The Heart Surgery Forum

Heart Surg. Forum **2026**; 29(3): 51551
https://doi.org/10.31083/HSF51551

Review

Perioperative Risk Assessment and Management of Redo Cardiac Surgery

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Academic Editor: Jeffrey H. Shuhaiber
Submitted: 16 September 2025 Revised: 12 November 2025 Accepted: 10 December 2025 Published: 10 March 2026

Abstract

Advances in percutaneous cardiac interventions for both coronary and valvular diseases have led to a decline in the number of redo cardiac surgical procedures. Patients who require redo cardiac surgery have typically exhausted percutaneous options, placing these patients in a high-risk category where surgical intervention remains the only viable option. Contemporary redo operations most often involve native or prosthetic valve endocarditis, aortic graft infections, or complex valvular reconstructions in patients with failing hearts. In addition, novel challenges have emerged following transcatheter valve replacement, leading to new forms of redo valve surgery. Redo coronary artery bypass grafting (CABG) has become uncommon due to the widespread use of durable arterial grafts at initial operation and the increasing expertise of interventional cardiologists in treating conduit or native vessel stenoses percutaneously. Patients who still require redo CABG often have multiple coronary stents, complicating surgical revascularization. Consequently, morbidity and mortality remain significantly higher for redo cardiac surgery compared with primary procedures. This review summarizes predictors of perioperative morbidity and mortality and outlines best practices in the risk assessment and management of patients undergoing redo cardiac surgery.

Keywords: redo cardiac surgery; percutaneous cardiac interventions; transcatheter aortic valve replacement; perioperative management; surgical risk

1. Introduction

Historically, the adage "as long as there is cardiac surgery, there will always be redo cardiac surgery", reflected the limited durability of tissue valves and the thrombotic complications associated with mechanical prosthetic valves. In addition, perivalvular leaks, failed valve repairs, and prosthetic valve infections have necessitated redo valve surgery [1]. Meanwhile, the main indications for redo coronary artery bypass grafting (CABG) include progression of coronary artery disease, failure of non-arterial bypass grafts, and anastomotic stenosis in both arterial and venous grafts, resulting in persistent angina.

In the late 20th and early 21st centuries, 15–20% of all cardiac procedures performed at institutions that performed cardiac surgery were redo operations. However, advances in catheter-based interventions over the last two decades have allowed many patients to be treated percutaneously, improving symptoms and delaying the need for surgery [2]. Subsequently, patients often present for surgery later, with more advanced disease, making redo procedures increasingly complex and high-risk.

The widespread adoption of transcatheter valve interventions, such as transcatheter aortic valve replacement (TAVR) and transmitral valve replacement (TMVR), has created a new subset of redo cardiac surgeries due to complications, such as malpositioned or malfunctioning valves that obstruct blood flow [3]. Patients who have undergone prior CABG are frequently selected for percutaneous valve procedures, and any subsequent complications may necessitate urgent open surgical intervention or high-risk repeat percutaneous procedures. Thus, surgeons must become familiar with newer complications arising from technical advancements, such as ruptures of anatomical structures during balloon inflation, necessitating emergency high-risk surgeries. Moreover, congenital cardiac procedures performed in childhood may require revision as the patient grows, further increasing the need for redo surgery [4].

Calvelli *et al*. [5] retrospectively studied 250 patients who underwent redo surgery for both valve and coronary indications, reporting a 30-day mortality of 13.6% and a 1-year mortality of 21.2%. Colkesen *et al*. [6] reviewed 109 redo cardiac surgeries performed by a single surgical team, concluding that while redo cardiac surgery can be performed safely, a Euro Score II $>$5 and recent-onset atrial fibrillation (AF) significantly increase postoperative risk. Similarly, the Society of Thoracic Surgeons (STS) considers mortality rates $\geq$8% as very high risk; the SCS takes the following risk factors and assigns points for each: patient demographics, comorbidities, functional status, and procedure-specific factors [7]. Globally, redo cardiac surgery now reflects a trend toward more complex case profiles, as evidenced by both the reduction in straightforward redo CABG and the increasing frequency of high-risk operations, such as TAVR explant [8].

The review aims to summarize changes in cardiac disease and highlight the latest surgical management trends, enabling surgeons to provide better care to patients.

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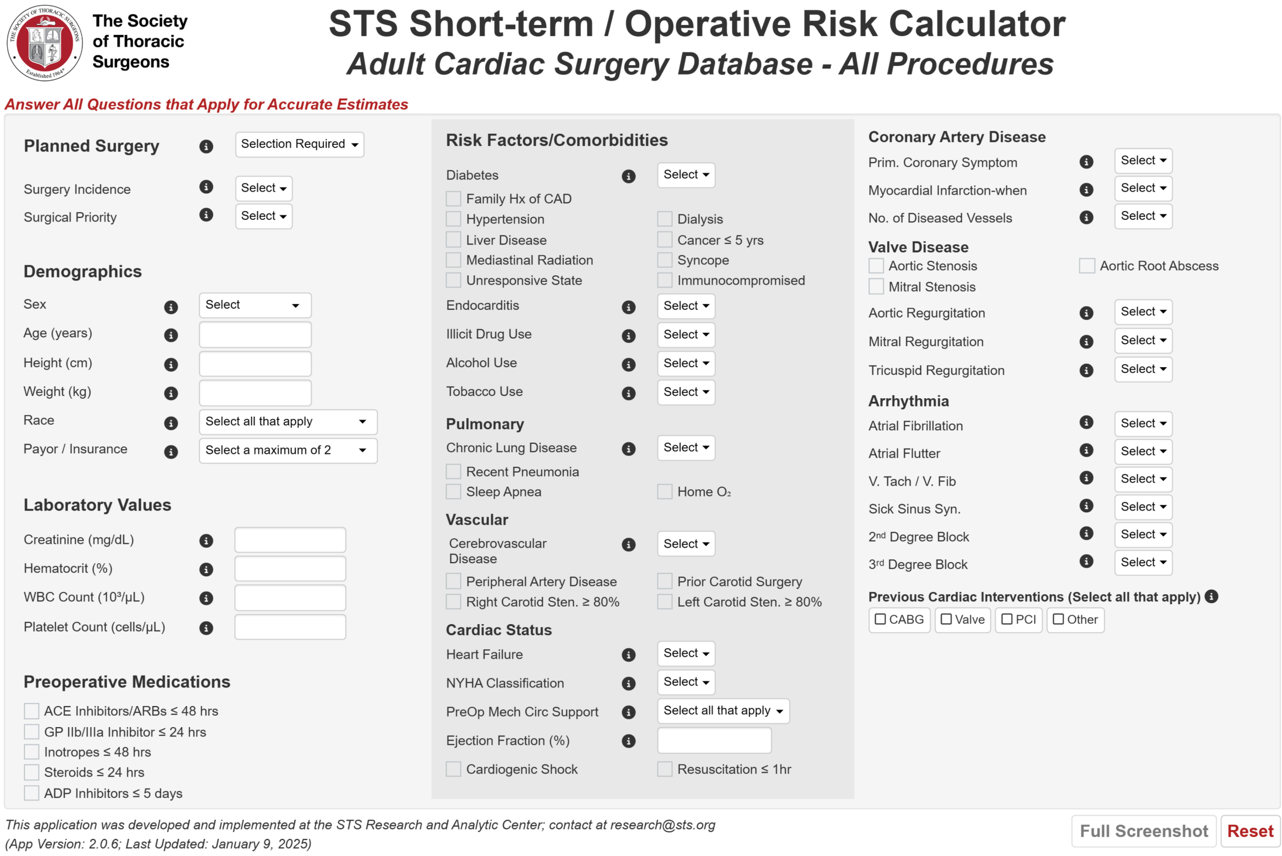


Fig. 1. STS Operative Risk Calculator. Visual representation of the factors associated with operative risk.

2. Perioperative Risk Assessment

The risk associated with redo cardiac surgery can be categorized as patient-related, procedure-related, surgeon-related, and institution-related. While patient- and procedure-related risks have been well-studied, surgeon- and institution-related risks are less frequently documented.

