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An Extracorporeal Membrane Oxygenation Use in a Patient With Multiple Mitral Paravalvular Leaks

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1. Abstract

Title: An Extracorporeal Membrane Oxygenation Use in a Patient With Multiple Mitral Paravalvular Leaks: A Case Report and Literature Review

Background: Paravalvular leaks (PVLs) are a recognized complication following valve replacement surgery, often leading to significant morbidity. Their management is particularly challenging in high-risk patients, especially those with severe pulmonary hypertension, which increases surgical risk and perioperative mortality. Transapical PVL closure is a viable treatment option but carries risks such as access-related complications, myocardial perforation, and catastrophic bleeding. Extracorporeal membrane oxygenation (ECMO) serves as a critical life-saving intervention in such cases, providing circulatory stabilization and central unloading during intraoperative crises.

Case presentation: We present a 75-year-old female with a history of aortic and mitral valve replacement, pulmonary embolism, chronic atrial fibrillation, and diabetes mellitus, who developed severe mitral regurgitation due to five mitral PVLs (See Appendix Figures A1 and A2 for pre-repair TEE images showing multiple PVLs and associated regurgitant flow). Echocardiography revealed preserved left ventricular function, a markedly dilated right ventricle, and severe pulmonary hypertension (100 mmHg). During an attempted transapical transcatheter PVL closure, the markedly enlarged right ventricle was mistakenly accessed instead of the left ventricle, resulting in catastrophic right ventricular rupture and severe bleeding. The surgeon temporarily controlled the hemorrhage manually, but direct suture closure was deemed too high-risk due to the potential for further myocardial rupture in the setting of severe pulmonary hypertension. To prevent circulatory collapse, emergent peripheral veno-arterial ECMO was initiated for central unloading and hemodynamic stabilization. A Foley catheter was inserted through the RV rupture and inflated as a tamponade, followed by three pledged-reinforced “U” sutures to repair the defect. The next day, the patient remained on ECMO and was transferred to the hybrid operating room, where a transapical PVL closure was successfully performed in 4 of the 5 PVLs, reducing mitral regurgitation to mild (See Appendix Figure A3). ECMO was discontinued the following day. Postoperatively, the patient developed acute renal failure requiring renal replacement therapy but was discharged to rehabilitation on postoperative day 40.

Objective: This thesis aims to evaluate the role of ECMO in managing severe intraoperative complications during high-risk mitral PVL interventions, particularly in cases of myocardial rupture, severe pulmonary hypertension, and hemodynamic collapse. Through the case study of a 75-year-old patient who experienced unintended right ventricular rupture during transapical PVL closure, we highlight the challenges of PVL repair in high-risk patients and the role of ECMO in preventing catastrophic cardiovascular collapse. In parallel, through a comprehensive literature review, we analyze existing evidence on ECMO's application in PVL management, myocardial rupture repair, and intraoperative bleeding control. This review is to contextualize the findings of our case study within current clinical trends and to identify gaps in knowledge regarding ECMO utilization in elderly cardiac surgery patients.

Methods: A systematic literature review was conducted to assess ECMO utilization in high-risk cardiac procedures, including PVL management, myocardial rupture, and intraoperative bleeding control. Studies evaluating prophylactic versus emergency ECMO use were reviewed to determine optimal management strategies for ECMO deployment.

Results: This case underscores ECMO's role as a vital hemodynamic support strategy in cases of myocardial rupture and severe intraoperative bleeding. Literature findings confirm ECMO's potential to improve procedural success rates and perioperative survival in high-risk cardiac interventions, though it presents risks such as coagulopathy, thromboembolic events, renal dysfunction, and vascular complications. Evidence suggests that prophylactic ECMO use may lead to improved outcomes compared to emergency ECMO initiation. Moreover, this case highlights the effectiveness of novel hemostatic strategies such as the Foley catheter tamponade technique in managing acute myocardial rupture.

Conclusion: ECMO remains a vital adjunct in high-risk cardiac procedures, particularly in cases where myocardial rupture and hemodynamic instability pose extensive threats to patient survival. This case emphasizes the importance of early ECMO deployment, novel hemostatic interventions, and a staged approach to PVL management in structurally complex valvular procedures. While ECMO provides perioperative support, long-term data on its use in PVL repair remains limited,

emphasizing the importance of continued research into selection criteria, weaning strategies, and geriatric outcomes.

Keywords: Paravalvular leaks, extracorporeal membrane oxygenation, transapical closure, right ventricular rupture, myocardial perforation, surgical bleeding control, pulmonary hypertension.

2. Introduction

2.1 Background

Mitral regurgitation (MR) is a valvular disorder characterized by the improper closure of the mitral valve, leading to retrograde blood flow from the left ventricle into the left atrium during systole. This regurgitant flow elevates left atrial pressure and can subsequently lead to pulmonary hypertension, resulting in symptoms such as dyspnea and fatigue. The mitral valve apparatus, which consists of leaflets, chordae tendineae, papillary muscles, and annulus, plays a key role in maintaining proper valve function. Structural abnormalities affecting any of these components can contribute to MR, with major causes including mitral valve prolapse, rheumatic heart disease, ischemic heart disease, and infective endocarditis [1].

Infective endocarditis can lead to MR by causing leaflet perforation and the formation of vegetations, which interfere with proper leaflet coaptation. Over time, scarring and valvular retraction progressively impair leaflet coaptation, ultimately resulting in clinically relevant valvular insufficiency. In acute severe MR, the left atrium is typically normal in size but has reduced compliance, leading to a sudden rise in left atrial pressure. This abrupt increase can cause pulmonary edema, elevated pulmonary vascular resistance, and right-sided heart failure. Despite a marked increase in left atrial pressure, acute MR may only cause mild left atrial enlargement, and chest radiographs may not always demonstrate noticeable cardiac enlargement. In contrast, chronic MR leads to eccentric left ventricular hypertrophy due to volume overload, shifting the left ventricular pressure-volume relationship and predisposing patients to myocardial decompensation. Over time, left ventricular stiffness increases, leading to progressive heart failure, rising end-systolic volume, declining ejection fraction, and neurohormonal activation, including elevated natriuretic peptide levels [1].

Paravalvular leaks (PVLs), also known as paraprosthetic leaks, are an uncommon complication following surgical or transcatheter valve replacement, particularly affecting the heart valve prosthesis in all positions. PVLs result from incomplete healing at the annular suture line or mechanical stress between the prosthetic valve and the native annular tissue, leading to regurgitant blood flow through the gap. While small PVLs are often hemodynamically inconsequential, larger defects may cause heart failure symptoms or hemolytic anemia due to shear stress-induced red blood cell destruction. The morphology of PVLs varies, with crescentic, oval, or round defects that may run parallel, perpendicular, or serpiginous to the valve annulus. Mechanical prosthetic valves have a higher incidence of PVLs compared to bioprosthetic valves, largely due to the lack of biological integration between the prosthesis and the native tissue [2].

Clinically important PVLs can result in severe hemolysis or heart failure, increasing morbidity and mortality. Surgical repair has traditionally been the standard of care for symptomatic PVLs, but redo valve surgery carries high procedural risks, particularly in elderly or frail patients. Percutaneous PVL closure has emerged as an alternative, offering a minimally invasive approach with a lower risk of complications. Indications for PVL closure include symptomatic heart failure and persistent hemolysis, whereas contraindications include active systemic or local infection, ongoing ischemia, mechanical instability of the prosthetic valve, intracardiac thrombus, or a life expectancy of less than six months [3].

There are three main access approaches for percutaneous PVL closure: transfemoral, transseptal, and transapical. The transfemoral retrograde approach is commonly used for aortic PVLs or medial mitral PVLs. Transseptal access, guided by fluoroscopy and transesophageal echocardiography, is preferred for mitral PVLs, or challenging aortic PVLs. Transapical access, on the other hand, is the method of choice for difficult-to-reach mitral PVLs, particularly in patients with both mechanical aortic and mitral prostheses, where an occluder device may also be deployed to close the access site [3].

Extracorporeal membrane oxygenation (ECMO) has gained increasing prominence as a temporary mechanical circulatory support system, providing hemodynamic stabilization in cases of acute cardiac and respiratory failure. Veno-arterial ECMO (VA-ECMO) facilitates both circulatory and gas exchange support, consisting of a venous cannula for blood drainage, a pump, an oxygenator, and an arterial cannula for oxygenated blood return to systemic circulation. Cannulation may be performed via peripheral or central access, depending on the clinical indication [4].

