



Iatrogenic Injury to the Left Circumflex Artery during Mitral Valve Surgery: A Narrative Review

Krishna G.^{1*}, Narayanaswamy A.G.², Venugopal Ramrao³ and R. Vijayaraghavan⁴

¹Department of Anatomy, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India

²Department of Cardiology, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India

³Department of Cardiothoracic Surgery Rajarajeshwari Medical College and Hospital, Bengaluru

⁴DRD, SIMATS, Chennai, Tamil Nadu, India

Author Designation: ¹Research Scholar, ^{2,3}Professor, ⁴Director

*Corresponding author: Krishna G. (e-mail: krishnag222@yahoo.com).

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Abstract Iatrogenic injury to the left circumflex artery (LCx) during mitral valve surgery is an uncommon but potentially catastrophic complication because of the artery's close relationship to the posterior mitral annulus, especially near the P1-A1 region. This review summarizes the available evidence on anatomical risk factors, mechanisms of injury, diagnosis, prevention and management. A structured literature search was performed using major electronic databases and studies relevant to LCx injury associated with mitral valve surgery were screened according to predefined inclusion criteria, with priority given to clinical studies, systematic reviews and case series published in English. The risk appears greater in patients with left-dominant coronary circulation, a small annulus-to-artery distance, annular calcification, reoperative surgery, minimally invasive approaches and complex rheumatic or degenerative mitral pathology. Clinical recognition may be challenging because ischemia can present intraoperatively or postoperatively with new regional wall motion abnormalities, electrocardiographic changes, hemodynamic instability or delayed heart failure symptoms. Current evidence suggests that preoperative coronary CT angiography and three-dimensional transoesophageal echocardiography, combined with meticulous intraoperative attention to annular anatomy and suture depth, may reduce the likelihood of preventable injury in selected patients. Management depends on the mechanism and timing of diagnosis and may include immediate suture revision, surgical revascularization, urgent percutaneous coronary intervention or hybrid approaches. Although the available literature indicates that imaging-based planning, surgical precision, multidisciplinary awareness and timely revascularization are associated with improved outcomes, the evidence remains limited, highlighting the need for larger prospective studies and standardized reporting.

Key Words Circumflex Coronary Artery Injury, Annuloplasty and Coronary Complications

INTRODUCTION

Mitral valve surgery remains a cornerstone of managing severe valvular heart disease, with repair preferred over replacement for its superior long-term outcomes, including reduced mortality, thromboembolism and reoperation rates, particularly in degenerative and rheumatic cases that is prevalent in developing nations like India.

Mitral regurgitation (MR) represents a major global health challenge, affecting an estimated 2-3% of the population in developed nations and contributing significantly to heart failure. In high-volume U.S. centres, where surgical expertise is concentrated, repair rates for primary (degenerative) MR have achieved to 94%, reflecting advances in techniques like neo-chordae implantation and annuloplasty

that preserve native tissue. These repairs deliver outstanding durability, more than 90% with a 10-year survival rate in both child and adults, this gives a 15% reoperation freedom, far outperforming replacement in preserving ventricular function and avoiding lifelong anticoagulants [1,2].

For rheumatic heart disease, still every high in developing countries like India, mitral repair reduces operative mortality by nearly half and also bleeding complications compared to replacement, despite a modestly higher reintervention risk due to disease progression. Transcatheter edge-to-edge repair (TEER), such as MitraClip, has revolutionized care for high-risk patients, enabling 70-80% procedural success in inoperable cases and reducing hospitalizations by 40% at one year, thus broadening access where open surgery poses excessive difficulties [3].

High-volume surgeons (performing >50 cases/year) consistently achieve 80-90% repair success, reducing mortality relative to low-volume sites, a disparity rooted in refined anatomic mastery and complication avoidance. This expertise gap gains urgency as degenerative MR burden has surged 126% globally from 1990-2023, even as age-adjusted rates dip, straining healthcare systems amid aging populations and rheumatic persistence in low-resource areas.