2.1 Patient-Related Risk Factors

The ACS-NSQIP (American College of Surgeons-National Surgical Quality Improvement Program) Surgical Risk Calculator is widely regarded as a reliable general surgical risk assessment tool put forth by the American College of Surgeons. Other validated tools include the STS Operative Risk Calculator for cardiac surgery (Fig. 1) and specialized calculators such as the Revised Cardiac Risk Index (RCRI).

Several patient factors increase the risk of redo cardiac surgery:

(1) Advanced age: patients $\geq$65 years often have diffuse arteriosclerosis, requiring thorough preoperative assessment to reduce morbidity and mortality.

(2) Poor left ventricular function: Left ventricular ejection fraction (LVEF) less than 30% is considered severely reduced performance and needs better preoperative preparation before surgery, as surgical outcomes do correlate with normal LVEF (50–70%) or poor function.

(3) Renal dysfunction: Elevated serum creatinine and need for perioperative dialysis correlate with higher mortality.

(4) Pulmonary hypertension and poor pulmonary function: Mean pulmonary artery pressure $>$20 mmHg or Forced Expiratory Volume in one second (FEV1) $<$50% predicts prolonged ventilatory support and a higher risk. These patients require proper evaluation and should be informed of the associated increased surgical risk.

(5) Urgency of operation: An urgent operation reflects severe hemodynamic imbalance, either from blood loss or poor ventricular function from a failing heart. Cardiac surgery mortality is directly related to the hemodynamic condition of the patient before surgery.

(6) Number of previous sternotomies: While major cardiac centers have reported that first-time redo cardiac surgery is of no higher risk than a first-time cardiac surgery, the majority of the surgeons agree that mortality rates increase with multiple repeat sternotomies.

(7) Interval between sternotomies: A repeat sternotomy within one year of previous cardiac surgery has shown poorer outcomes from observational studies.

(8) Presence of a patent left internal thoracic artery (LITA) crossing the midline: A patent LITA graft to the left anterior descending coronary artery has proven beneficial

to survival; meanwhile, any injury to the structure during surgery has exponentially increased the mortality risk.

(9) Preoperative anemia: Hemoglobin levels $\leq$8 g/dL reduce oxygen delivery, increasing the risk of lactic acidosis and poor outcomes.

Ascending aortic calcification, identified on preoperative computed tomography (CT), increases the risk of cerebral embolism during surgical manipulation [9]. To mitigate this, surgeons may use a "no-touch" aortic technique or alternative strategies, which may prolong cardiopulmonary bypass (CPB) time or introduce unfamiliar technical challenges.

Extended CPB times, postoperative bleeding, and inotropic support requirements are generally higher in redo procedures compared to first-time operations, contributing to increased rates of perioperative AF, morbidity, and mortality. Additional factors, such as prior stroke and high frailty scores, further elevate risk. The Hospital Frailty Risk Score (HFRS) is a useful predictor of short- and mid-term postoperative disability, with scores $<$5 indicating low risk and $>$15 indicating high risk [10].

Bianco *et al.* [11] reviewed 1700 patients undergoing redo cardiac surgery between 2011 and 2017, finding that redo surgery is an independent predictor of both early and late morbidity and mortality.

Patients presenting for redo cardiac surgery rarely exhibit a single risk factor; instead, these patients more commonly have multiple comorbidities. Risk stratification tools, such as the STS and EuroSCORE, integrate these variables to provide estimates of operative morbidity and mortality, thereby facilitating informed consent. Nonetheless, an ethical challenge persists, while surgery may represent the only life-saving option, certain high-risk patients, such as older individuals in cardiogenic shock requiring multivalvular procedures, may not survive despite intervention by experienced surgical teams.

2.2 Procedure-Related Risk Factors

Outcomes are generally better for first-time redo surgeries than for second- or multiple-repeat operations. Complex procedures, such as double or triple valve surgeries or aortic root replacements with arch reconstruction, require prolonged CPB times and are associated with increased perioperative complications. Insler *et al.* [12] reported operative mortality rates of 4.7% for elective redo double or triple valve procedures and 1.7% for single-valve redo surgeries.

Re-operative aortic root replacements or type A aortic dissection repairs have higher mortality unless performed by experienced surgeons [13]. The presence of patent arterial grafts, particularly a right internal thoracic artery (RITA) crossing the midline, and urgent operative indications also place patients in a higher risk category [14].

2.3 Surgeon-Related Risk Factors

Surgeons specializing in aortic, mitral, or coronary procedures generally achieve better outcomes than general cardiac surgeons; experience with redo operations is critical for safely managing complex dissections and unexpected complications. Although no formal requirement exists, performing at least 50 cardiac procedures annually is recommended to maintain proficiency, yet no specific mandate addresses redo surgery experience [15]. While there is specialization in pediatric surgery and in aortic and mitral valve surgery, no special requirement exists to perform redo cardiac surgical procedures.

Rappoport *et al.* [15] studied 1,362,218 first-time patients who underwent CABG and 93,985 resternotomy CABG reported to The Society of Thoracic Surgeons Adult Cardiac Surgery Database between 2010 and 2019. Primary outcomes were in-hospital mortality and morbidity (M and M) rates calculated per hospital and per surgeon. Outcomes were compared across six total cardiac surgery volume categories. Multivariable generalized linear mixed-effects models were used, considering continuous case volume as the main exposure, adjusting for patient characteristics and within-surgeon and hospital variation. Rappoport *et al.* [15] observed only an inverse relationship between total cardiac case volume and resternotomy CABG outcomes at the surgeon level, indicating that individual surgeon experience, rather than institutional volume, is the key determinant [16].

At the Cleveland Clinic, Kindzelski *et al.* [17] implemented a two-pilot strategy in which a senior surgeon assisted during critical portions of complex redo procedures. Longer CPB and aortic cross-clamp times were strongly correlated with surgeon experience, and perioperative complications increase with operative duration.

2.4 Institution-Related Risk Factors

High-volume centers (HVCs) demonstrate better outcomes than low-volume centers, highlighting the importance of multidisciplinary postoperative care. HVCs typically provide continuous staff coverage, rapid access to blood bank support, and immediate intervention for acute events, such as cardiac tamponade or neurological complications, which improves the ability to "rescue" patients from complications. Na *et al.* [18] reported positive outcomes in centers with a cardiac intensivist managing post-op care compared with centers without an intensivist. Strobel *et al.* [19] studied a total of 43,641 patients from the STS database, included across 17 centers during the study period. Of these, 5315 (12.2%) developed an FTR (failure to resuscitate) complication, and 735 experienced FTR. Increasing center-level case volume was associated with significantly higher center-level major complication rates but lower mortality and FTR rates (all *p*-values $<$ 0.01). Observed-to-expected FTR was significantly associated with case volume (p = 0.040). Increasing case volume was independently associated with a reduced FTR rate in the final multivariable model (odds ratio, 0.87 per quartile; confidence interval, 0.799–0.946; p = 0.001) [19].

Fig. 2. Dissection in the plane of adhesions during redo cardiac surgery. Careful dissection in the plane of adhesions during redo cardiac surgery will avoid injury to normal cardiac structures.

Subsequently, the STS has published guidelines for multidisciplinary resuscitation of post-cardiac surgery patients, a framework more effectively implemented in high-volume centers [19,20].

2.5 Preoperative Preparation for Cardiac Surgery

Implementing perioperative protocols to enhance recovery after cardiac surgery (ERACS) has been the most effective way to address and correct comorbidities as much as possible before surgery, *e.g.*, by addressing anemia, smoking cessation, nutritional screening, and prehabilitation in high-risk patients [21]. Pulmonary toilet and breathing exercises have also been implemented to avoid prolonged intubation. Meanwhile, the use of erythropoietin in combination with intravenous iron therapy has helped increase Hgb levels before surgery [22]. Patients should be evaluated for neurovascular disease before surgery to rule out a high degree of bilateral carotid artery stenosis, and those with symptomatic carotid stenosis with 70% or higher stenosis should undergo carotid endarterectomy to prevent perioperative stroke.