Since its introduction in 1972, ECMO has played a vital role in high-risk cardiac procedures, including transcatheter aortic valve implantation (TAVI), complex percutaneous coronary intervention (PCI), and cases where weaning from cardiopulmonary bypass (CPB) is difficult. Compared to CPB, ECMO systems have a more compact circuit with reduced air-blood contact, minimizing the need for aggressive anticoagulation while also reducing coagulopathy and systemic inflammatory responses [5].

2.2 Case Significance

PVL closure is a technically demanding procedure, particularly in high-risk patients with severe pulmonary hypertension or prior valve interventions. Transapical PVL closure, while offering direct access to the mitral valve, carries risks of ventricular perforation, bleeding, and hemodynamic collapse, necessitating careful procedural planning. In high-risk cases, ECMO can serve as a life-saving intervention, providing temporary circulatory support in the event of catastrophic intraoperative complications.

The present case reinforces the value of early ECMO deployment in preventing cardiovascular collapse following a procedural complication. Additionally, it demonstrates the successful use of a Foley catheter tamponade as a novel temporary hemostatic strategy. Given the complexity of PVL repair in patients with severe pulmonary hypertension, further evaluation of ECMO as both a prophylactic and rescue intervention are warranted in this setting.

2.3 Rationale for Literature Review

Despite advancements in PVL closure techniques, there remains a lack of consensus regarding the optimal management of high-risk PVL patients, particularly those requiring ECMO support during intervention. While ECMO has been widely studied in postcardiotomy shock and perioperative support, its application in PVL repair remains underexplored.

This thesis includes a comprehensive literature review to evaluate ECMO's role in PVL management, myocardial rupture repair, and intraoperative bleeding control. The primary objectives of this review are to: Analyze existing evidence on ECMO-assisted PVL interventions, compare prophylactic versus emergency ECMO deployment strategies, and identify gaps in knowledge regarding ECMO use in elderly cardiac surgery patients.

By synthesizing current literature with insights from this case study, this thesis aims to contribute to the ongoing discussion on ECMO-assisted PVL interventions and highlight future research directions in structural heart disease management.

3. Case report

The patient is a 75-year-old woman with a history of coronary artery disease, atrial fibrillation, diabetes mellitus, hypertension, and pulmonary embolism. For these conditions, she had been managed with warfarin, beta blockers, ACE inhibitors, insulin, and loop diuretics. Two years prior to admission, the patient underwent atrial and mitral valve replacement due to atrial and mitral regurgitation associated with infective endocarditis.

The patient was presented with dyspnea on minimal exertion. The 6-minute walk test was 180 meters. Laboratory tests noted elevated BNP levels of 1387 pg/mL, hemoglobin of 124 g/dL, and LDH of 230 U/L. Transesophageal echocardiography revealed the presence of five mitral paravalvular leaks, resulting in severe regurgitation. The left ventricle demonstrated preserved systolic function, while the right ventricle was significantly enlarged but maintained systolic function. The estimated pulmonary artery pressure was 100 mmHg. The leaks were measured as follows: at 10:00, 6 x 6 mm; at 14:00, 2 x 2 mm; at 16:00, 5 x 4 mm; at 17:00, 4 x 4 mm; and at 18:00, 6 x 6 mm.

A catheter-based transapical closure procedure was planned; however, it was complicated by severe bleeding from the apex of the right ventricle during the placement of orthogonal U-shaped sutures.

Literature review

4.1 ECMO in Cardiac Surgery

4.1.1 Introduction to ECMO

Venoarterial extracorporeal membrane oxygenation (VA-ECMO) is a highly effective yet complex intervention that provides temporary mechanical circulatory support for patients in severe cardiac or cardiopulmonary failure. Successful implementation requires a well-established infrastructure, a proficient multidisciplinary medical team, and a comprehensive patient assessment that considers both indications and contraindications [6].

In cardiology, VA-ECMO is primarily utilized for conditions such as cardiac arrest, cardiogenic shock, post-cardiotomy shock, refractory ventricular tachycardia, and the management of acute complications arising from invasive procedures. Its fundamental role is to act as a bridge, whether to recovery, long-term ventricular assist device (VAD) support, heart transplantation, or a definitive clinical decision. However, due to its resource-intensive nature, VA-ECMO should not be administered to patients with no chance of survival or irreversible multi-organ failure. As technology advances, understanding the evolving indications, contraindications, and protocols for ECMO initiation, management, and weaning remains crucial for optimizing patient outcomes [6].

Evolution and Expanding Role of VA-ECMO

Over the past decade, the clinical application of VA-ECMO has broadened substantially across various critical care settings. Historically, it was primarily indicated for post cardiotomy shock, a condition managed by cardiac surgeons. However, its use has extended to multifactorial cardiogenic shock and cardiac arrest, with cardiologists playing an increasingly important role in decision-making and patient management. Between 2002 and 2012, the proportion of patients receiving VA-ECMO for post cardiotomy shock declined from 56.9% to 37.9%, reflecting a shift toward broader applications. At the same time, there was a marked rise in adult patients with cardiopulmonary failure receiving VA-ECMO support, emphasizing its growing importance in acute cardiovascular care. [6]

The Extracorporeal Life Support Organization (ELSO) registry further illustrates this trend. Over the past five years, VA-ECMO has been utilized in 8,846 patients, including 1,281 neonates, 1,590 pediatric patients, and 5,975 adults, demonstrating its widespread application across different age groups and clinical settings [7].

Table 1: Trends in VA-ECMO Utilization

Year range	Post-cardiotomy VA-ECMO %	Total VA-ECMO case reported
2002-2012	56.0 % → 37.9%	Increasing trend
Last 5 years	-	8846 cases (ELSO)

Indications and Contraindications for VA-ECMO

VA-ECMO provides both respiratory and cardiac support in various critical conditions. It is indicated in cases of low cardiac output (cardiac index <2L/min/m²) and hypotension (systolic blood pressure <90 mmHg) that persist despite inotropic support and intra-aortic balloon pump support. Cardiogenic shock resulting from conditions such as acute coronary syndrome, refractory cardiac arrhythmia, sepsis-induced cardiac depression, myocarditis, pulmonary embolism, drug toxicity, cardiac trauma, anaphylaxis, acute decompensated heart failure, or septic shock may also necessitate VA-ECMO when the heart is unable to pump adequate blood to meet the body's needs. In addition, it is used during high-risk cardiac procedures to provide temporary circulatory support. In postoperative heart failure, particularly when patients cannot be weaned off cardiopulmonary bypass after cardiac surgery, VA-ECMO plays an important role in allowing the heart to rest and recover. It is also beneficial in cases of primary graft failure following heart or heart-lung transplantation. Furthermore, VA-ECMO serves as a bridge to long-term ventricular assist device (VAD) support or to heart or lung transplantation in patients requiring extended circulatory assistance [8].

Despite its life-saving potential, VA-ECMO is not an appropriate intervention for all patients, and both absolute and relative contraindications must be carefully assessed. Absolute contraindications to VA-ECMO include irreversible noncardiac organ failure with limited survival potential such as advanced anoxic brain injury or metastatic cancer as well as structural cardiac conditions like unrepaired aortic dissection or severe aortic regurgitation. Patients with irreversible cardiac failure who are not eligible for heart transplantation or long-term ventricular assist device (VAD) support are also unsuitable candidates. Also, conditions like pulmonary hypertension with a mean pulmonary artery pressure exceeding 50 mmHg and cardiogenic shock are contraindications, as veno-venous (VV)-ECMO is not a viable option in such cases. Relative contraindications involve severe coagulopathy or an inability to tolerate anticoagulation therapy, such as in patients with advanced liver disease. Furthermore, restricted vascular access due to severe peripheral arterial disease, extreme obesity, or previous limb amputation can create big obstacles to the successful initiation of VA-ECMO [6, 8].

Table 2: Indications and Contraindications for VA-ECMO

Indications VA-ECMO	**Contraindications VA-ECMO**
Cardiogenic shock	Irreversible organ failure
Acute coronary syndrome	Metastatic cancer
Refractory cardiac arrhythmia	Severe coagulopathy
Sepsis-induced cardiac depression	Advanced anoxic brain injury
Myocarditis	Pulmonary hypertension > 50 mmHg (VV-ECMO)
Pulmonary embolism	Unrepaired aortic dissection
Postoperative heart failure	Severe aortic regurgitation
Primary graft failure (transplant)	Peripheral vascular disease

Clinical Implications

The evolution of VA-ECMO from a postoperative cardiac support strategy to a frontline intervention for cardiogenic shock and cardiac arrest demonstrates its growing role in emergency cardiovascular care. Its increasing use across diverse patient populations has led to multidisciplinary ECMO teams, with cardiologists playing a more prominent role in patient selection, ECMO initiation, and long-term management.