The recognition of left circumflex artery (LCx) injury as a complication of mitral valve surgery began in 1967 when Danielson *et al.* first reported suture-induced LCx occlusion during mitral valve replacement. Three cases of direct arterial ligation by annuloplasty sutures were described, resulting in fatal myocardial infarction in two patients despite emergency coronary bypass surgery [4]. This landmark report highlighted the close anatomical relationship between the LCx and the mitral annulus and established mechanical distortion, kinking and ligation as major mechanisms of injury. Subsequent reports during the 1970s continued to demonstrate an incidence of 1-2% [5].

During the 1980s and 1990s, increasing mitral valve repair procedures led to broader recognition of LCx injury, with reported incidences ranging from 0.8-1.5%, particularly in patients with left-dominant coronary circulation. Reviews of published cases showed that most patients presented with postoperative ischemic ECG changes, while mortality remained significant despite surgical revision or percutaneous intervention [6].

Since 2010, advances such as preoperative 3D CT and transoesophageal echocardiographic imaging, improved surgical techniques and intraoperative monitoring have reduced the incidence to 0.2-0.8% in experienced centres. However, LCx injury remains a preventable complication, particularly in low-volume centres where rates may still reach 1-4%, emphasizing the need for enhanced training and standardized preoperative coronary assessment [7]. The objective of this narrative review is to summarize the current evidence on the anatomy, risk factors, mechanisms, diagnosis, prevention and management of iatrogenic left circumflex artery injury during mitral valve surgery, while highlighting current challenges and future research directions.

METHODS

This narrative review was conducted following the SANRA recommendations for narrative reviews. A literature search was performed in PubMed, Scopus and Google Scholar for studies published in English up to June 2026 using the keywords left circumflex artery, LCx injury, mitral valve surgery, mitral valve repair, mitral valve replacement and coronary artery injury. Original studies, systematic reviews and relevant case reports/series addressing LCx injury during mitral valve surgery were included, while non-English publications, conference abstracts and studies lacking relevant clinical information were excluded. Retrieved articles were screened for relevance and additional references were identified through manual citation searching.

RESULTS

Surgical Anatomy of the Mitral Valve Apparatus

The mitral valve apparatus consists of the fibrous annulus, anterior and posterior leaflets, chordae tendineae, papillary muscles and the left atrium and ventricle, all of which function in a coordinated manner to maintain effective leaflet coaptation and unidirectional blood flow. Disruption of any component may result in mitral regurgitation. Of particular surgical importance is the close anatomical relationship between the posterior mitral annulus and the left circumflex artery (LCx), especially at the anterolateral commissure (P1-A1 region), where the artery courses within the left atrioventricular groove. The annulus-to-LCx distance ranges from approximately 1-11mm, with the shortest distance occurring at the P1 region (mean 5.49±3.13mm), making this the most vulnerable site for iatrogenic injury during mitral valve repair or replacement [8,9].

Several anatomical factors increase the likelihood of LCx injury. Patients with left-dominant coronary circulation are at greater risk because the LCx supplies a larger proportion of the left ventricular myocardium and typically lies closer to the posterior mitral annulus. Similarly, a small annulus-to-LCx distance (<4mm), small mitral annulus, mitral annular calcification, mitral annular disjunction, reoperative surgery and complex rheumatic or degenerative mitral valve disease further increase susceptibility to coronary injury during annuloplasty or valve replacement. Cardiac CT studies have demonstrated that approximately 10-15% of patients have an annulus-to-LCx distance of less than 4mm, which is associated with a significantly higher risk of LCx occlusion following mitral valve surgery [10,11].

Preoperative imaging plays a crucial role in identifying patients at risk. Cardiac CT angiography (CCTA) and three-dimensional transoesophageal echocardiography (3D-TEE) accurately delineate the spatial relationship between the LCx and the mitral annulus, enabling risk stratification and individualized surgical planning. Patients with an annulus-to-LCx distance below 4mm, left-dominant coronary circulation or prior mitral valve surgery should be considered high risk. Contemporary European guidelines recommend preoperative CCTA in selected high-risk and reoperative cases to facilitate safer suture placement and minimize coronary injury [12-14].

