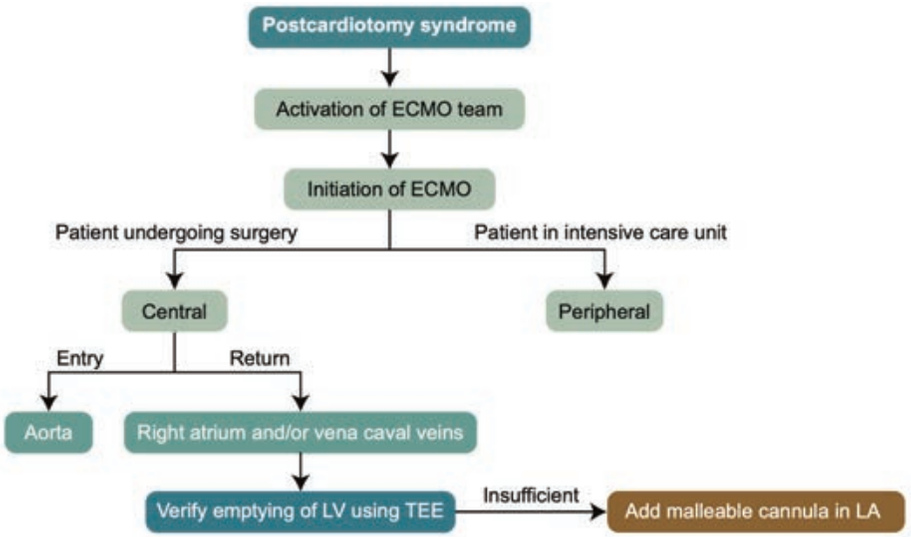

Figure 4. Algorithm to decide the configuration of cannulation in postcardiotomy shock. ECMO: extracorporeal membrane oxygenation; LA: left atrium; LV: left ventricle; TEE: transesophageal echocardiography.

annular plane systolic excursion was 5 mm, aortic velocity time integral was 4.7 cm, and cardiac output was 1.8 l/min. These were undoubtedly very low values, indicating poor cardiac function and contributing to the decision to use circulatory therapy. These same parameters were measured upon therapy withdrawal, revealing the following values: mean left ventricle ejection fraction was 51.6%, mean tricuspid annular plane systolic ejection was 12 mm, mean aortic velocity time integral was 18.2 cm, and cardiac output was 4.5 l/min. Most patients had records with target echocardiographic parameters, but some patients could not complete echocardiographic evaluation.

Importantly, the current patient assessment carried out by the ECMO team at this center is comprehensive and includes additional parameters such as the Interagency Registry for Mechanically Assisted Circulatory Support classification, age, type of pathology, evaluation of chronic or acute irreversible organic conditions, absence of contraindications, and team consensus.

Furthermore, we have decision algorithms for VA ECMO weaning and cannulation configuration in postcardiotomy shock. For a patient with postcardiotomy syndrome, we activate an ECMO alert to make the equipment available as soon as possible. We use central or hybrid cannulation if the patient is in the operating room. Our hybrid configuration consists of aortic cannulation with a polytetrafluoroethylene tubular, which is across through skin below the xiphoid appendix, and then is connected to the aortic cannula; this maneuver allows definitive sternal close. Venous drainage is carried out with a femoral or jugular cannula. If the patient is in intensive care and his clinical state is critical, we opt for peripheral femoral cannulation. We verify in all cases that the left ventricle is decompressed. The weaning begins when the patient presents data of cardiac recovery with adequate pulse pressure, mean arterial pressure over 60 mmHg with low dose or no vasopressor support, and without metabolic complications. We generally perform this protocol after 72 hours of placing the ECMO.

Our approach involves a gradual reduction in ECMO flow followed by a comprehensive hemodynamic evaluation. If hemodynamic deterioration occurs, the previous flow supply is reinstated, and subsequent weaning attempts are made (**Fig. 4**) (**Fig. 5**). The ECMO team was better trained in all aspects during the second half of the study period, which coincided with the better results obtained in the latest cases. In-hospital staff training began in 2017; from then on, theoretical-practical seminars are held every six months, allowing team members to transmit knowledge and experience.

Information regarding the outcomes of ECMO use in the context of cardiac surgery remains limited. While a few large series have reported results on ECMO therapy over the past three decades [23], its application has increased in the post-cardiac surgery setting. Remarkably, despite its widespread use, ECMO therapy after cardiac surgery has not shown a clear association with improved outcomes [24, 25].