Data from the ELSO registry confirms a considerable increase in ECMO utilization, underscoring the need for continuous advancements in patient selection criteria, management strategies, and outcome optimization. Future research should focus on refining initiation protocols, determining optimal ECMO duration, and improving weaning strategies to enhance survival rates and long-term patient outcomes. Continued refinement of risk stratification models is essential to ensure that VA-ECMO is utilized effectively in patients who are likely to benefit from circulatory support.

4.1.2 ECMO in High-Risk Cardiac Interventions

Prophylactic VA-ECMO in Percutaneous Coronary and Structural Interventions

The use of VA-ECMO in high-risk cardiac interventions has garnered increasing clinical interest, given its capacity to provide hemodynamic support in critically ill patients undergoing complex procedures. High-risk percutaneous coronary and structural interventions often present procedural challenges, particularly in patients with severe comorbidities, hemodynamic instability, and underlying cardiac dysfunction. The use of VA-ECMO whether prophylactically or emergently has been associated with improved procedural success rates and enhanced patient outcomes [9].

A prospective study at Maria Pia Hospital in Turin, Italy, evaluated prophylactic VA-ECMO use in complex percutaneous coronary and structural interventions. The study included 27 high-risk patients, the majority of whom had severe left ventricular dysfunction (70%), diabetes (37%), and chronic kidney disease (41%). The procedures performed included complex percutaneous coronary intervention (PCI), transcatheter aortic valve implantation (TAVI), MitraClip implantation, and combined interventions. The results showed a procedural success rate of 96%, with only one in-hospital mortality attributed to a major vascular complication at the ECMO access site. At an 11-month follow-up, four deaths were recorded, three of which were due to non-cardiovascular causes. These findings suggest that prophylactic VA-ECMO enhances both safety and procedural success in complex cardiac interventions in high-risk patients [9].

Elective VA-ECMO in High-Risk PCI

Building on these findings, a retrospective study on elective VA-ECMO use in high-risk PCI demonstrated similarly favorable in-hospital and mid-term outcomes. The study involved five male patients with a mean age of 66.8 years and an average left ventricular ejection fraction of 26.6%, all of whom underwent complex PCI, unprotected left main interventions. All procedures were successful, with one patient requiring femoral artery repair. VA-ECMO was weaned successfully in all cases, with support lasting less than 24 hours in most patients. Importantly, no major adverse cardiovascular or cerebrovascular events occurred during hospitalization or within one year, further reinforcing VA-ECMO's role in improving procedural safety in high-risk PCI [10].

ECMO in Structural Valve Interventions (TMVR)

Expanding beyond coronary interventions, ECMO has also demonstrated fundamental utility in transcatheter mitral valve replacement (TMVR). A case study reported the strategic use of VA-ECMO in a critically ill patient with rheumatic heart disease and bioprosthetic mitral valve dysfunction. The patient presented with severe mitral stenosis, cardiogenic shock, and multiorgan failure, further compounded by marked pulmonary hypertension. VA-ECMO was initiated preemptively to stabilize hemodynamics, facilitating the successful implantation of a 29-mm valve-in-valve prosthesis. Special considerations were taken to mitigate the risk of left ventricular outflow tract (LVOT) obstruction. Post-procedure, the patient exhibited improved cardiac function and pulmonary pressures, underscoring the importance of multidisciplinary planning and ECMO's role in complex valvular interventions [11].

Emergency vs. Prophylactic VA-ECMO in TAVI

Further supporting these findings, a retrospective study evaluated the emergency and prophylactic use of VA-ECMO in TAVI procedures to manage life-threatening complications. Among 131 TAVI cases, emergency VA-ECMO was required in 7% of patients due to ventricular perforation, cardiogenic shock, or ventricular tachycardia. From August 2011 onward, prophylactic VA-

ECMO was utilized in 11% of patients deemed exceedingly high-risk, characterized by a logistic EuroSCORE nearly double that of the general TAVI population (30% vs. 15%). The study found that procedural success was 100% with prophylactic VA-ECMO compared to 78% with emergency use, while 30-day mortality was 0% versus 44%, respectively. Rates of major vascular complications and life-threatening bleeding were similar between both groups, suggesting that prophylactic VA-ECMO offers a safer approach for selected high-risk patients undergoing TAVI [12].

A comprehensive review of VA-ECMO use in TAVI further reinforced these findings by analyzing 5,115 patients who required VA-ECMO either emergently or prophylactically. Among them, 102 (2%) required VA-ECMO, with 66 cases for emergencies and 22 cases for prophylactic support. Emergency VA-ECMO was most often used for left ventricular free wall rupture (22%), hemodynamic instability (19%), and ventricular arrhythmias (11%), resulting in a 61% survival rate and a 29% conversion rate to surgical aortic valve replacement. In contrast, prophylactic VA-ECMO, applied in very high-risk patients with severe comorbidities, demonstrated a 100% survival rate with no procedural deaths. Although major complications such as bleeding and vascular access issues occurred in 16% of cases, their incidence did not differ dramatically between emergency and prophylactic groups. Overall, in-hospital survival was 73%, with the prophylactic ECMO group demonstrating superior outcomes. The study concluded that while emergency VA-ECMO remains vital for managing life-threatening complications, prophylactic ECMO in high-risk patients is associated with improved outcomes and warrants consideration during preoperative heart team discussions [13].

Table 3 summarizes studies directly comparing emergency and prophylactic VA-ECMO in TAVI procedures, reporting procedural success rates, 30-day mortality, and complication rates.

Table 3: Comparative Summary of Prophylactic vs. Emergency VA-ECMO in TAVI Procedures

Study [Citation]	Total Patients	Emergency VA-ECMO (%)	Prophylactic VA-ECMO (%)	Procedural Success (%)	30-Day Mortality (%)	Major Complications
Retrospective Study [12]	131	7%	11%	Emergency: 78%, Prophylactic: 100%	Emergency: 44%, Prophylactic: 0%	Similar vascular & bleeding complications
Comprehensive Review [13]	5,115	66 cases (64.7%)	22 cases (21.6%)	Emergency: 61%, Prophylactic: 100%	Emergency: comparatively higher, Prophylactic: 0%	Similar bleeding & vascular complications

Both studies consistently demonstrate that prophylactic VA-ECMO is associated with improved procedural outcomes and reduces mortality compared to emergency VA-ECMO, supporting its strategic use in selected high-risk TAVI patients. The findings suggest that preemptive hemodynamic support with VA-ECMO should be an essential consideration in very high-risk patients undergoing TAVI, particularly those with high-risk comorbidities and increased procedural risk.

VA-ECMO in Postcardiotomy Cardiogenic Shock (PCS)

Building on the findings regarding VA-ECMO use in TAVI, a retrospective study evaluated its application in patients undergoing valvular surgery complicated by refractory postcardiotomy cardiogenic shock (PCS). The study included 87 patients, with a mean age of 65 years, an average left ventricular ejection fraction (LVEF) of 46%, and an additive EuroSCORE of 6.1%. VA-ECMO support lasted an average of 61 hours, with intra-aortic balloon pump (IABP) implantation in 47.1% of cases [14].

Successful weaning from VA-ECMO was achieved in 59% of patients, and 49% were discharged. Multivariate analysis identified age >65 years, postoperative renal replacement therapy, peak lactate ≥12 mmol/L, and VA-ECMO duration >60 hours as independent predictors of in-hospital mortality, while IABP support was found to be protective. Persistent heart failure with an LVEF <40% was associated with increased post-discharge mortality. Despite these risks, long-term survival among hospital survivors was favorable, with a 92% survival rate at 1 year and 66% at 5 years [14].

ECMO Use in Other High-Risk Surgical Settings

The application of ECMO has expanded beyond cardiac surgery, allowing high-risk perioperative procedures that might otherwise be deemed too hazardous. In thoracic surgery, ECMO has increasingly replaced traditional cardiopulmonary bypass (CPB) in complex procedures such as lung transplantation and tracheobronchial reconstruction, as it minimizes CPB-associated risks such as systemic inflammation, coagulopathy, and prolonged ischemia-reperfusion injury [15].