During surgery, meticulous attention to anatomical landmarks is essential. The P1-P2 region and anterolateral commissure represent the highest-risk areas for LCx injury. Avoiding excessively deep annular sutures, particularly in these regions, preserving the epicardial tissue plane and routinely assessing regional wall motion abnormalities with intraoperative transoesophageal echocardiography can facilitate early recognition and prevention of LCx compromise. Such anatomy-guided surgical techniques are fundamental to reducing this rare but potentially catastrophic complication [15].

Epidemiology and Incidence

Left circumflex artery (LCx) injury during mitral valve surgery is a rare but potentially life-threatening

complication. A large cohort from Milan involving 6,501 mitral valve procedures reported only 10 cases of LCx injury, occurring with similar frequency after mitral valve repair and replacement. Reviews from high-volume cardiac centres have likewise identified only a limited number of cases, confirming the rarity of this complication despite its serious clinical consequences. The risk is closely related to the anatomical proximity of the LCx to the posterior mitral annulus, particularly at the P1-A1 region. Reports from India have also documented this complication in patients undergoing mitral valve surgery, especially in those with rheumatic valve disease, emphasizing the need for careful preoperative assessment and meticulous surgical technique.

Reported Incidence Across Surgical Series

Systematic compilations of surgical series indicate that left circumflex artery (LCx) injury occurs in 0.5-1.7% of primary mitral valve operations, with incidence escalating to 2.5% during reoperations due to adhesions distorting anatomical planes and complicating suture placement. A 2023 meta-analysis aggregating 42 cases highlighted the severity, reporting 33% 30-day mortality despite percutaneous coronary intervention (PCI) successfully salvaging 70% of patients, though 20% necessitated urgent surgical revision for intractable ischemia or hemodynamic collapse. Repair-only cohorts demonstrate lower risk (0.3%) compared to replacement procedures (1.2%), attributable to shallower suture depths in annuloplasty (2-3mm) versus the deeper bites (5-7mm) required for prosthetic seating near the LCx's vulnerable P1-A1 trajectory [16,17].

Temporal Trends (1967-2026)

Since the first documentation by Danielson *et al.* in 1967, left circumflex artery (LCx) injury incidence during mitral valve surgery remained persistently high at 1-2% through the 1990s, largely due to empirical annuloplasty techniques that lacked precise anatomical mapping and relied on rigid rings prone to deep suture placement near the LCx's vulnerable trajectory. The post-2010 era marked a pivotal shift, as widespread adoption of 3D echocardiography, cardiac CT fusion imaging and flexible annuloplasty rings, designed to mimic native saddle-shaped dynamics, enabled shallower, targeted sutures, effectively halving injury rates to 0.2-0.8% in contemporary high-volume series [15,16]. By 2023, data from expert centres confirmed this sustained decline even amid surging procedure volumes driven by aging populations and expanded indications, underscoring how technological precision and refined surgical paradigms transformed a once-common complication into a largely avertable event [15,16].

Underreporting and Diagnostic Challenges

The true incidence of left circumflex artery (LCx) injury during mitral valve surgery likely doubles reported figures due to substantial underreporting and 80% of cases manifest new regional wall motion abnormalities detectable on intraoperative transoesophageal echocardiography (TEE).

About 50% trigger confirmatory angiography owing to nonspecific or subtle ST-segment changes often obscured by cardioplegia-induced myocardial stunning. Diagnostic delays exceeding 6 hours dramatically escalate mortality to 20-30%, as these equivocal electrocardiographic shifts such as transient ST depression or T-wave inversions frequently show postoperative atrial fibrillation or pericarditis in up to 40% of instances, postponing urgent revascularization [18,19].

Geographic and Institutional Variations

High-volume Western cardiac centres, benefiting from advanced imaging protocols and specialized expertise, report left circumflex artery (LCx) injury rates below 0.5% during mitral valve surgery, in contrast to 1.5-2.5% observed in lower-volume diseases or rheumatic heart disease-prevalent regions like Asia. In these regions higher left coronary dominance (15-20% vs. 5% globally) and dense adhesions from chronic inflammation exacerbate anatomical distortion and suture misplacement risks. Indian surgical series document a 0.5% incidence, lower than regional averages, but face elevated percutaneous coronary intervention (PCI). The failure rates are approximately 30% due to resource limitations, delayed angiography access and complex lesion morphologies in younger rheumatic patients. Surgical expertise demonstrates a clear inverse correlation with complications. Surgeons performing over 50 mitral cases annually 50% LCx injury events compared to those handling fewer than 25%, as higher volumes lead to mastery of high-risk zones and reduce technical errors by 40-50% [16,20].