2.6 Management of Redo Cardiac Surgery

Redo cardiac surgery presents unique challenges due to adhesions, altered anatomy, and previous grafts or prostheses. Thus, successful management relies on meticulous preoperative planning, intraoperative strategies, and postoperative support.

2.6.1 Preoperative Planning

Preoperative imaging is essential for assessing the relationships among the sternum, cardiac structures, and grafts [23]. CT angiography is the standard for evaluating:

- Sternum-to-heart distance.
- Location of patent grafts (particularly LITA or RITA).
- Aortic calcification or aneurysmal segments.

2.6.2 Cardinal Steps in Redo Cardiac Surgery

- Prevention of reentry-related injury to cardiac structures.
- Adequate exposure of the surgical site of operation.
- Limiting CPB time.
- Proper myocardial protection and accelerating the recovery of ventricular function as early as possible with both inotropic and mechanical support.

If any one of these steps does not occur properly, a cascade of complications will occur, resulting in increased length of stay in the intensive care unit (ICU) and leading to higher morbidity and mortality. The underlying experience and the learning curve of the surgical team determine the outcome.

2.6.3 Redo Sternotomy

Redo sternotomy carries a high risk of injury to underlying cardiac structures, even for experienced surgeons, unless meticulous precautions are implemented (Fig. 2). Preoperative CT imaging is routinely used to identify areas where cardiac structures are adherent to the sternum, helping avoid inadvertent injury [23]. Intraoperative transesophageal echocardiography (TEE) provides continuous monitoring of ventricular and valvular function, thrombi, and air emboli throughout the procedure.

To minimize reentry injury, a strict surgical technique should be adopted, and surgeons should learn from previous mistakes (Video 1).

(1) Incise only the anterior table of the sternum with an oscillating saw.

(2) Spread the sternal edges with a cast spreader from the xiphoid process up.

(3) Slowly incise the posterior table with scissors.

(4) Use a mammary retractor to lift the sternum gradually.

(5) Carefully lyse adhesions to protect cardiac structures.

Video 1. Spreading the sternal edges with a cast spreader and incising the posterior table with scissors. This clip highlights the controlled, stepwise approach used during reentry to minimize injury to underlying cardiac structures. Video associated with this article can be found in the online version, at https://doi.org/10.31083/HSF51551.

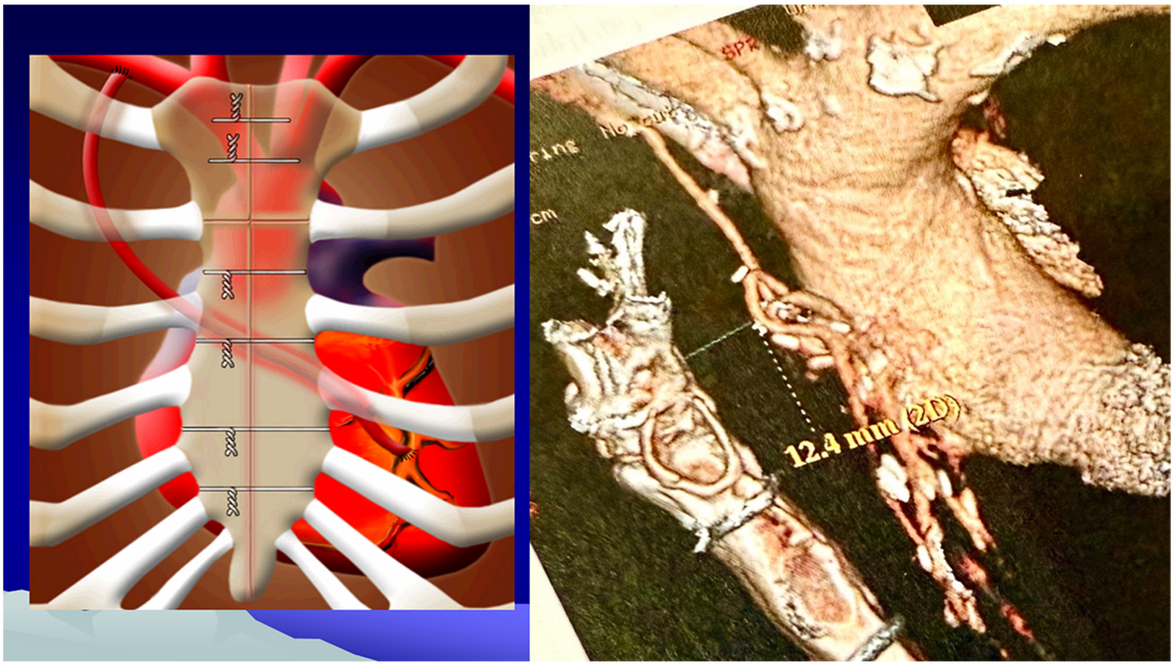


Fig. 3. Angiogram of the distance between the pedicle RITA and the back of the sternum. RITA, right internal thoracic artery.

This technique provides a consistent and reproducible approach to safe redo sternotomy. An extra few minutes spent during sternal reentry will save several hours of surgical time if vascular structures are injured.

Internal thoracic artery grafts pose additional challenges. LITA may lie beneath the sternum if harvested and brought over intact pleura (Video 2). Currently, surgeons access the LITA through a pericardial window to avoid adherence to the back of the sternum. The RITA, when anastomosed to left anterior descending (LAD) artery, crosses the midline underneath the sternum. However, the RITA is more adherent to the surface of the ascending aorta than to

Video 2. Angiographic and intraoperative views of the course and proximity of the left internal thoracic artery to the posterior aspect of the sternum. Angiographic and intraoperative views of the variable distance between the LITA graft and the sternal edge along the associated trajectory. These emphasize the potential vulnerability of the conduit during redo sternal reentry. Video associated with this article can be found in the online version, at https://doi.org/10.31083/HSF51551.

the back of the sternum (Fig. 3). Notably, injuring the LITA during redo sternotomy is easier than injuring the RITA.

Before angioplasty, this author preferred pedicle RITA to the LAD and pedicle LITA to the circumflex branches, as the left subclavian artery is more prone to atherosclerosis and occlusion than the innominate and right subclavian arteries; pedicle grafts can also reduce cross-clamp time.

CPB allows cardiac decompression and the repair of inadvertent injuries. In select cases, peripheral cannulation and CPB before sternotomy are indicated when imaging shows vital structures adherent to the sternum [24]. Although this increases bypass time and bleeding risk, this process is also known to mitigate catastrophic injury. Hemodynamically unstable patients, whether due to cardiac failure or active bleeding, may benefit from CPB before sternotomy. Mortality correlates with procedural complexity, from tamponade relief to aortic root or arch replacement. Central cannulation after most of the dissection is performed is ideal to limit CPB duration.

2.6.4 Adequate Exposure

Surgical site exposure is key to a quick operation, whether open or minimally invasive, and this exposure reduces CPB time (Fig. 4). Prolonged aortic cross-clamping time and CPB have led to perioperative myocardial dysfunction and several postoperative complications, such as bleeding, AF, prolonged ventilatory support, and subsequent respiratory complications. The experience of the surgeon is critical, and deliberate dissection to improve access is faster and safer than operating with limited exposure.

2.6.5 Myocardial Protection

Continuous TEE monitoring enables detection of regional wall-motion abnormalities to guide perfusion.

This author relied on antegrade induction with a combination of adenosine and lidocaine and maintenance with retrograde tepid potassium blood cardioplegia via the coronary sinus catheter. This technique uses the three types of cardiac arrest: hyperpolarized, polarized, and depolarized, which provide instantaneous cardiac arrest to start the operation. Proper positioning of the retrograde catheter is important to perfuse the right ventricle. In redo cases, adhesions need to be released behind the coronary sinus to guide the catheter into the sinus; otherwise, the catheter may perforate the sinus. Watching the right ventricular surface reveals whether sufficient cardioplegic solution is being delivered or whether additional supplemental methods are needed, such as an additional antegrade dose. Currently, either Del Nido or HTK (histidine–tryptophan–ketoglutarate) cardioplegia is used. Some studies favor the HTK solution for prolonged aortic cross-clamping [25].

