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# Extracorporeal Membrane Oxygenation Support for Post-Cardiotomy Cardiogenic Shock

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<http://dx.doi.org/10.5772/intechopen.76217>

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## Abstract

Cardiogenic shock following cardiac surgery is rare, but a serious complication. Patients who suffer from severe valvular disease, low cardiac function, massive myocardial infarction, and acute aortic dissection have high risk of cardiogenic shock after surgery. Extracorporeal membrane oxygenation (ECMO) is a last resort treatment option for such patients. However, ethical concerns exist regarding whether ECMO is worthwhile for them, because it carries a huge financial burden, and the mortality of ECMO patients following cardiac surgery is reported to be as high as 60–80%. No guideline exists regarding optimal patient selection, duration of mechanical support, and management of ECMO. There are many unanswered questions in this field. This is a comprehensive review regarding the most recent available evidences in the field of ECMO support for post-cardiotomy cardiogenic shock.

**Keywords:** cardiac surgery, cardiogenic shock, extracorporeal membrane oxygenation support

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## 1. Introduction

Post-cardiotomy cardiogenic shock occurs in approximately 1% of adult cardiac surgical patients [1, 2]. For these patients, extracorporeal membrane oxygenation (ECMO) is a device for temporary mechanical circulatory support allowing cardiac and pulmonary recovery or as a bridge to further therapeutic alternatives.

However, the outcomes of ECMO use for post-cardiotomy patients are not satisfactory. Inhospital mortality has been reported to be as high as 60–85%. In addition, ECMO use

requires blood products, manpower, and special resources; therefore, it is associated with a significant financial burden to the institution.

No clear guidelines exist regarding the management of ECMO after cardiac surgery. The decision to place a patient on ECMO after cardiac surgery is difficult. Physicians have to make a decision based on individual circumstances, considering the balance between risks and benefits of ECMO.

## **2. VA-ECMO for post-cardiotomy cardiogenic shock**

### **2.1. Initiation of ECMO**

The causes of cardiogenic shock following cardiac surgery are divided into three categories: reversible, potentially reversible, and irreversible [3]. Reversible and potentially reversible causes of inability to wean from cardiopulmonary bypass include myocardial stunning, localized acute myocardial infarction, and acute pulmonary hypertension. Irreversible causes include pre-existing severe ventricular dysfunction, massive acute myocardial infarction, and chronic pulmonary hypertension.

ECMO offers the possibility of providing a bridge for maintaining organ perfusion and oxygenation allowing time for the heart and lung function to recover [4]. Theoretically, ECMO is indicated for reversible or potentially reversible cardiogenic shock; however, it is hard to tell the reversibility of stunned or infarcted myocardium, and how long it would take for recovery.

### **2.2. ECMO set-up**

ECMO following cardiac surgery is often established centrally, i.e., an arterial line through the ascending aorta and a venous line through the right atrium [5, 6]. If the chest is not open, or if there is a concern for leaving the chest open due to the risk of infection or bleeding, ECMO is established peripherally. This consists of a venous cannula in the femoral vein and an arterial cannula in the femoral artery.

If central ECMO is initiated, one can consider tunneling arterial and venous cannulas through the abdomen, so that the chest can be closed to reduce the risk of infection and bleeding [7].

### **2.3. Management of ECMO**

ECMO management should be done in an intensive care unit, and perfusionists, cardiac surgeons, and intensivists should be involved.

Heparinization is a controversial issue in ECMO management. While anticoagulation is necessary to prevent formation of clots in the ECMO circuit, it increases the risk of bleeding from the cannulation sites and surgical fields [8]. Ko et al. suggested avoiding use of heparin for the first 24 hours of ECMO support [9].

There is no consensus regarding anticoagulation management. Most centers use activated clotting time (ACT) to monitor the level of anticoagulation. ACT should be kept above 160 seconds during full flow of ECMO; whereas, it should be kept higher (>180 or >200 seconds) if patients have artificial valves or ECMO is in low flow [10]. Blood transfusion is to be expected due to blood loss and coagulopathy. Some centers use thromboelastography to guide what blood products (platelets, fresh frozen plasma, or cryoprecipitate) are necessary during ECMO management [11].

Some centers use bivalirudin instead of heparin for the management of ECMO, and some previous studies showed the superiority of bivalirudin over heparin [12, 13].

#### **2.4. Management of left ventricular distension**

Left ventricular distension can happen as a result of inadequate drainage of the right atrium, shunting of blood between the bronchial and pulmonary artery circulation, and inadequate ejection of the left ventricle against the afterload posted by the ECMO. This can result in increased wall stress, increased myocardial oxygen consumption, pulmonary edema, and hemorrhage. There are some strategies to alleviate left ventricular distension [14].

Seib et al. described a technique of left heart decompression with blade and balloon atrial septostomy [15]. They reported that this technique could successfully alleviate left atrial hypertension and pulmonary edema.