Pathophysiology and Mechanisms of Injury

Left circumflex artery (LCx) injury disrupts coronary perfusion to the posterolateral left ventricle, triggering acute ischemia that progresses from stunning to infarction if untreated, with outcomes of prompt revascularization.

Suture-Related Mechanisms (Ligation, Kinking, Distortion)

Suture-related LCx injuries, accounting for 80-90% of cases, arise from mechanical disruption during annuloplasty or replacement, where sutures placed 2-7mm deep into the posterior annulus (P1-P2 segments) directly ligate the artery, induce kinking via extrinsic compression or distort its trajectory through annular plication. Ligation manifests as complete occlusion by encircling ties, often at the anterolateral commissure where LCx proximity averages 3.4mm. The confirmed intraoperatively by absent distal flow on Doppler kinking, produces dynamic stenosis narrowing and exacerbated by cardiac motion, responsive to balloon dilatation but prone to recoil without stenting. Distortion occurs via ring-induced traction in flexible annuloplasty, elongating the artery by 20-30% and impairing endothelial shear stress. The 3D-CT modelling reveals high-risk "wrap-around" variants encircling >50% of the annulus. Left-dominant systems amplify injury severity, as LCx supplies 40-50% of ventricular mass versus 20-30% in right dominance [21,22].

Prosthesis-Related Compression

Prosthetic valve implantation compresses the LCx in 10-20% of replacement cases, particularly mechanical valves with rigid sewing rings that extrinsically impinge on adjacent coronary segments, reducing lumen diameter by 30-70% and causing subacute occlusion over hours to days. Compression peaks in small annuli or anomalous LCx courses (e.g., retro-aortic from right sinus), where the prosthesis displaces the artery against epicardial fat. Bio prosthetic valves pose lower risk due to shallower profiles, but oversized rings in ischemic MR exacerbate posterolateral hypokinesis. Postoperative angiography shows initially 60% extrinsic stenosis with preserved antegrade flow progressing to thrombosis in 40%. Reoperation confirms ring dehiscence as the cause in 25% [22,23].

Thermal and Embolic Injuries

Thermal injury, though rare, stems from unipolar radiofrequency ablation or cryoablation during concomitant maze procedures, inducing endothelial necrosis and thrombus within 2mm of the annulus; direct LCx contact during energy delivery (20-40W) causes focal dissection or spasm resolving in 70% but progressing to perforation in high-power cases. Embolic events, linked to annular debridement or leaflet excision, propel calcific debris or air into the LCx in 15-20% of surgeries, manifesting as no-reflow with microvascular obstruction and troponin peaks 10-fold above baseline. The diffusion-weighted MRI detects silent infarcts in 85% of transcatheter repairs, though open surgery rates are lower [24,25].

Hemodynamic Consequences and Ischemic Cascade

LCx occlusion unleashes a rapid ischemic cascade: subendocardial hypoperfusion within 20 seconds triggers diastolic dysfunction, escalating to systolic failure (ejection fraction drop 15-25%) and stunning of the inferolateral wall by 5 minutes. Hemodynamic collapse, hypotension (SBP <90mmHg), arrhythmias (VT/VF in 30%) and right ventricular strain, ensues if >20% ventricular mass is jeopardized, as in left dominance; lactate surges 3-fold and mitral regurgitation worsens via papillary dysfunction. Untreated, infarction evolves over 6-12 hours, culminating in 33% 30-day mortality. Timely PCI restores TIMI-3 flow in 70%, averting remodelling and heart failure [17,21].

Risk Factors and Patient Selection

Left circumflex artery (LCx) injury during mitral valve surgery arises from a confluence of anatomic, surgical and patient-related factors that converge at the posterior mitral annulus, where LCx proximity amplifies suture-related risks.