Interestingly, a debate has arisen regarding the protection of the left ventricle when a patent ITA graft is present. Some studies have recommended leaving the graft undisturbed and cooling the body to prevent fibrillation caused by warm blood perfusion [26]. The approach of this author has been to isolate and occlude the graft when visible, facilitating routine operation while preventing undue stretch during chest retraction. Meanwhile, releasing adhesions around the graft further reduces the risk of graft stretch injury (Fig. 5). Although this approach differs from conventional recommendations about managing patent ITAs, in my experience, no arterial graft injuries have occurred.

2.6.6 Supporting Ventricular Function

Depending on the length of aortic cross-clamping and preoperative ventricular function, patients can develop vasoplegic syndrome or a sudden change in ventricular afterload. This is because of low peripheral vascular resistance (PVR), associated with high cardiac output and very low systolic blood pressure. While catecholamines are considered the first-line treatment, non-catecholamine agents such as methylene blue are also used to increase PVR [27]. TEE evaluation of cardiac chambers, filling volumes, wall motion abnormalities, and mitral and tricuspid regurgitation will help steer proper postoperative management. The causes of ventricular dysfunction are multifactorial, including surgical tissue trauma, myocardial ischemia-reperfusion injuries, downregulation of beta-adrenergic receptors, coronary embolization (*e.g.*, air, atheroma), activa-

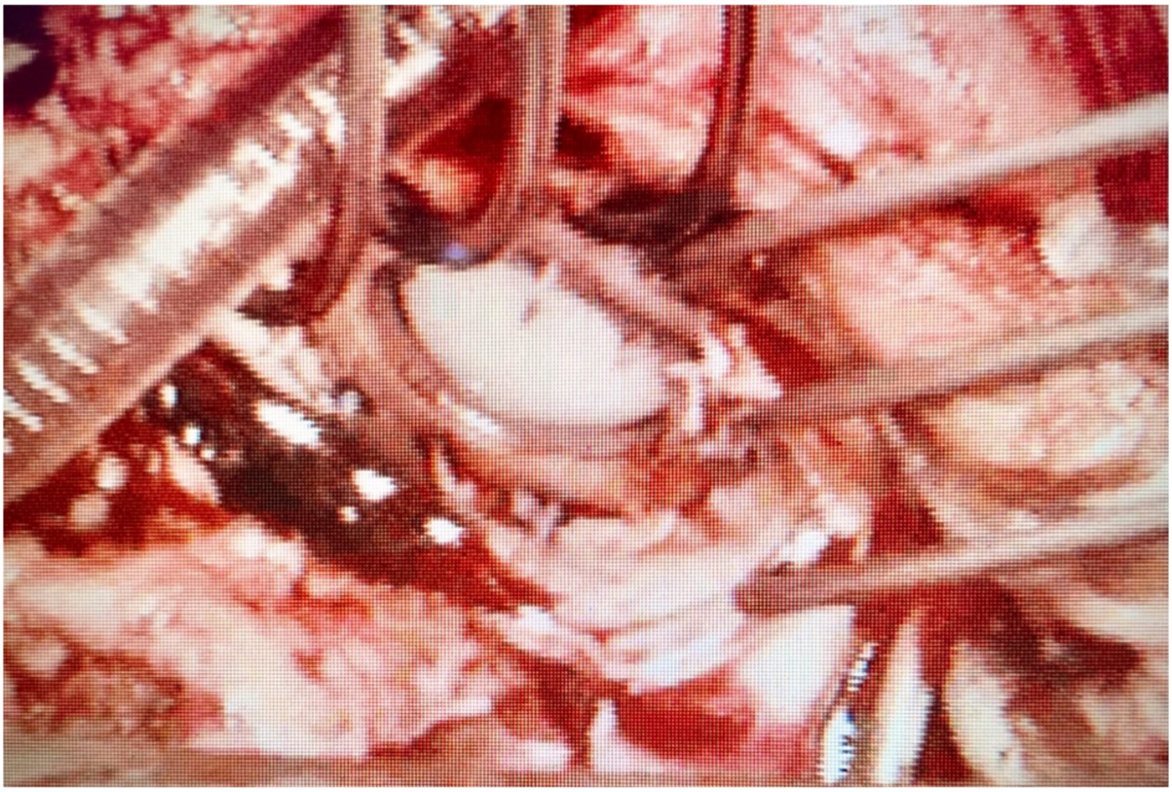


Fig. 4. Trans septal approach with clear visibility of the mitral annulus.

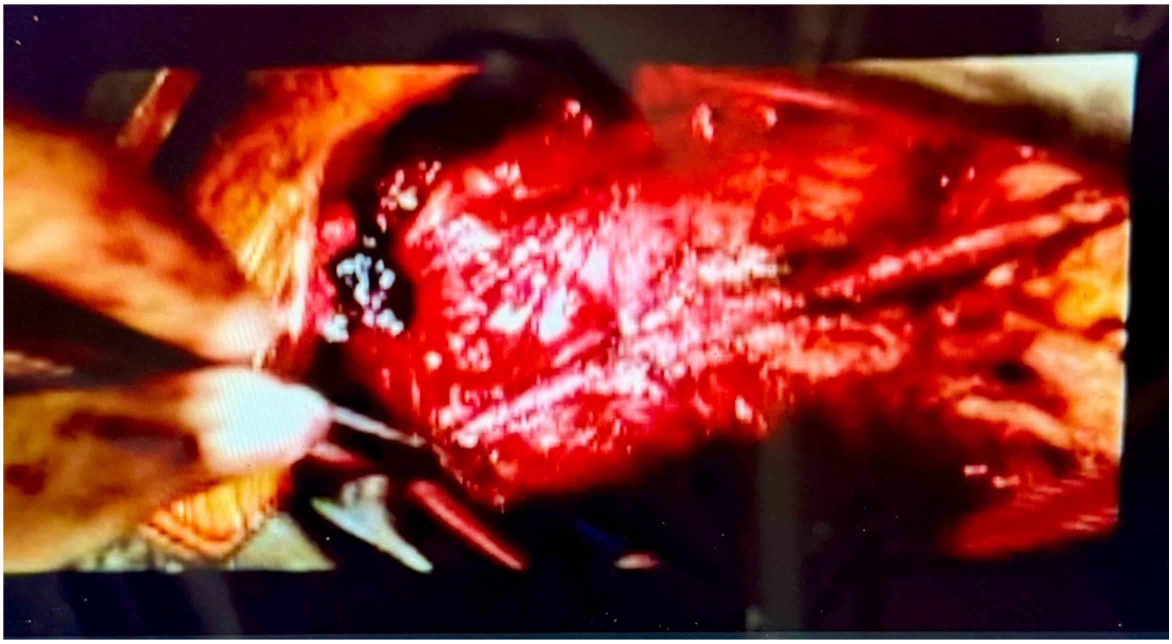


Fig. 5. Completely mobilized patent RITA graft across the midline.

tion of inflammatory and coagulation cascades, as well as uncorrected pre-existing cardiac disease.