ECMO has also become a central tool in obstetric emergencies, particularly in cases of severe respiratory failure during pregnancy and the postpartum period. Clinical guidelines now advocate for early referral of pregnant patients with acute respiratory distress syndrome (ARDS) to ECMO centers to improve outcomes. Similarly, in trauma care, VA-ECMO has demonstrated improved survival rates in polytrauma patients, particularly in cases involving severe thoracic trauma, cardiac contusion, or blast injuries [15].

Furthermore, ECMO is increasingly utilized in anesthetic emergencies, such as intraoperative cardiac arrest, where its use has been associated with improved survival. As its perioperative applications continue to expand, ECMO is becoming a cornerstone of support in critically ill surgical patients across multiple disciplines [15].

ECMO as Perioperative Salvage Therapy in Liver Transplantation

A case study further reinforced ECMO’s perioperative role as salvage therapy in liver transplantation, particularly following severe post-reperfusion cardiac collapse. A 42-year-old patient with hepatopulmonary syndrome undergoing liver transplantation developed vasoplegia and cardiovascular instability shortly after graft reperfusion, necessitating emergent VA-ECMO initiation for circulatory support [16].

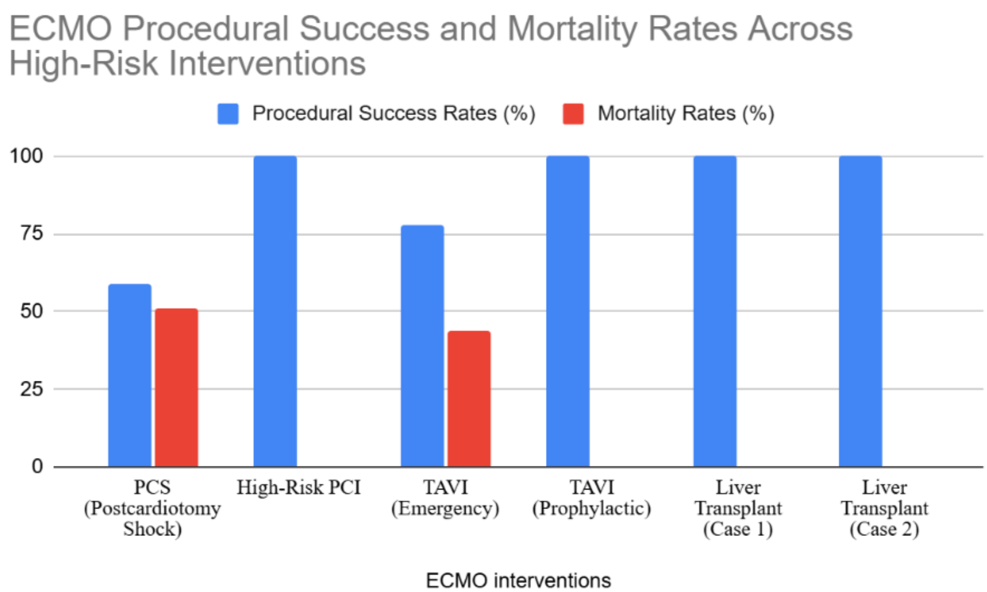
Despite stabilizing systemic perfusion, differential hypoxia due to intrapulmonary shunting required conversion to veno-arterial-venous (VAV)-ECMO to provide both circulatory and respiratory support. Within 24 hours, laboratory markers indicated primary graft nonfunction, prompting urgent re-listing for liver re-transplantation. During the waiting period, VAV-ECMO maintained systemic circulation and oxygenation, preventing further metabolic deterioration. The patient successfully underwent liver re-transplantation while remaining on VAV-ECMO, continuous renal replacement therapy (CRRT), and maximal vasopressor support [16].

Postoperatively, ECMO support was transitioned to VV-ECMO for respiratory assistance, allowing gradual ventilator weaning and successful extubation. The patient remained hemodynamically stable and was discharged three months post-transplant. This case emphasizes ECMO's flexibility in managing perioperative complications in high-risk transplant patients and underscores the importance of multidisciplinary collaboration among ECMO specialists, transplant surgeons, and anesthesiologists [16].

Another case report described the use of VA-ECMO as salvage therapy in a 53-year-old liver transplant recipient who developed refractory cardiogenic shock and cardiac arrest upon graft reperfusion, despite a normal pre-transplant cardiac evaluation. After 45 minutes of unsuccessful cardiopulmonary resuscitation (CPR), pharmacological resuscitation, and defibrillation, intraoperative VA-ECMO was initiated, enabling completion of the liver transplant [17].

Postoperatively, the patient developed severe multivessel coronary artery disease, necessitating coronary artery bypass grafting (CABG) under ECMO support due to the high bleeding risk associated with dual antiplatelet therapy. VA-ECMO was successfully weaned after four days, with left ventricular recovery (ejection fraction 55%) and stable liver function. The patient was discharged on postoperative day 26 and remained clinically stable at a 10-month follow-up. This case underscores VA-ECMO's essential role in managing intraoperative cardiac collapse and showcases its capacity to stabilize complex perioperative emergencies [17].

Graph 1: Procedural Success and Mortality Rates in ECMO-Supported High-Risk Interventions



Graph 1 demonstrates the procedural success and mortality rates across various high-risk ECMO-supported interventions, including post-cardiotomy cardiogenic shock (PCS), high-risk percutaneous coronary intervention (PCI), emergency and prophylactic VA-ECMO in transcatheter aortic valve implantation (TAVI), and liver transplantation. The data showcases the improved outcomes associated with prophylactic ECMO use in selected high-risk patients, particularly in structural interventions and perioperative management.

4.1.3 Outcomes and Prognosis

Impact of Age on VA-ECMO Outcomes

A retrospective analysis evaluated VA-ECMO outcomes among 355 elderly patients from 2007 to 2016, examining the influence of age on survival rates. While in-hospital mortality remained high across all age groups, age emerged as a prominent predictor of mortality beyond 63 years, with a marked increase after 72 years. Patients older than 72 had a higher prevalence of coronary artery disease (CAD), previous strokes, and chronic kidney disease, which contributed to lower ECMO weaning rates (47% vs. 76%) and higher in-hospital mortality (69%) compared to younger counterparts (52%) [18].

Multivariate analysis identified age >72, coronary artery disease, and acute decompensated heart failure as independent predictors of mortality. These results advocate for patient-specific risk assessment in elderly individuals and emphasize both the potential and the limitations of ECMO in this age group. Moreover, they underscore the importance of evidence-based patient selection to optimize both outcomes and resource allocation [18].

In contrast, another study analyzing short-term (discharge) and long-term (one-year) survival among 131 older (≥65 years) versus younger (<65 years) VA-ECMO recipients found that age alone was not an independent predictor of mortality. Initial findings indicated higher mortality among older patients; however, after adjusting for comorbidities, age lost statistical significance. Instead, coronary artery bypass graft (CABG) history, peripheral vascular disease, and renal failure requiring dialysis emerged as independent predictors of mortality. These results emphasize that ECMO eligibility should be determined by comprehensive patient evaluations, rather than chronological age alone, reinforcing the essential role of comorbidities in predicting ECMO outcomes [19].

Table 4: Comparative Summary of Age and Comorbidity Impact on VA-ECMO Outcomes

Study [Citation]	**Total Patients**	**Age Groups Compared**	**Survival at Discharge (%)**	**Survival at 1 Year (%)**	**Key Predictors of Mortality**	**Conclusions & Recommendations**
Retrospective Analysis [18]	355	≤ 72 years vs. >72 years	≤72: 48%, >72: 31%	Not reported	Age (>72 yrs), CAD, Acute decompensa	In patients older than 72, ECMO is associated with poorer outcomes,

					ted heart failure	reinforcing the need for careful risk stratification before initiation.
Retrospective Study [19]	151	<65 years vs. ≥65 years	Overall: 48%	Overall: 44%	CABG history, Peripheral vascular disease, Renal failure/dialysis	Comorbidities, rather than age alone, determine ECMO eligibility, underscoring individualized patient assessment.

Comparative Analysis and Clinical Implications

The findings summarized in Table 4 presents important factors influencing VA-ECMO outcomes in relation to patient age and comorbidities. The retrospective study by [18] found that patients older than 72 years experienced reduced survival benefits from ECMO, indicating that increasing age negatively impacts clinical outcomes.

Conversely, the findings from citation [19] challenge strict age-based selection criteria, showing that when adjusted for comorbidities, age alone is no longer an independent predictor of mortality. Instead, coronary artery bypass graft history, peripheral vascular disease, and renal failure requiring dialysis were found to be stronger predictors of survival.