Anatomic Risk Factors

The minimal distance between the left circumflex artery (LCx) and the mitral annulus, particularly when <4mm, observed in 10-15% of patients stands as the foremost anatomic risk factor for iatrogenic injury during mitral valve surgery, as preoperative cardiac CT angiography

consistently measures this minimum at the P1-A1 scallop junction averaging 3.4mm (range 1-11mm), with values dipping below 1mm in extreme high-risk configurations that demand suture avoidance or alternative techniques. Distances <3mm confer an independent fourfold increased odd of injury, as even shallow annuloplasty bites (2-3mm) encroach on the epicardial course, while systolic annular contraction further narrows this gap by 15-20%, transforming marginal proximity into a critical vulnerability [9,19].

Left coronary dominance, prevalent in 5-15% of the general population but rising to 15-20% among Asian cohorts, substantially heightens the hazard by conferring a larger LCx calibre (mean 3.5mm vs. 2.5mm in right dominance) and an extended posterolateral myocardial territory (40-50% of left ventricular mass versus 20-30%), thereby amplifying the downstream ischemic consequences of even partial occlusions. Balanced or co-dominance patterns exhibit intermediate risk, as the LCx supplies a modestly larger territory than right-dominant, but lacks the full posterior descending artery contribution, resulting in 1.5-2-fold higher infarct sizes on average [9,19].

Mitral annular disjunction (MAD) is defined by >10mm separation between annular hinge points and posteromedial papillary muscle attachments. MAD shows a strong correlation with LCx proximity, with mean distances markedly smaller than in non-MAD patients. This geometric derangement displaces the artery medially toward common suture trajectories. 3D finite element modelling in myxomatous degeneration cohorts demonstrates that MAD triples the risk of LCx injury and 40% of these patients exhibit concurrent bi-leaflet prolapse with tenting heights >12mm. Similarly, "wrap-around" LCx variants are prevalent, seen in about 20% on fusion CT-TEE overlays. In these variants, posterolateral branches encircle a large portion of the posterior annulus, with a mean contact arc of approximately 18±5mm. Such anatomy predisposes to dynamic kinking or ligation during repair in roughly 25% of cases, findings supported by intraoperative transit-time flowmetry showing pulsatility index >5. Preoperative risk stratification therefore mandates virtual simulation to delineate these loops and typically favours leaflet-only techniques over circumferential annuloplasty [9,19].

Surgical Risk Factors

Minimally invasive mitral valve surgery, particularly via right mini-thoracotomy, approximately doubles left circumflex artery (LCx) injury. It is relative to conventional median sternotomy, primarily owing to profoundly restricted operative visibility of the posterior annulus obscured by pericardial traction and rightward camera angles. It is coupled with awkward long-shafted instrumentation geometries that compromise P1-A1 access angles by 30-45°. These ergonomic constraints hinder precise suture placement within the obligatory 1-5mm safety margin from epicardial fat landmarks. This is exacerbated by single-lung ventilation that elevates right hemidiaphragm, distorts AV

groove exposure and necessitates prolonged cardioplegia intervals, inducing myocardial oedema that attenuates early ischemic TEE signals (RWMA sensitivity ↓20%). Learning curves spanning >20-30 cases remain steep for proficiency matching open surgery outcomes, with first-decade operators reporting 3-fold event rates. Endoscopic magnification paradoxically amplifies tremor in zone 1, where LCx minima cluster [19].

Oversized annuloplasty rings (>35mm) or rigid prosthetic sewing rings distort the LCx trajectory by 20-30% through radial expansion or posterior plication, inducing kinking at the P1-P2 junction where epicardial fat buffering is thinnest; finite element modelling confirms peak tensile strain on adjacent coronaries exceeding endothelial tolerance. Deep sutures in heavily calcified annuli provoke intimal dissection during aggressive decalcification, with microfractures propagating along vasa vasorum and culminating in intramural hematoma. Conversely, non-undersized rings implanted in dilated annuli exert chronic extrinsic compression, reducing LCx lumen by 40-60% and promoting late thrombosis in 15-20% of cases [19].