Either pharmacological support using inotropic agents or mechanical support using an intra-aortic balloon pump (IABP) or even a short-term ventricular assist device (VAD) will be required in difficult cases that cannot be weaned off with inotropic agents alone. At one time, an IABP was liberally inserted before surgery in high-risk patients; however, a more cautious approach is now taken because of limb ischemia and other complications. Indeed, an IABP is currently not inserted unless patients are in cardiogenic shock or considered at extreme risk. Ranucci *et al*. [28] published results from a large multicenter randomized controlled trial (RCT) (high-risk CABG, n $\approx$ 250), and found

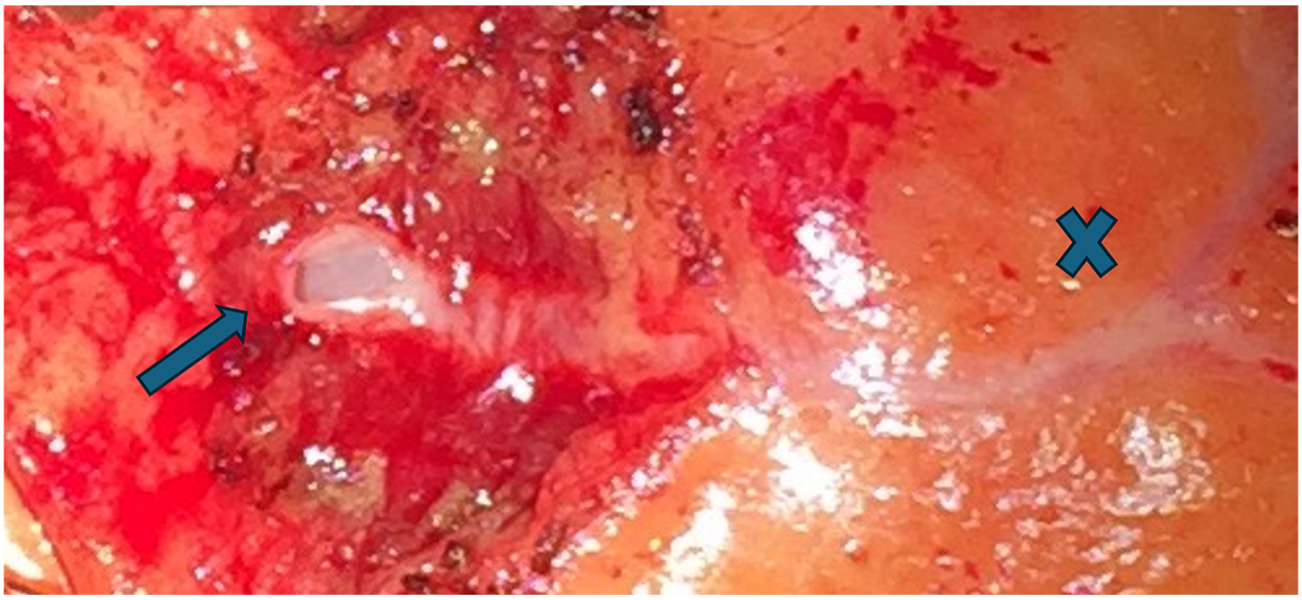


Fig. 6. Sites for distal anastomosis. The arrow shows soft, large caliber intramuscular LAD, while the X area shows superficial LAD that is accessible but of very small caliber.

no mortality benefit and higher complication risk (vascular/bleeding) with a preoperative IABP.

Early application of supportive measures facilitates faster myocardial recovery. In cases of severe myocardial edema, delayed sternal closure may be necessary [29]. If the edema persists beyond 3–4 days, preventing closure, this indicates significant myocardial injury and may necessitate ventricular support with a VAD. Hence, clinical judgment in this occurrence guides whether to continue aggressive care or consider the likely prognosis.

2.7 Procedure Related Risks

2.7.1 Redo Coronary Artery Revascularization

Redo CABG gained popularity soon after surgical revascularization achieved widespread acceptance. The earlier reoperations were primarily due to saphenous vein graft (SVG) failure. As the LITA became the preferred conduit, new complications emerged, including arterial spasm, anastomotic stenosis, and the "string sign", which occasionally required repeat surgical intervention [30]. Similarly, early use of the radial artery as a conduit was associated with frequent occlusion, prompting temporary abandonment until vasodilator therapy was adopted to prevent vasospasm and improve graft patency [31]. Another unspoken cause for the graft failure is the poor choice of site in the coronary artery for anastomosis by the surgeon. Success in redo CABG also depends on identifying soft, suitable sites for distal anastomosis (Fig. 6).

According to the STS database, the incidence of redo CABG has steadily declined—from 6% in 2000 to approximately 2% in recent years. A critical aspect of redo surgery is the careful dissection and preservation of patent vein and arterial grafts, which must be mobilized from adhesions before the heart can be safely lifted for revascularization [32,33]. Historically, embolization from diseased vein grafts represents a major cause of poor outcomes, but the introduction of statin therapy has significantly reduced the burden of vein graft atherosclerosis [34,35].

Thus, multiple strategies are now employed depending on the anatomy and culprit vessel, including off-pump, on-pump, and hybrid procedures. The concept of target vessel revascularization has broadened surgical access approaches beyond standard repeat sternotomy, including right or left thoracotomy and even subxiphoid approaches [36]. Another limiting factor is the scarcity of available conduits, which often necessitates balancing surgical bypass of critical vessels with percutaneous stenting of others [30,33]. On rare occasions, this author has used off-label heparin-bonded thin-walled 4–5 mm Gore-Tex grafts designed for hemodialysis to bypass distal branches of the right coronary artery. Right ventricular failure is one of the problems surgeons encounter after long cross-clamp times; however, bypassing any right coronary branches will prevent these problems. We should not focus on the long-term patency of these grafts, but rather on how readily we can wean from CPB. For instance, an 82-year-old female with severe aortic stenosis and mitral regurgitation, severe CAD, peripheral vascular disease, and bilateral vein stripping underwent AVR, MV repair, and double ITA grafts and Gortex grafts; the video was taken at the 3-month follow-up (Video 3).

The advent of PCI has dramatically reduced the number of redo CABG procedures, especially for localized stenotic lesions. Advances in PCI now allow stenting of nearly every coronary branch, although this has created new challenges for surgery. Redo CABG patients often present with diffusely diseased native vessels covered in stents,

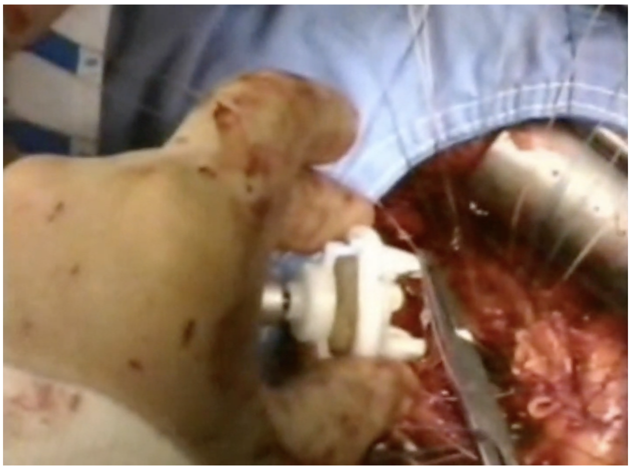
Video 3. Follow-up CT angiography of the aorta, internal thoracic arteries, and coronary arteries. This demonstrates the patency and anatomical relationships after complex valve and coronary surgery. The video associated with this article can be found in the online version, at https://doi.org/10.31083/HSF51551.

poor left ventricular function, and dependence on a patent LITA-to-LAD graft. Meanwhile, injury to this graft can result in devastating short- and long-term outcomes.

Although myocardial protection strategies and surgical techniques are similar to those in primary operations, the higher mortality in redo CABG is largely due to:

- Incomplete revascularization, as target vessels are often smaller, diseased, or previously stented.
- Limited conduit availability, since optimal grafts may have been used in the initial procedure.
- Poor ventricular function, resulting from prior ischemic damage. Furthermore, breaking down all the adhesions around the heart to expose the target vessel transects collateral vessels that have developed through the adhesions over the years.

Moreover, redo sternotomy and CABG carry higher mortality in patients with prior CABG (4.3%) compared to those with sternotomy for non-revascularization procedures (2.4%) [33,37].