These results underscore the greater clinical relevance of comorbidities over chronological age in VA-ECMO patient selection. As a result, they advocate for an individualized patient assessment strategy when determining ECMO candidacy, rather than imposing rigid age restrictions. This personalized approach could lead to more effective allocation of ECMO resources and improved survival rates in older patient populations.

Long-Term Recovery and Quality of Life in ECMO Survivors

Previous studies have put light on the ethical, economic, and clinical challenges associated with VA-ECMO use, particularly emphasizing age-related mortality risks and advocating for individualized patient selection based on comorbidities rather than chronological age alone. However, beyond survival outcomes, limited data exists regarding the long-term recovery experiences of ECMO survivors.

A qualitative study involving 16 ECMO survivors (aged 23–65 years) identified three distinct recovery phases: Trauma and Vulnerability, Resiliency and Recovery, and Survivorship. All participants experienced substantial physical challenges, with two-thirds reporting psychological or cognitive impairments, and 25% being unable to return to employment. Recovery trajectories were notably influenced by personal circumstances, family support, and healthcare interactions. These findings emphasize the prolonged and multifaceted nature of ECMO recovery and support the need for specialized post-discharge care and long-term follow-up to address cognitive, psychological, and social outcomes [20].

Further emphasizing the complexities of ECMO management, a multicenter cohort study across 23 Australian hospitals examined 6-month outcomes in 442 ICU patients who received ECMO for respiratory failure, cardiac failure, or cardiac arrest. Among the 391 patients with follow-up data, 66% experienced death or moderate-to-severe disability, with 67% of VA-ECMO patients, 54% of VV-ECMO patients, and 82% of extracorporeal cardiopulmonary resuscitation (eCPR) recipients falling into these categories. These findings underscore the challenges associated with post-ECMO recovery and support the importance of thoughtful patient selection and coordinated, long-term multidisciplinary follow-up. [21].

Furthermore, VA-ECMO complications remain a major challenge, with bleeding identified as the most common complication, occurring in 22.3% of patients with refractory cardiogenic shock. However, Evidence suggests that implementation of a 24/7 ECMO team following standardized protocols is associated with reduced complication rates, highlighting the value of coordinated multidisciplinary management.[22]. Another study identified acute limb ischemia (ALI) as a prominent vascular complication in 16.5% of ECMO patients, particularly affecting peripheral VA-ECMO cases (26.1%). ALI was associated with lower survival rates and an increased risk of limb amputation, emphasizing the necessity of consistent vascular management protocols to mitigate complications and improve patient outcomes [23].

Predictors of Successful Weaning from VA-ECMO

With the increasing use of VA-ECMO for cardiac failure, predicting successful weaning remains a major challenge due to the lack of standardized guidelines. A systematic review analyzing 20 studies identified key prognostic factors associated with successful VA-ECMO weaning. Findings revealed that higher left ventricular ejection fraction (LVEF) and left ventricular outflow tract velocity time integral (LVOT VTI) at the time of weaning were strong predictors of successful ECMO weaning. Lower lactate and CK-MB levels at admission were also associated with higher weaning success rates. Despite these insights, the study noted a moderate-to-high risk of bias due to confounding variables and small sample sizes, emphasizing the need for larger, high-quality studies to establish clear weaning criteria and improve clinical decision-making [24].

4.2 Complications in High-Risk Cardiac Interventions

4.2.1 Surgical Risks in Transapical PVL Closure

Paravalvular leak (PVL) is a well-documented complication following mitral valve surgery, frequently resulting in morbidity related to heart failure and hemolytic anemia. While both surgical and percutaneous repair techniques are available, the percutaneous approach has gained preference due to its lower procedural risk. Among percutaneous strategies, the transapical (TA) approach offers direct access to the mitral annulus, allowing precise device delivery and reducing fluoroscopy time compared to transseptal or retrograde approaches. However, despite these advantages, TA access carries specific risks, including left anterior descending (LAD) artery puncture and post-procedural bleeding, necessitating meticulous surgical technique and the use of closure devices to minimize complications [25].

The challenges associated with TA access are also evident in its use for transcatheter aortic valve implantation (TAVI), where complications such as apical bleeding, pseudoaneurysm formation, and myocardial dysfunction have been reported. A study of 143 patients who underwent transapical TAVI between June 2007 and August 2010 reported elevated procedural risk associated with this approach. The cohort, with a mean age of 80 ± 6 years and a mean logistic EuroSCORE of 21 ± 13%, experienced severe apical bleeding in 7% of cases, leading to procedure termination in three patients without valve implantation [26].

Among the remaining patients, some required cardiopulmonary bypass support, median sternotomy, or both, often necessitating surgical re-exploration. Additionally, apical pseudoaneurysm formation occurred in 2% of cases, with one patient requiring surgical revision. The 30-day survival rate among patients with apical bleeding, pseudoaneurysm, or re-exploration was 75%, with a 1-year survival of 59%, compared to 94% and 80%, respectively, in patients without complications ($p = 0.012$). Furthermore, 8% of patients experienced secondary wound healing issues, and echocardiographic follow-up at six months and one year revealed apical hypo- or akinesia in 33% and 37% of patients, respectively, indicating potential long-term myocardial dysfunction [26].

These findings emphasize that while TA access remains a valuable alternative for high-risk patients requiring structural heart interventions, its associated risks must not be overlooked. The development of major bleeding, pseudoaneurysms, and myocardial dysfunction can substantially worsen prognosis and contribute to prolonged recovery. Therefore, careful patient selection, refined procedural strategies, and long-term monitoring are essential for improving safety and efficacy in transapical interventions.

Further supporting the efficacy of TA access, a cohort study of 26 patients undergoing TA mitral PVL closure reported a 7.1% complication rate and a 35% reduction in fluoroscopy time compared to conventional access routes. A retrospective review of 17 high-risk patients undergoing TA PVL closure also demonstrated a 94% procedural success rate, comparable to surgical approaches. These findings suggest that while transapical PVL closure carries some procedural risks, it remains a promising alternative, offering efficient procedural execution and reduced fluoroscopy exposure. Additional comparative studies are needed to further establish its optimal role in mitral PVL management [25, 27].

4.2.2 ECMO as a Rescue Strategy in TAVR-Related Emergencies

Transcatheter aortic valve replacement (TAVR) is associated with a high risk of life-threatening cardiovascular complications, necessitating effective rescue strategies. Among these, extracorporeal membrane oxygenation (ECMO) has emerged as a pivotal intervention for patients experiencing severe hemodynamic instability [28].

A study analyzing 230 TAVR procedures reported that 4.3% of patients required emergent VA-ECMO due to catastrophic complications, including left ventricular perforation, aortic root rupture, coronary obstruction, valve embolization, and ventricular arrhythmias. The median duration of ECMO support was 87 minutes, and despite the severity of these complications, ECMO facilitated additional life-saving interventions, such as valve-in-valve implantation, surgical left ventricular repair, aortic root rupture repair, and coronary bypass grafting. While the study reported three in-hospital deaths, ECMO successfully stabilized the remaining patients, preventing further deterioration. These findings emphasize on ECMO's indispensable role as a safety measure in TAVR emergencies, particularly in hemodynamically unstable patients. As TAVR expands to higher-risk populations, ECMO should be considered an integral procedural safeguard, ensuring rapid intervention in cases of severe cardiovascular collapse [28].

Expanding upon these findings, another study assessed the use of both emergency and elective ECMO in high-risk TAVR patients. Among a cohort of 46 patients, four required emergency ECMO due to progressive left ventricular dysfunction post-pericardiotomy (n=2) and cardiogenic shock following balloon aortic valvuloplasty (BAV) (n=2). Particularly, in two of these cases, cardiopulmonary resuscitation (CPR) was required before ECMO initiation, highlighting ECMO's role in stabilizing patients experiencing severe hemodynamic collapse. These patients exhibited extremely high-risk profiles, including aortic stenosis with peak transvalvular gradients reaching up to 6.6 m/s, making them particularly vulnerable to perioperative decompensation [29].

Additionally, three patients received elective ECMO support due to severe pulmonary hypertension (mPAP >60 mmHg) and/or markedly reduced left ventricular ejection fraction (LVEF <20%), conditions that pose increased challenges during TAVR. In these cases, ECMO was proactively initiated preoperatively, ensuring hemodynamic stability and minimizing the risk of intraoperative deterioration. For extremely high-risk patients, ECMO cannulation sites were surgically exposed before anesthesia induction, allowing for immediate ECMO access in case of sudden instability. The arterial access routes varied, including the femoral artery (n=5), external iliac artery (n=1), and subclavian artery (n=1), depending on individual vascular anatomy [29].