Aiyagari et al. described a technique of decompressing the left atrium by placing a transeptal left atrial drainage incorporated into the ECMO circuit [16]. This drainage cannula can be placed via a patent foramen ovale [17]. The left ventricle can be vented directly by placing a catheter percutaneously through the aortic valve into the left ventricle [18, 19].

Alternatively, other type of mechanical circulatory assist devices such as the Impella (Abiomed Inc., Danvers, MA) or the TandemHeart (CardiacAssist Inc., Pittsburgh, PA) can decompress the left ventricle [20].

#### **2.5. Weaning of ECMO**

The length of ECMO support ranges between 3 and 14 days [21]. Fiser et al. suggested that consideration of discontinuing ECMO should be given after 48 to 72 hours of ECMO initiation, either by moving to an implantable ventricular assist device or by withdrawal of ECMO [22]. Distelmaier et al. reviewed their experience of ECMO use in 354 patients, and found that prolonged ECMO support was associated with poor outcomes [23]. They suggested reevaluation of therapeutic strategies after 7 days of ECMO, because mortality increases dramatically afterward.

A pulmonary artery catheter and transesophageal echocardiography are essential in weaning ECMO to assess the cardiac function. If a patient can successfully maintain a reasonable cardiac output on a low pump flow, ECMO can be discontinued.

## 2.6. Outcomes

The surgical outcomes of ECMO support for post-cardiotomy cardiogenic shock in adult patients are summarized in **Table 1**. Overall, about half of the patients could be weaned off ECMO; however, inhospital mortality was around 60–80%. In other words, only a quarter of the patients survived to be discharged home. Pokersnik et al. concluded that advancements in technology improved oxygenator durability, but had little impact on overall survival rates [39].

Study	Number of pts	Successful weaning of ECMO	Survival
Rastan et al. [24]	517	63.3% was successfully weaned from ECMO	Inhospital mortality was 75.2%. Cumulative survivals were 17.6% after 6 months, 16.5% after 1 year, and 13.7% after 5 years.
Muehrcke et al. [25]	23	39.1% was weaned from ECMO, 13.0% underwent LVAD	Inhospital mortality was 69.6%.
Elsharkawy et al. [26]	233	12.0% was converted to implantable LVAD	Inhospital mortality was 64%.
Zhao et al. [27]	24	66.7% was weaned off ECMO	Inhospital mortality was 66.7%.
Ko et al. [9]	76	55.3% was weaned off ECMO, 2.6% underwent LVAD, and 2.6% underwent transplantation	Inhospital mortality was 73.7%.
Biancari et al. [28]	148	4.1% underwent LVAD	Inhospital mortality was 64.2%. One-, 2-, and 3-year survival was 31.0%, 27.9%, and 26.1%, respectively.
Khorsandi et al. [29]	27	15% underwent short-term VAD implantation	Inhospital mortality was 59.3%.
Ariyaratnam et al. [3]	14	50% was weaned off ECMO	Inhospital mortality was 85.7%.
Smedira et al. [30]	202	23.8% underwent transplantation, 35.1% was weaned off ECMO	30-day mortality was 62%. Survival at 5 years was 24%.
Bakhtiary et al. [31]	45	56% had successful weaning of ECMO	Inhospital mortality was 71%. During follow-up period up to 3 years, 22% were alive.
Hsu et al. [32]	51	53% had successful weaning of ECMO	Inhospital mortality was 67%. 29% patients were alive at 1-year postop.
Li et al. [33]	123	56% had successful weaning of ECMO	Inhospital mortality was 65.9%.
Saxena et al. [34]	45	53% were weaned off ECMO	Inhospital mortality was 75.6%.
Papadopoulos et al. [35]	360	58% had successful weaning of ECMO	Inhospital mortality was 70%.
Unosawa et al. [36]	47	62% had successful weaning of ECMO	Inhospital mortality was 32%. The actuarial survival rates were 34.0% at 30 days, 29.8% at 1 year, and 17.6% at 10 years.

Study	Number of pts	Successful weaning of ECMO	Survival
Slottosch et al. [37]	77	62% had successful weaning of ECMO	30-day mortality was 70%.
Zhang et al. [38]	32	44% had successful weaning of ECMO	30-day mortality was 68.8%. At a follow-up period of 3.9 years, the overall survival rate was 12.5%.
Doll et al. [2]	219	60% had successful weaning of ECMO	Inhospital mortality was 76%. Among survivors, 74% were alive at 5-year follow-up.
Magovern et al. [10]	55	65% were weaned off ECMO	Inhospital mortality was 64%.
Pokersnik et al. [39]	49	55% were weaned off ECMO	Inhospital mortality was 67%.
Guihaire et al. [40]	92	48% were weaned off ECMO	Inhospital mortality was 63%. Overall 1-month and 6-month survival rates were, 42% and 39%, respectively.