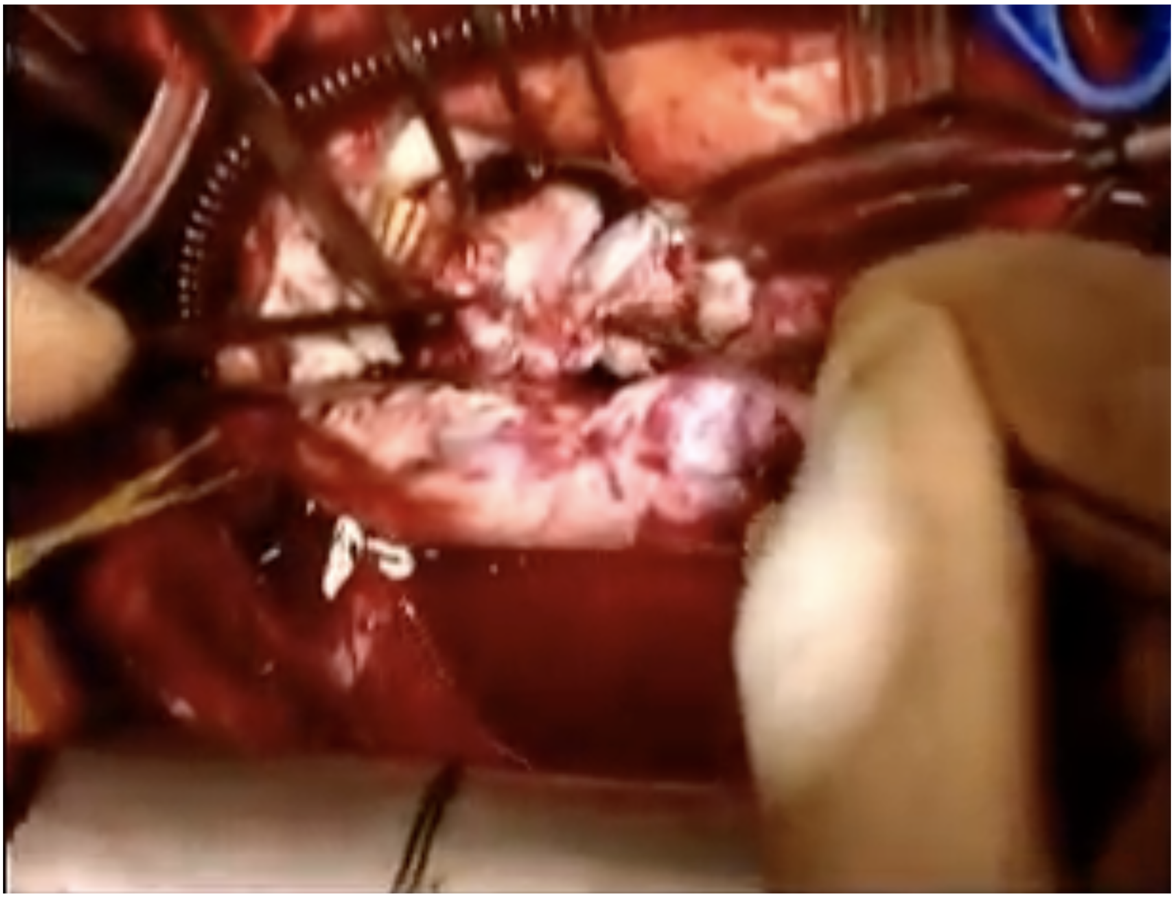
Video 4. Intraoperative demonstration of mitral and aortic valve replacement via aortic transection during double valve replacement. The video demonstrates key operative steps, including careful sternotomy, adhesiolysis, transection of the ascending aorta, and exposure of the mitral valve for replacement alongside the aortic valve. The atriotomy on the dome is deliberately positioned away from the aortic root, leaving a segment of atrial wall to facilitate safe retractor placement. The video associated with this article can be found in the online version, at https://doi.org/10.31083/HSF51551.

2.7.2 Redo Mitral Valve Surgery

Redo mitral valve surgery carries a significantly higher operative risk compared to primary procedures. Reported mortality reaches 12.5% in low-volume centers and can rise to 28% in cases complicated by perioperative events. Onorati and colleagues [38], in a multicenter registry review, identified acute myocardial infarction, stroke, respiratory failure, acute kidney injury requiring hemodialysis, re-exploration for bleeding, and multiple transfusions as major predictors of mortality [38]. Prolonged cross-clamp and CPB times further increase the likelihood of complications.

Thus, surgical approaches and exposure remain critical. Median sternotomy is preferred when additional procedures (*e.g.*, CABG) are anticipated. However, adhesions after prior surgery limit exposure compared to the initial operation. Standard approaches include left atriotomy, left atrial dome incision, or trans-septal right atrial approaches (with modifications such as extending into the superior vena cava).

Less common strategies include transaortic or trans-left ventricular routes. Indeed, a complete transection of the aorta was performed during double valve replacement, with mitral valve surgery through the left atrial dome, then replacement of the aortic valve and approximation of the aortic edges [39] (Video 4). Minimally invasive access via left or right thoracotomy has also been employed. Patient factors—such as obesity or chronic emphysema—can make



Video 5. Intraoperative demonstration of extensive pannus formation on a bioprosthetic mitral valve in an older patient, three years after implantation. The video shows stepwise pannus debridement, removal of the bioprosthetic valve, inspection of the explanted valve, and implantation of a new bioprosthetic mitral valve. The video associated with this article can be found in the online version, at https://doi.org/10.31083/HSF51551.

exposure difficult, and meticulous dealring is essential to avoid embolic complications.

Redo mitral valve replacement is technically more demanding than primary surgery. Prosthetic valves, particularly well-healed mechanical prostheses, require careful dissection to avoid disruption of the atrioventricular groove, a catastrophic complication [40]. Meanwhile, the removal of a bioprosthetic valve is equally challenging: struts may adhere to the ventricular myocardium, and forceful extraction risks ventricular rupture. The presence of an aortic prosthesis adds further complexity, especially at the anteromedial annulus, where suture placement is technically difficult and predisposes to paravalvular leaking.