The study found that one-year survival among ECMO-supported TAVR patients was 83.3%, comparable to patients who did not require ECMO support. These findings reinforce ECMO's utility not only in emergency situations but also in elective high-risk cases, ensuring hemodynamic stability and improving procedural outcomes. Furthermore, these results suggest the importance of a multidisciplinary heart team approach, where preoperative risk assessment, ECMO access planning, and timely intervention are key in optimizing patient safety and long-term outcomes [29].

Although ECMO is not routinely required for TAVR, its proactive use in selected high-risk patients can mitigate catastrophic complications, enhance survival rates, and ultimately improve overall procedural safety [29].

4.2.3 Severe Pulmonary Hypertension and Surgical Outcomes

Outcomes of Cardiac Surgery in Patients with Severe Pulmonary Hypertension

Pulmonary hypertension (PH) is a well-established risk factor for increased perioperative morbidity and mortality in cardiac surgery. Its impact is particularly relevant in patients undergoing valve interventions, where elevated pulmonary pressures exacerbate the right ventricular dysfunction and increase the likelihood of adverse perioperative outcomes [30].

A retrospective descriptive study assessed the outcomes of cardiac surgery in patients with severe PH at a tertiary-level hospital in Murcia between 2016 and 2019. The study analyzed demographic data, surgical variables, and postoperative follow-up outcomes among 69 patients who underwent cardiac surgery. The mean patient age was 68.3 ± 11 years, with a female predominance (54%). Preoperatively, 45% of patients had atrial fibrillation, and 22% underwent urgent surgery. The average New York Heart Association (NYHA) functional class before surgery was 2.5 ± 0.6 [30].

Among the surgical interventions, 57% involved single-valve surgery, while 30% included multi-valve procedures. Postoperatively, patients had a median ICU stay of 2 days and a median hospital stay of 11 days. The in-hospital mortality rate was 11.6%; however, none of the patients who received intraoperative nitric oxide therapy died postoperatively. At a median follow-up of 16 months, the mortality rate was 5%, and the 30-month survival rate was 94%. At follow-up, 48% of patients had moderate pulmonary hypertension, 26% had mild PH, and 26% continued to have severe PH. The mean NYHA functional class improved to 1.6 ± 0.5, indicating functional recovery in most patients. These findings suggest that while severe PH is associated with high perioperative mortality, long-term outcomes remain favorable. Early surgical intervention and intraoperative strategies, such as nitric oxide therapy, may contribute to improved survival and functional recovery in this patient population [30].

Pulmonary Hypertension and Outcomes After Transcatheter Mitral Valve Repair

A cohort study of 4,071 patients from the Society of Thoracic Surgery/American College of Cardiology Transcatheter Valve Therapy registry analyzed the impact of PH on clinical outcomes following transcatheter mitral valve repair (TMVr) for severe mitral regurgitation. Patients were stratified based on their invasive mean pulmonary arterial pressure (mPAP) into four groups: no PH (mPAP <25 mm Hg), mild PH (mPAP 25–34 mm Hg), moderate PH (mPAP 35–44 mm Hg), and severe PH (mPAP ≥45 mm Hg). The study found that PH was associated with increased one-year mortality and hospital readmissions for heart failure. However, despite these risks, TMVr remained a safe and effective intervention, leading to improved functional capacity even in patients with severe PH [31].

Minimally Invasive vs. Full Sternotomy in Patients with Pulmonary Hypertension

A retrospective review compared outcomes between minimally invasive mitral valve surgery (MIMVS) and conventional full sternotomy (FS) in patients with PH, aiming to determine whether less invasive approaches improve recovery while maintaining surgical efficacy. The study included 591 patients, with 317 undergoing MIMVS and 274 undergoing FS. To adjust for baseline differences, nearest-neighbor propensity matching was performed, yielding 112 well-matched pairs for analysis [32].

Despite longer cardiopulmonary bypass times (137 vs. 89.5 minutes, $P < .001$) and cross-clamp times (102 vs. 63 minutes, $P < .001$) in the MIMVS group, these patients demonstrated several perioperative benefits. MIMVS was associated with shorter initial ventilator times (6 vs. 9.6 hours, P < .001), reduced hospital length of stay (7 vs. 8 days, P = .049), and lower rates of blood product usage (26.8% vs. 41.1%, P = .03). The comparable 30-day and 10-year survival indicates that the minimally invasive approach maintains long-term survival efficacy [32].

These findings indicate that MIMVS is a viable alternative to FS in patients with PH, offering advantages in postoperative recovery without increasing surgical risk. Given that PH is an independent predictor of morbidity and mortality in cardiac surgery, the ability to minimize surgical trauma while maintaining durability is a crucial consideration in patient selection for mitral valve interventions [32].

To summarize the key findings, a comparison between MIMVS and FS is provided in **Table 5**:

Table 5. Outcomes Comparison Between Minimally Invasive and Full Sternotomy Approaches in Mitral Valve Surgery

Parameter	**MIMVS (n=317)**	**FS (n=274)**	**P-value**
Cardiopulmonary bypass time (min)	137 ± 20	89.5 ± 18	<0.001
Cross-clamp time (min)	102 ± 15	63 ± 13	<0.001
Ventilator time (hours)	6 ± 1.2	9.6 ± 2.1	<0.001
Hospital length of stay (days)	7 ± 1.8	8 ± 2.3	0.049
Blood product usage (%)	26.8	41.1	0.03
30-day survival (%)	100	97.3	0.12
10-year survival (%)	Comparable	Comparable	0.661

Preoperative and Postoperative Pulmonary Hypertension in Mitral Valve Surgery

A retrospective cohort study evaluated the impact of both preoperative and persistent postoperative pulmonary hypertension (PH) on long-term mortality in patients undergoing mitral valve surgery (MVS) for severe mitral regurgitation. The study included 488 patients who underwent MVS between 2011 and 2016, with preoperative pulmonary artery pressures assessed via right-heart catheterization [33].

PH was highly prevalent in this population, with 85% of patients exhibiting elevated pulmonary artery pressures before surgery. Notably, each 10-mmHg increase in preoperative mean pulmonary artery pressure was associated with a 1.38-fold increase in mortality risk (95% CI, 1.13–1.68). Additional markers of poor prognosis included higher pulmonary vascular resistance, transpulmonary gradient, and right atrial pressure, all of which correlated with worse survival outcomes [33].

Among the 231 patients with postoperative echocardiograms, persistent PH defined as pulmonary artery systolic pressure ≥35 mmHg was initially associated with a two-fold increased risk of mortality. However, after adjusting for demographics and comorbid conditions, this association was no longer statistically significant. This suggests that while preoperative PH is a strong predictor of mortality, the long-term significance of persistent PH after surgery remains unclear [33].

These findings emphasize the importance of early intervention in patients with severe mitral regurgitation and preoperative PH, as delaying surgery may contribute to pulmonary vascular remodeling and worsen long-term survival. Further studies are needed to clarify whether targeted therapies for PH or optimized surgical timing can improve outcomes in this high-risk patient cohort [33].

4.2.4 Hemostatic Strategies in Cardiac Surgery

Suture less hemostatic repair techniques have emerged as an effective approach for managing myocardial rupture while minimizing additional trauma to fragile cardiac tissue. The study by Makhoul et al. emphasizes two primary hemostatic strategies: the glued-hemostatic patch technique and the glued pericardial patch technique. Both approaches eliminate the need for sutures, reducing the risk of further myocardial damage [34].

In the glued-hemostatic patch technique, fibrin-based glue is applied over the infarcted myocardial area, ensuring coverage that extends beyond the rupture margins. A hemostatic patch, such as TachoSil, is then placed immediately, with gentle pressure applied until the glue sets, creating a stable seal. This method is particularly useful for small, well-defined rupture sites where bleeding is controlled [34].

For more complex or irregular rupture sites with persistent bleeding, the glued pericardial patch technique is utilized. This involves applying external pressure by creating a pericardial pocket and injecting hemostatic material between the pericardium and the infarcted myocardium. This strategy ensures continuous compression, aiding in hemostasis while reinforcing the damaged myocardial wall [34].