**Table 1.** Outcomes of ECMO use for post-cardiotomy cardiogenic shock.

Risk factors associated with hospital mortality were age [24, 26, 33, 35, 37, 40], diabetes [24, 26], obesity [24], female gender [33], pulmonary disease [28], atrial fibrillation [34], and chronic kidney disease [24, 28, 30, 34]. It is also suggested that the level of lactate [24, 28, 34, 35, 37, 38, 40], creatine kinase isoenzyme MB [38], longer duration of ECMO support [36, 37], mean lactate concentration [33], and lactate clearance [33] were predictors of inhospital mortality. In terms of surgical procedures, valvular surgery is generally associated with poor outcomes [40], and coronary artery bypass is associated with better outcomes [24].

Not many papers reported long-term outcomes after ECMO use for post-cardiotomy cardiogenic shock. One-year survival rate was around 20–30%. Despite high inhospital mortality, some papers reported the quality of life of survivors were acceptable with New York Heart Association functional class I or II [2, 9].

Biancari et al. performed a meta-analysis of the outcomes of ECMO for post-cardiotomy adult patients [41]. They investigated 31 studies reported on 2986 patients who required post-cardiotomy ECMO. The weaning rate from ECMO was 59.5%, and hospital survival was 36.1%. One-year survival rate was 30.9%. However, there is a criticism for this paper, as it included post-transplant patients [42]. Usually the outcomes of planned ECMO use following heart transplantation are better than those of unplanned non-transplant post-cardiotomy ECMO.

## 2.7. Complications of ECMO

ECMO is associated with high incidence of complications.

Major hemorrhage is the most commonly reported complication associated with ECMO institution. The reasons for excessive bleeding in ECMO patients are the surgical trauma, thrombocytopenia, activation of leukocytes, and necessity of anticoagulation. Rastan et al.

reported that more than half of the patients required re-exploration of the chest for bleeding [24]. Golding et al. reported that 87.3% required re-exploration for bleeding [43].

Cerebrovascular events also occurred frequently. Smedira et al. reported that 33% of the patients developed neurologic events [30], and Rastan et al. reported that the incidence of cerebrovascular events was 17.4% [24]. The reasons for high incidence of cerebrovascular events include the operative procedure itself, hemodynamic instability, lack of pulsatile flow, retrograde perfusion via peripheral circuit, and anticoagulation-related injuries.

Leg ischemia is a complication specifically associated with peripheral ECMO institution [44]. Rastan et al. reported that about 20% of the patients developed leg ischemia and 9.2% required leg fasciotomy [24]. However, the risk of this complication can be reduced by using a distal leg perfusion cannula [24], or by using a dacron or hemashield prosthetic graft sewn onto the artery to maintain both central arterial blood flow as well as distal limb perfusion [32].

A meta-analysis performed by Biancari et al. reported that the rate of reoperation for bleeding was 42.9%, major neurological event 11.3%, lower limb ischemia 10.8%, deep sternal wound infection 14.7%, and renal replacement therapy 47.1% [41].

## 2.8. Bridge to alternatives

When patients have difficulty of being weaned from ECMO, physicians need to consider if they have to withdraw ECMO from them, or if they proceed to alternative options. Patients were more likely to be considered for bridging to heart transplantation if they are less than 60 years of age. Smedira et al. reported that 24% were bridged to heart transplantation [30]. However, heart transplantation is not an available option in all countries.

Other options include left ventricular assist device (LVAD) or right ventricular assist device (RVAD). Muehrcke et al. reported that 4 out of 23 patients were transferred to an implantable LVAD from ECMO [25]. Pokersnik et al. reported that 2 out of 49 patients were bridged to long-term devices—bi-ventricular assist devices [39].

## 2.9. Hospital transfer

Post-cardiotomy shock may happen at institutions which do not have much experience with the management of mechanical circulatory support devices. In addition, not all institutions have options of long-term devices such as LVAD, or transplantation. Therefore, the development of a robust program of tertiary referral is of paramount importance [45]. Javidfar et al. reported no transport-related mortality or morbidity in patients who were transported via an ambulance with ECMO [46].

Teman et al. reported that patients with post-cardiotomy cardiac shock transported to a tertiary care center had a nearly 50% survival [47].

Weaning to recovery, institution of long-term support as a bridge to recovery, transition to transplantation or destination therapy, as well as device withdrawal and palliative care should be discussed in a multidisciplinary team including cardiologists, surgeons, intensivists, psychiatrists, and social workers [21].

### 3. Conclusions

The surgical mortality after ECMO use for post-cardiotomy cardiogenic shock remains high despite technological advancement. However, ECMO is the last resort to keep a patient alive who would otherwise expire on the operating table. According to the literatures, ECMO can be a salvage treatment in about one-third of these patients. Increased age, chronic kidney disease, and high level of lactate are major risk factors associated with hospital mortality. Also longer duration of ECMO support is associated with poor outcome. There is no guideline regarding optimal patient selection, duration of mechanical support, and management of ECMO.

A careful decision-making is necessary before ECMO is initiated, because ECMO is associated with a significant burden to a facility. As patients who need ECMO are always heterogeneous, the decision should be based on an individual basis.

A transfer to a tertiary center is critically important, because they can provide the transition to further supports, such as heart transplantation and implantable ventricular assist devices for patients who have difficulty of being weaned from ECMO.

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