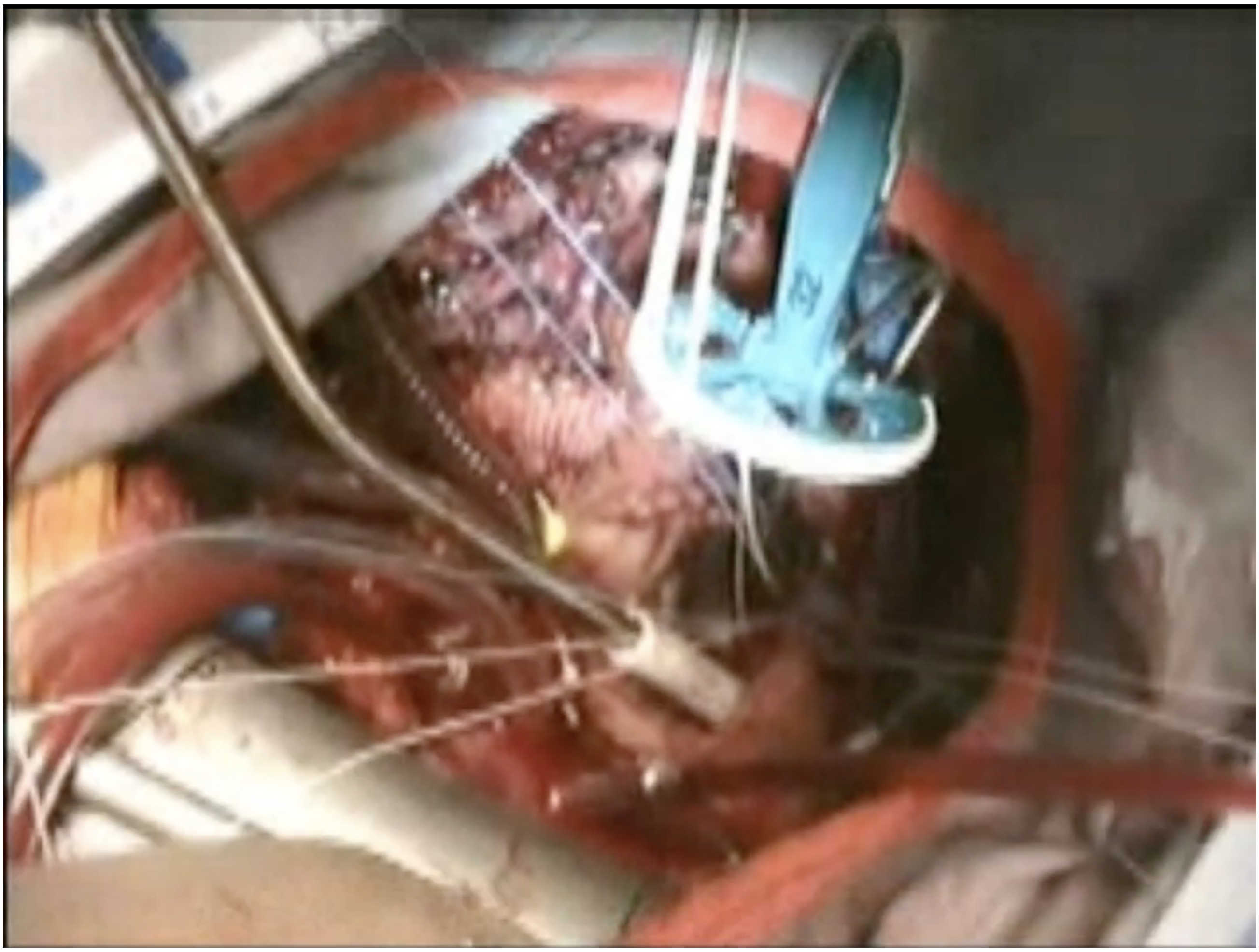
Valve-in-valve TMVR offers a percutaneous option for patients with bioprosthetic valve failure and is becoming the standard of care [41,42]. Surgical removal and replacement remain necessary in cases of extensive pannus formation. Pannus is an overgrowth of fibrous tissue containing smooth muscle cells, secondary to an inflammatory process at the surgical site. Extensive pannus ingrowth is observed over the atrial and ventricular sides of a bioprosthetic valve over 3 years in an older woman (Video 5).

Recently, many surgeons advocated for the right thoracotomy approach for redo mitral surgery, as this approach avoids extensive dissection through scar tissue and often provides superior exposure. Minimally invasive and robotic-assisted techniques have further improved safety and visualization [43]. Nevertheless, complete dealring in the redo setting before unclamping the aorta remains a critical step to prevent air emboli to the brain.

The experience of the surgeon is perhaps the single most important determinant of outcome in redo mitral valve surgery.

Patients with isolated mitral regurgitation are increasingly opting for transcatheter therapies (*e.g.*, trans-atrial or edge-to-edge repair) to reduce heart failure symptoms [44]. Fukuhara *et al*. [40], analyzing STS registry data of 318 patients, described outcomes after mitral reoperations following transcatheter mitral valve replacement (TMVR). These included:

- Valve-in-valve TMVR.
- Valve-in-ring TMVR.
- Valve-in-native mitral annulus TMVR.



Video 6. Complex redo cardiac surgery in an older male with severe calcified ascending aorta, aortic stenosis, mitral regurgitation, and patent coronary grafts. The video includes preoperative echocardiography demonstrating double valve regurgitation and aortic stenosis, intraoperative views showing careful adhesiolysis, use of a Fogarty balloon catheter for endoaortic occlusion of a porcelain aorta, removal of heavy aortic calcification, aortic valve replacement, MV repair, and replacement of the ascending aorta and reimplantation of the vein grafts, followed by postoperative echocardiography. The video associated with this article can be found in the online version, at https://doi.org/10.31083/HSF51551.

Patients undergoing TMVR in the native valve were older and had more comorbidities, conferring a higher surgical risk than the other groups. Meanwhile, correcting severe regurgitation with valve replacement can abruptly increase left ventricular afterload, precipitating LV failure. Additionally, right ventricular dysfunction may ensue when concomitant tricuspid repair or replacement is performed. These challenges often result in difficult separation from CPB, necessitating high-dose inotropes, IABP support, or even ventricular assist devices. Such patients typically experience prolonged ICU stays with high morbidity and mortality.

2.7.3 Redo Tricuspid Valve Surgery

Tricuspid regurgitation is the primary indication for redo tricuspid valve surgery. This indication is most commonly secondary to mitral valve disease with pulmonary hypertension, or to tricuspid valve endocarditis related to intravenous drug use. Some patients also present after failed initial tricuspid repair or replacement.

In a Toronto series, Jeganathan *et al*. [45] reported an in-hospital mortality of 13.2% for redo tricuspid procedures. Meanwhile, right ventricular failure remains the major determinant of outcome and is the leading cause of early and late mortality. Postoperative complete heart block, necessitating a permanent pacemaker, occurs in 10–20% of patients. In addition, hepatic congestion often contributes to coagulopathy and perioperative bleeding, requiring multiple blood product transfusions. Unfortunately, this transfusion burden may exacerbate right-sided heart failure and worsen prognosis.

2.7.4 Redo Aortic Valve and Root Surgery

Redo aortic valve or root surgery is among the highest-risk cardiac procedures, indicated for prosthetic valve endocarditis or aortic root/arch replacement. Prolonged cross-clamp times (~200 minutes) highlight the need for meticulous myocardial and cerebral protection with antegrade and retrograde perfusion.

Murana *et al*. [46] compared 344 redo cases with 16,627 patients across 12 centers, reporting an in-hospital mortality of 9.6% versus 12%. These findings underscore the impact of surgical judgment and experience, with high-volume centers achieving superior outcomes [47].

In cases of endocarditis with annular abscess, aortic homografts are often the conduit of choice, despite the associated greater long-term risk of degeneration in younger patients. This strategy minimizes the risk of prosthetic infection, as graft-related sepsis carries particularly poor outcomes [48].

2.7.5 Redo Multivalvular Surgery

Redo multivalvular surgery carries a higher risk than isolated valve reoperation, especially in patients with heart failure, dilated cardiomyopathy, or advanced age (octogenarians). In a study of 101 patients, Taghizadeh-Waghefi *et al*. [49] reported 13.9% in-hospital and 43.8% one-year mortality, with postoperative delirium as an independent risk factor.

2.7.6 Adults With Congenital Heart Disease

Adults with congenital heart disease (CHD) either require reoperation for residual or late complications (*e.g.*, valve deterioration) or present with previously undiagnosed defects. The most common indications for reoperation are valve dysfunction, residual/recurrent defects, or arrhythmias. Mayo Clinic published their institutional experience with 984 adult patients (495 male) with CHD who underwent reoperation between January 1993 and December 2007 The mean age at reoperation was 36.4 years [50]. The most common diagnoses were conotruncal anomaly, 361 (37%); Ebstein/tricuspid valve, 174 (18%); pulmonary stenosis/right ventricular outflow obstruction, 92 (9%); single ventricle, 71 (7%); atrioventricular septal defect, 64 (7%); subaortic stenosis, 62 (6%); aortic arch abnormalities, 23 (2%); anomalous pulmonary veins [50].

Notably, the need for reoperation has increased as more adults survive after congenital heart defect repair. According to the STS database, the most common procedures are superior cavopulmonary anastomosis and Fontan operations. Pulmonary outflow tract stenosis or atresia often requires enlargement as patients reach adulthood. The emergence of adult cardiac comorbidities, including CAD and valvular disease, further increases surgical risk. Studies, such as from the Mayo Clinic, show that the number of redo sternotomies correlates with higher mortality [51].

2.8 Managing Unexpected Complications

Redo cardiac surgery carries a higher risk of intraoperative complications due to dense adhesions, prior grafts, prosthetic material, and altered anatomy. Preparedness, careful planning, and rapid response are essential to minimize morbidity and mortality [52].