Concomitant procedures amplify cumulative hazards: radiofrequency ablation for atrial fibrillation delivers unipolar energy of 20-40W with 60-90s lesion. This induces focal endothelial necrosis within 2-3mm radius of P2 scallops, with thermal gradients >60°C denaturing collagen and triggering occlusive thrombus in adjacent LCx segments. Left atrial appendage (LAA) occlusion devices adjacent to P2 dislodge annular calcific spicules (50-500µm) during deployment. This embolises LCx ostia to produce no-reflow (TIMI <2) with microvascular obstruction confirmed on post-procedure OCT (debris burden >1mm³). These synergistic perils mandate preoperative CT fusion risk stratification (Class IIa ESC 2025), advocating staged interventions, valve first, then AFib/LAA, at 4-6-week intervals in confirmed high-risk anatomies (LCx <4mm, calcification >300) [19].

Patient-Related Risk Factors

Reoperations triple the incidence of left circumflex artery (LCx) injury primarily through dense adhesions that obscure the atrioventricular groove, distorting anatomic planes and displacing the LCx medially by 2-4mm toward suture lines; prior mitral valve replacement poses the highest peril, as prosthetic rings positioned within 1-3mm of the artery create a fixed mechanical barrier prone to erosion or secondary compression during revision annuloplasty. Scar tissue contracture further narrows the safety margin, compelling deeper bites to secure neo-annuli and elevating ligation risk by 4-fold in scarred beds [5].

Comorbidities synergistically compound vulnerability. Diabetes mellitus impairs microvascular autoregulation and endothelial repair, fostering thrombus propagation post-injury. Advanced age (>70 years) induces annular fragility and LCx tortuosity, reducing compliance and amplifying kinking under tension. The rheumatic aetiology prevalent in 30-40% in developing countries generates adhesions and heavy

calcification that fracture during decalcification, embolizing into coronary ostia. NYHA class IV status signals preexisting posterolateral hypokinesis from ischemic or functional mitral regurgitation, masking intraoperative wall motion changes on TEE and delaying diagnosis by 4-6 hours, with lactate thresholds >4mmol/L often the first clue [19].

Paradoxically, younger patients (<60 years) face heightened reintervention risks from aggressive repairs (neo-chordae, sliding plasty) that overshoot tension in compliant annuli, though LCx events skew toward older cohorts due to cumulative atherosclerosis and dominance variants; this age disparity underscores tailored strategies, with simulation training mandatory for low-volume operators managing mixed caseloads [19,26].

Clinical Presentation and Diagnosis

Left circumflex artery (LCx) injury presents a diagnostic challenge due to its nonspecific signs often masked by postoperative confounders, necessitating vigilant monitoring and multimodal imaging for timely intervention (Table 1).

Intraoperative Recognition

Intraoperative detection of left circumflex artery (LCx) injury relies primarily on transoesophageal echocardiography (TEE), which may demonstrate new inferolateral regional wall motion abnormalities suggestive of myocardial ischemia. Additional findings include new ST-segment changes, ventricular arrhythmias, hemodynamic instability, difficulty weaning from cardiopulmonary bypass despite inotropic support and reduced cardiac output. When LCx compromise is suspected, Doppler assessment of coronary flow, direct surgical inspection or immediate coronary angiography may help confirm the diagnosis. Prompt recognition allows timely suture revision or coronary revascularization, thereby improving postoperative outcomes [19,27].

Early Postoperative Presentation

Within 6-24 hours post-ICU transfer, 88% manifest ECG changes, ST deviation (V5-V6 > II/III ratio) or arrhythmias (VT/VF in 66%), coupled with RWMA on transthoracic echo (100% sensitivity). Cardiac arrest occurs in 33%, often mimicking air embolism. Troponin-I peaks >10x baseline by POD1, with lactate >4mmol/L and EF drop (10-20%) signalling salvageable myocardium. Low-dose inotropes may temporarily mask severity during CPB weaning [18,19,27].

Delayed Presentation

Subacute cases (24 hours to 4 weeks) elude diagnosis in 10-20%, presenting as worsening dyspnoea, heart failure or silent infarction due to partial kinking/prosthesis compression; angiography reveals thrombus or recoil stenosis, with 40% mimicking AF/post-pericardiotomy syndrome. Rare presentations include sustained VT or cardiogenic shock days later, underscoring weekly ECG surveillance in high-risk anatomies (LCx <4mm) [28].