As a conclusion, postcardiotomy VA ECMO was utilized in just over 1% of cardiac surgery patients experiencing postcardiotomy shock. Circulatory therapy was commonly required during congenital malformation procedures, particularly in high-risk patients. Successful ECMO cases demonstrated shorter therapy durations, typically within 7 days. Our center's outcomes align with numerous published reports, further supporting VA ECMO as a viable option for critically ill patients. VA ECMO improves outcomes by providing circulatory support in cases where alternative support measures prove inadequate.

Study limitations

As limitations in this study, the data used in this study were based on the clinical records; however, bias related to variability in inter-rater reliability may be present. The sample size was small because postcardiotomy VA ECMO is performed infrequently at our center, which limited our ability to calculate measures of association. However, this descriptive study fulfilled our objectives and must be understood from this perspective.

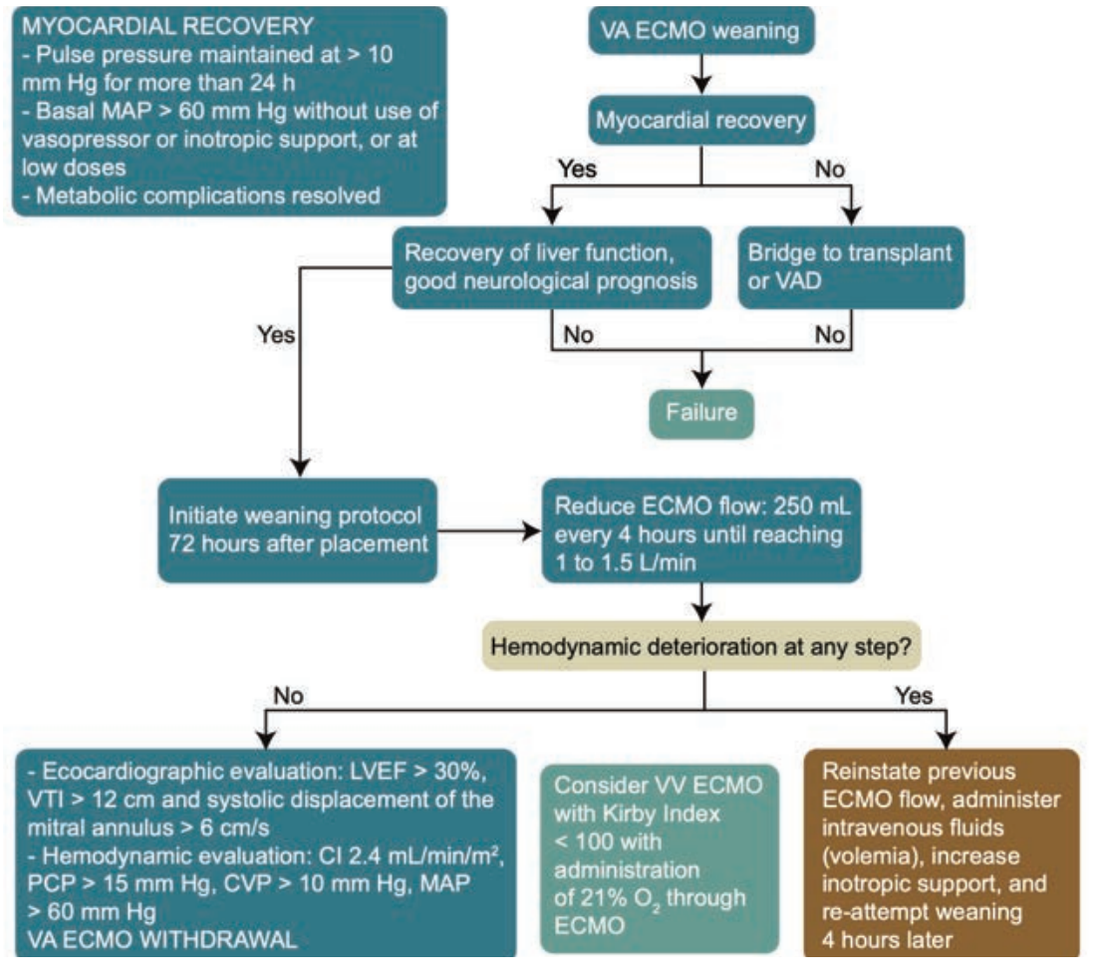

Figure 5. Venoarterial ECMO weaning algorithm. CI: cardiac index; CVP: central venous pressure; ECMO: extracorporeal membrane oxygenation; MAP: mean arterial pressure; PCP: pulmonary capillary pressure; VA: venoarterial; VAD: ventricular assist device; VV: venovenous.

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