A variety of hemostatic materials play a vital role in these techniques. TachoSil, a fibrin-coated collagen matrix, is commonly used to promote clot formation and adhesion. Pericardial patches provide broader coverage for larger defects, while surgical glues such as Bioglue, Tisseel, and Coseal are employed to enhance mechanical stability and sealing strength [34].

Postoperative management focuses on preventing re-rupture, with strict afterload reduction, controlled blood pressure maintenance, and prolonged bed rest to minimize myocardial stress. These sutureless hemostatic strategies offer a promising alternative in cardiac surgery, particularly in cases where traditional suturing techniques pose a risk of further myocardial disruption [34].

Expanding on the role of hemostatic techniques in ventricular rupture repair, another study demonstrated the successful surgical management of a right ventricular free-wall rupture using a combination of autologous pericardial patching and fibrin glue reinforcement. In cases where the myocardial tissue is severely compromised and traditional suturing alone may not provide adequate stability; this approach offers an effective alternative. The repair was achieved by securing a pericardial patch to the healthy epicardium with fine polypropylene sutures, ensuring minimal tension on the fragile infarcted tissue. To further reinforce the repair and enhance hemostasis, fibrin Bioglue was applied between the patch and the epicardium, creating a strong seal and reducing the risk of postoperative bleeding [35].

5. Discussion

5.1 Key Findings from the Case Study

This case study presents a 75-year-old woman with extensive cardiovascular comorbidities, including coronary artery disease, atrial fibrillation, diabetes mellitus, hypertension, and a history of pulmonary embolism. The patient developed five mitral paravalvular leaks (PVLs), leading to severe mitral regurgitation and secondary pulmonary hypertension, with an estimated pulmonary artery pressure (PAP) of 100 mmHg. Due to the severity of her condition and high surgical risk, a transapical PVL closure was planned as the preferred intervention. However, the procedure was complicated by severe bleeding due to right ventricular apex perforation, necessitating emergent veno-arterial extracorporeal membrane oxygenation (VA-ECMO) deployment for hemodynamic stabilization. Following ECMO initiation, the PVLs were successfully closed (Appendix Figure A3 demonstrates post-repair imaging.).

A fundamental aspect of this case was the intraoperative deployment of VA-ECMO to manage acute hemodynamic collapse. Severe right ventricular bleeding created an immediate life-threatening scenario, where conventional haemostatic measures alone were insufficient. The necessity of ECMO in this setting underscores its expanding role in high-risk valvular interventions, particularly in patients with severe pulmonary hypertension and right ventricular dysfunction, where perioperative hemodynamic instability poses a serious concern. As demonstrated in this case, ECMO provided vital circulatory support, allowing for continued intervention while preventing catastrophic cardiovascular decompensation.

An additional key finding in this case was the unconventional yet effective use of a Foley catheter for temporary haemostasis. The right ventricular perforation presented a major bleeding challenge, and while pledget-reinforced sutures are commonly employed in such scenarios, immediate haemorrhage control was necessary. The Foley catheter tamponade technique provided rapid and effective bleeding control, facilitating subsequent surgical repair. This strategy demonstrates the importance of innovative and adaptable intraoperative haemostatic techniques, particularly in complex structural heart interventions where conventional bleeding control measures may not suffice.

Once hemodynamic stability was achieved with ECMO support, transapical PVL closure was completed, effectively reducing mitral regurgitation to mild. The patient remained on ECMO for circulatory support and was successfully weaned off the following day. Postoperatively, the patient developed acute renal failure requiring renal replacement therapy (RRT), a well-recognized complication associated with ECMO use, prolonged hemodynamic instability, and perioperative ischemic insults [18, 19]. Despite this complication, the patient demonstrated progressive recovery and was successfully discharged to a rehabilitation facility on postoperative day 40.

This case demonstrates that even in high-risk surgical candidates, aggressive interventions can be both feasible and effective when carefully planned and executed. The successful use of ECMO as a salvage strategy highlights its critical role in managing catastrophic intraoperative complications. Furthermore, the effective application of the Foley catheter tamponade technique suggests a potential adjunctive approach for controlling severe intraoperative bleeding in select cases. These findings emphasize the need for multidisciplinary intraoperative decision-making, real-time adaptation to complications, and the integration of advanced circulatory support techniques in high-risk structural heart procedures.

5.2 The Role of ECMO in High-Risk Mitral Valve Interventions

The use of ECMO in this case exemplifies its indispensable role in managing intraoperative hemodynamic instability. ECMO serves as a circulatory bridge, providing adequate perfusion while mitigating right ventricular failure and acute volume overload, particularly in patients with severe pulmonary hypertension. While ECMO improves procedural success rates in high-risk cardiac surgery, its complications such as coagulopathy, thromboembolism, and end-organ dysfunction necessitate cautious implementation. Studies evaluating prophylactic ECMO use in high-risk procedures, such as PCI and TAVR, suggest that controlled initiation before hemodynamic deterioration leads to substantially lower mortality rates compared to emergency ECMO deployment [9, 12, 13].

Despite its expanding application in high-risk cardiac interventions, literature specifically evaluating ECMO use in mitral valve interventions, including PVL repair, remains limited. However, studies have demonstrated ECMO's utility in transcatheter aortic valve replacement (TAVR), high-risk PCI, and post-cardiotomy cardiogenic shock, suggesting its applicability in mitral PVL repair [11, 14]. Given the hemodynamic complexities associated with severe pulmonary hypertension, left ventricular dysfunction, and procedural instability in mitral valve surgery, the application of ECMO in this subset of patients remains a logical and necessary adaptation of existing knowledge.

5.3 The Impact of Severe Pulmonary Hypertension on Surgical Decision-Making

Severe pulmonary hypertension poses a major challenge in the perioperative setting, particularly in mitral PVL repair, where elevated right ventricular afterload can lead to right ventricular decompensation. Literature suggests that patients with pulmonary hypertension undergoing valve interventions have increased perioperative morbidity, with higher rates of prolonged mechanical ventilation, right ventricular failure, and in-hospital mortality [30, 31]. The integration of ECMO in this case helped mitigate these risks, reinforcing its role as a key supportive measure in patients with severe pulmonary vascular disease.

A crucial consideration in patients with severe PH undergoing structural interventions is long-term pulmonary hemodynamic management. While ECMO provides temporary unloading, its effect on pulmonary vascular remodeling and long-term right ventricular function remains uncertain. Adjunctive therapies such as pulmonary vasodilators or staged interventions may offer additional benefits in selected patients, warranting further research into multimodal approaches for PH management in the perioperative period [31].

5.4 Comparability of ECMO Outcomes Across Studies

An important challenge in evaluating ECMO outcomes is the heterogeneity in patient populations, ECMO indications, and procedural settings across studies. The variability in ECMO applications, ranging from prophylactic use in planned high-risk interventions to emergent deployment in cases of cardiovascular collapse, complicates direct comparisons of survival rates and complication profiles. The previously discussed graph comparing prophylactic versus emergency ECMO use in

TAVR procedures illustrated a stark contrast in procedural success rates and 30-day mortality [12, 13]. Similar challenges in data interpretation exist in ECMO-supported mitral valve interventions, where differences in preoperative risk profiles, underlying valve pathology, and pulmonary hypertension severity may significantly influence outcomes.

Long-term follow-up studies also indicate that ECMO survivors often experience reduced functional capacity, persistent fatigue, and psychological distress, suggesting the need for structured post-ECMO rehabilitation programs [20, 21]. Research evaluating post-discharge cardiac rehabilitation and psychological support for ECMO survivors may play an indispensable role in shaping long-term recovery outcomes.

6. Conclusion

This thesis evaluated the pivotal role of extracorporeal membrane oxygenation (ECMO) in managing severe intraoperative complications associated with high-risk mitral paravalvular leak (PVL) interventions. The comprehensive literature review emphasized ECMO's proven utility in stabilizing hemodynamic collapse, particularly among patients with complex valvular conditions and severe pulmonary hypertension, advocating the advantages of early, proactive ECMO utilization compared to emergency deployment.

The presented case study underscored ECMO's lifesaving capacity in severe procedural complications and illustrated the value of innovative intraoperative hemostatic techniques. Collectively, these findings demonstrate ECMO's potential to substantially enhance patient safety and procedural outcomes when integrated into multidisciplinary care framework for structural heart interventions.

Future research should focus on developing standardized ECMO application protocols, refining procedural techniques, enhancing imaging modalities and assessing long-term patient outcomes, and healthcare resource efficiency. Such advancements will strengthen ECMO's essential role as a fundamental component in high-risk cardiac surgery, ultimately improving clinical decision-making and patient management strategies.