2.8.1 Bleeding During Reentry or Dissection

Major hemorrhage can occur during sternal reentry or dissection around adhesions. Surgeons should anticipate high-risk areas, prepare alternative cannulation sites (*e.g.*, femoral or axillary), and have rapid hemostatic strategies prepared, including temporary packing, proximal and distal control, or rapid initiation of CPB.

2.8.2 Injury to Cardiac and Great Vessels

The aorta, pulmonary artery, right ventricle, inferior vena cava (IVC), and innominate vein are vulnerable during redo surgery. Management involves rapid identification, digital compression or temporary clamps, and direct repair or patch reconstruction. Preoperative imaging and careful adhesiolysis reduce the likelihood of catastrophic injury. Iatrogenic injury to the supra-diaphragmatic IVC, although rare, can occur during redo or complex procedures, especially in patients with a short, adherent IVC. Successful management relies on rapid hemorrhage control, optimal exposure, and careful prevention of tear propagation to limit hemodynamic instability and facilitate definitive repair.

2.8.3 General Principles

- Maintain readiness with backup cannulation and repair strategies.
- Coordinate with perfusion and anesthesia teams for rapid support.
- Early recognition and timely repair of injuries to minimize downstream complications.

2.9 Perioperative Management

2.9.1 Perioperative Bleeding

Perioperative bleeding remains one of the most frequent and challenging complications in redo cardiac surgery. Blood transfusions, along with the administration of platelets, fresh frozen plasma (FFP), and cryoprecipitate, are often required to correct coagulopathy. Significant postoperative bleeding has been reported in 18–41% of patients, many of whom are on dual antiplatelet therapy. This risk is magnified in emergencies, such as failed percutaneous coronary intervention or acute aortic dissection.

Thromboelastography (TEG) is now widely recognized as a powerful point-of-care tool in the management of perioperative bleeding, allowing targeted therapy and avoiding unnecessary blood product use [53].

Tranexamic acid is frequently administered to reduce blood loss. Heparin exerts an anticoagulant effect during CPB by binding to antithrombin (AT). Hence, heparin has little or no effect in patients with AT deficiency. Although transfusion of FFP may restore coagulation factors, in patients with AT deficiency, this process can paradoxically trigger residual heparin activity, worsening bleeding [54].

Management of patients who are on dual antiplatelet therapy requiring emergency surgery adds to the highest risk for perioperative bleeding [55].

2.9.2 Atrial Fibrillation

Postoperative AF reduces cardiac output and requires prompt management with calcium channel blockers, intravenous amiodarone, or electrical cardioversion. AF reduces cardiac output by eliminating the atrial kick, often necessitating inotropic support. Persistent AF (>48 hours) warrants anticoagulation. A review by Yao *et al*. [56] found oral anticoagulants effectively prevent thromboembolism without significantly increasing perioperative bleeding.

2.9.3 Acute Kidney Injury

Acute kidney injury (AKI) is a major postoperative complication associated with prolonged hospitalization, dialysis, and increased mortality. In 394 redo cardiac surgery patients, De Santo *et al*. [57] reported an incidence of AKI of 31.5% (stage 1), 9.1% (stage 2), and 16.2% (stage 3), with higher Kidney Disease Improving Global Outcomes (KDIGO) stages strongly associated with increased in-hospital mortality.

2.9.4 Prolonged Mechanical Ventilation

Prolonged mechanical ventilation (>24 h) is common after complex surgery and is associated with longer ICU stays, higher costs, and pulmonary complications. In some cases, tracheostomy is required for support [58].

2.9.5 Nutritional Support

Nutritional optimization is an essential but often overlooked aspect of recovery. Postoperatively, patients may experience gastrointestinal congestion and loss of appetite. Prolonged ICU stays, broad-spectrum antibiotics, and complications such as *Clostridium difficile* colitis further impair nutrition. Early enteral feeding via nasogastric tube, starting at 10–20 mL/h. High-protein formulas help preserve gut function; protein requirements range from 1.5–2.0 g/kg/day to support wound healing and overall recovery [59].

2.9.6 Neurological Complications

Stroke is a serious complication after cardiac surgery, with a profound impact on both patient and surgeon. Early detection with CT angiography and thrombolysis may improve outcomes, although many patients are left with permanent deficits.

Postoperative strokes are classified as early (shortly after extubation) or late (linked to new-onset AF or hemodynamic instability), with causes including emboli, hypoperfusion, or atheromatous debris.

2.9.7 Sternal Wound Complications

A sternal wound infection can compromise the success of a cardiac operation. Early recognition can simplify treatment by opening the skin wound before the entire sternum has broken down, which would otherwise require major reconstructive surgery.

Risk factors include:

- Diabetes with high HbA1c
- Obesity
- Prolonged surgery
- Re-exploration for bleeding
- Inadequate wound closure
- Bilateral internal thoracic artery harvest
- Prolonged mechanical ventilation
- Anemia and multiple blood transfusions
- Chronic renal failure requiring postoperative hemodialysis

Prevention includes strict glycemic control, weight-based antibiotics, and meticulous wound care, with early drainage for suspected infections to prevent spread into the mediastinum [60–62].

A literature review of three international studies highlights global outcomes in redo cardiac surgery. Schumacher *et al*. [63] reported a 30-day mortality of 6.4% in 187 German patients undergoing redo mitral valve surgery, mostly via standard sternotomy, following an initial minimally invasive approach, contrasting with outcomes after repeat minimally invasive surgery post-sternotomy. Kindzelski *et al*. [17] (Cleveland Clinic) demonstrated that redo cardiac surgery remains a viable option despite advances in percutaneous interventions. Over a decade, 7640 patients underwent redo procedures, divided into those with peripheral CPB before sternotomy (755) and central cannulation after sternotomy (5872), based on anatomy or hemodynamics. Procedures included 3611 aortic valve replacements and 2029 CABGs, with overall mortality of 3.5% and major sternal reentry injury in 2.8%, highlighting the trend toward high-volume centers for high-risk patients [64]. Fudulu *et al*. [65] analyzed 1107 redo sternotomy aortic root replacements in the UK over 20 years (median age 59, 26% female). Most cases involved composite root replacement (84%), with homograft (11%) and valve-sparing (5%) less common. Annual volume rose from 22 procedures in 2006 to 106 in 2017. Hospital mortality was 17%, stroke/ transient ischemic attack (TIA) 5.2%, and postoperative dialysis 11%, with no significant effect of center or surgeon volume on outcomes ($p > 0.05$) [65].

Young surgeons who began practicing now need to have an insight into how older surgeons performed complex operations without having the current-day equipment and technological advances. A case here shows an older male with severe calcified ascending aorta, aortic stenosis, and mitral regurgitation, along with patent RITA to LAD and patent vein grafts, aortic valve replacement, MV repair, replacement of the ascending aorta, and reimplantation of the vein grafts (Video 6).

3. Conclusion

Redo cardiac surgery remains a high-risk procedure requiring a multimodal approach after carefully assessing the risks versus the benefits to the patient. As newer techniques continue to be developed, what used to be the standard treatment may be replaced by another procedure that was not yet conceived. Both the experiences of the surgeons and the institution collectively drive the perioperative morbidity and mortality.

Abbreviations

CABG, coronary artery bypass grafting; LITA/RITA, left & right internal thoracic arteries; PCI, percutaneous coronary intervention; ACS-NSQIP, American college of surgeons-National surgical quality improvement program; HTK, Histidine-tryptophan and Ketoglutarate; RCRI, revised cardiac risk index; HFRS, hospital fragility risk score; TAVR, transaortic valve replacement; TMVR, trans mitral valve replacement; ERACS, Enhancing recovery after cardiac surgery; AKI, acute kidney injury; KDIGO, kidney disease improving global outcomes.

Author Contributions

VRM conceived and designed the study, and drafted the manuscript. XJ assisted in drafting the manuscript. VRM and XJ contributed to the interpretation of the work and to critical revision of the manuscript for important intellectual content. Both authors read and approved the final manuscript. Both authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

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