7. Appendix A: Transesophageal Echocardiography (TEE)

Figure A1. *3D TEE en face view of a prosthetic mitral valve showing multiple paravalvular regurgitant jets, consistent with the paravalvular leaks (PVLs).*

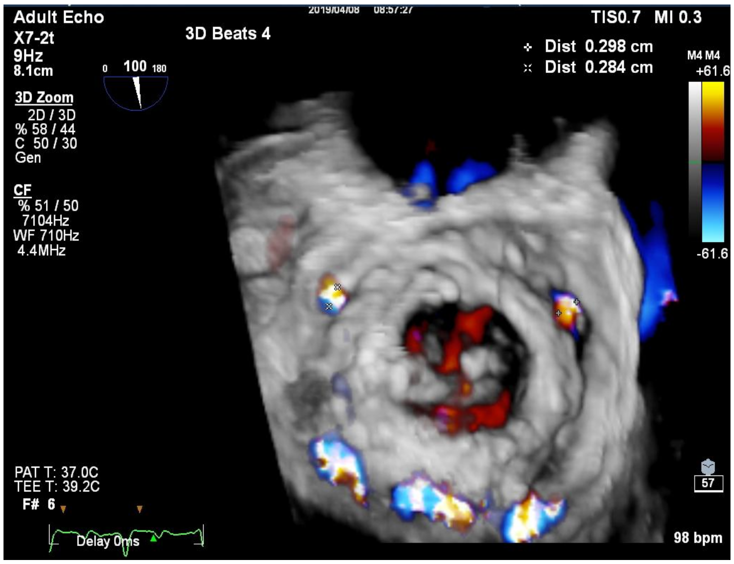


Figure A2 (A-B). *Sequential 3D TEE images showing turbulent paravalvular regurgitant flow prior to PVL closure*

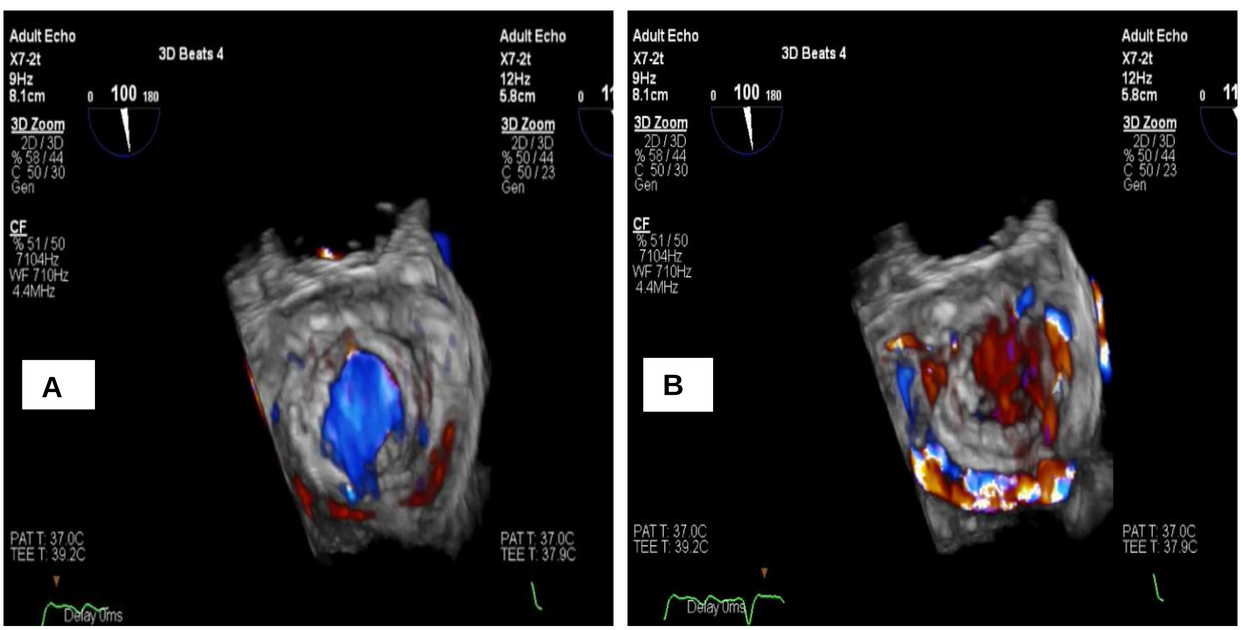
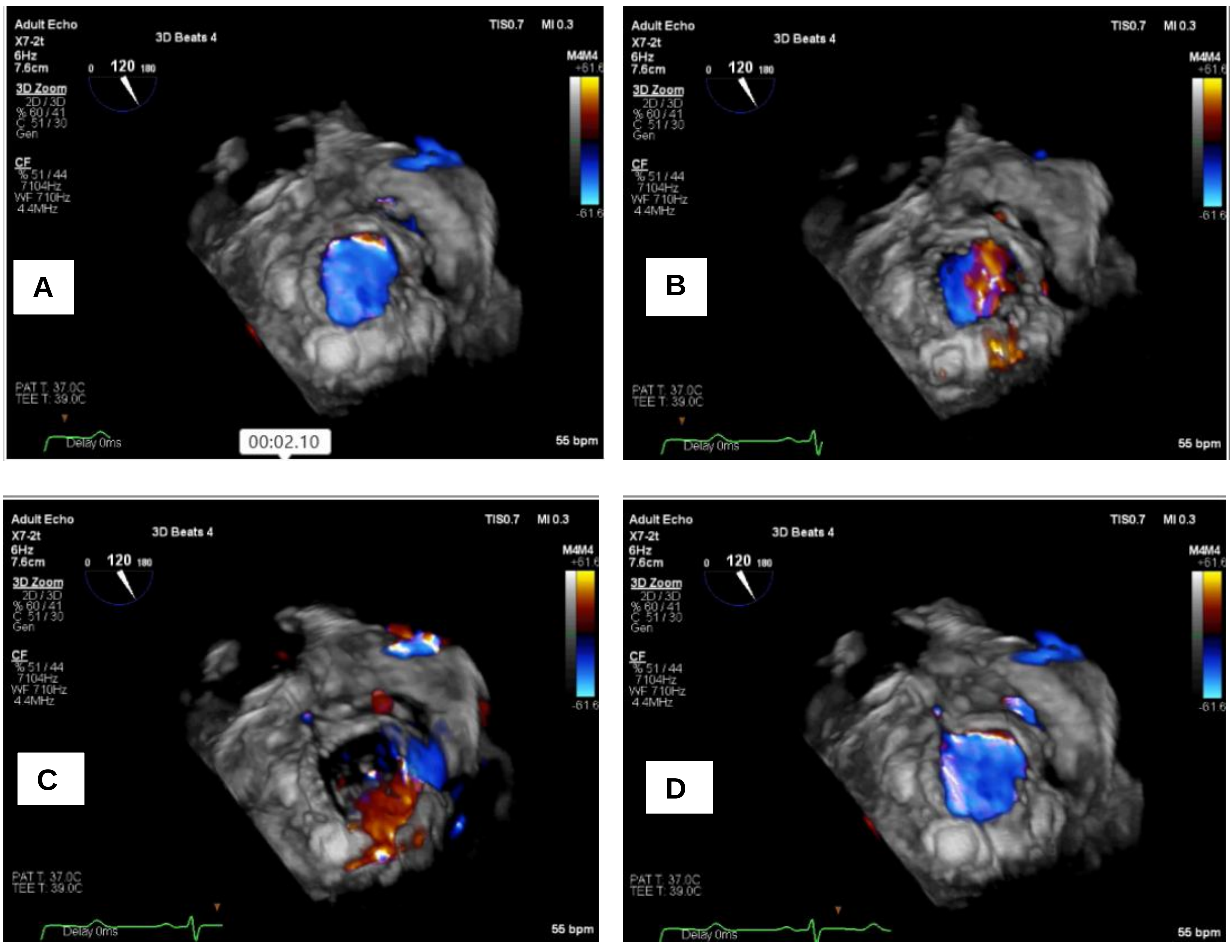


Figure A3 (A-D). *Sequential 3D TEE images showing color Doppler flow around the prosthetic mitral valve. Compared to pre-repair imaging (Appendix Figure A1, A2), which demonstrated five distinct PVLs, these images show markedly fewer and more localized regurgitant jets, consistent with successful PVL closure and minimal residual flow*.



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