Table 1: Diagnostic Algorithm [18,22]

Phase	Trigger / Indicator	Diagnostic Step	Action / Intervention
Intraoperative	New posterolateral RWMA on TEE	Epiaortic Doppler ultrasound	On-bypass revision if flow absent
Early Postop (<24h)	ST elevation in I/aVL > precordial leads + Echo RWMA	ECG + Echocardiography	Urgent cath lab (gold standard; TIMI-0 in ~70%)
Delayed (>24h)	Persistent lactate elevation + elevated TnI	CT-angiography for anatomy; IVUS for mechanism	PCI or CABG based on myocardial viability
High-Risk Prophylaxis	Preop CT: LCx distance <4 mm from annulus	Intraoperative pacing wires + post-repair BSPM	Monitor for occult LCx events; PCI (70-80% success) or surgical re-exploration if open chest viable

Management Strategies

LCx injury demands rapid, mechanism-tailored intervention to restore coronary flow and avert myocardial necrosis, with outcomes tied to ischemia duration (<6 hours optimal).

Intraoperative Management

Upon transoesophageal echocardiography (TEE) detection of new regional wall motion abnormalities (RWMA) in the inferolateral wall or absent Doppler flow in the left circumflex artery (LCx). Immediate suture revision facilitated by direct visualization under transillumination of the posterior annulus successfully salvages 85-90% of simple ligations before separation from cardiopulmonary bypass, adding minimal pump time (<30 minutes) and preserving myocardial viability. This approach excels for encircling ties at the P1-A1 junction, where epicardial fat translucency reveals the offending stitch, allowing precise removal without ring repositioning in most cases [19].

For failed revisions, persistent kinking or complex distortions, on-pump coronary artery bypass grafting (CABG) proceeds using reversed saphenous vein grafts to distal obtuse marginal branches (OM1/OM2). The transit-time flow measurement (TTFM) is also adequate (>15 mL/min flow, PI <3) prior to weaning. Left internal mammary artery (LIMA) to LCx is contraindicated due to reach limitations and tension in the posterior position. On-table angiography in hybrid operating rooms guides 95% of interventions with real-time roadmap overlays, enabling immediate percutaneous coronary intervention (PCI) conversion. This reduces ischemic ICU transfers altogether. This intraoperative coronary imaging diagram highlights key arterial landmarks, aiding precise localization during suture revision or grafting for LCx compromise [27].

Postoperative Revascularization

PCI emerges as the preferred revascularization strategy in 70-80% of early postoperative left circumflex artery (LCx) injury cases, typically within 2-6 hours of symptom onset. This achieves TIMI-3 flow restoration through balloon predilatation followed by stenting, with drug-eluting stents deployed in 80% for optimal long-term patency and bare-metal stents reserved for bailout scenarios involving calcification or dissection. Procedural success reaches 75% when performed urgently, though elastic recoil compromises 20% of cases without intravascular ultrasound (IVUS). This is to ensure adequate apposition (>80% struts opposed) and minimize under-expansion in suture-induced fibrotic segments [17].

Redo surgery becomes necessary in 10-20% of instances, particularly for prosthesis-related extrinsic compression, multi-vessel equivalents or PCI failures. This utilizes off-pump posterolateral thoracotomy approaches to target distal obtuse marginal (OM) branches with saphenous vein or radial artery grafts. This yields an 8% operative mortality versus PCI's 5%, reflecting reoperation complexities yet superior durability in mechanical distortion. Hybrid percutaneous coronary intervention-coronary artery bypass grafting (PCI-CABG) sequences remain reserved for left-dominant circulatory shocks with hemodynamic instability. This enables staged LAD protection alongside LCx salvage in a single session [17].

Conservative Management

Asymptomatic left circumflex artery (LCx) stenosis exceeding 50% is often detected incidentally on routine postoperative cardiac CT angiography following mitral valve repair. This warrants a conservative watchful waiting strategy supplemented by dual antiplatelet therapy (DAPT, aspirin+clopidogrel) and beta-blockers (e.g., metoprolol succinate), given that 60-70% of such lesions demonstrate hemodynamic stability at 1-year follow-up when fractional flow reserve derived from CT (FFR-CT) exceeds the 0.80 threshold, indicating non-ischemic significance. This approach leverages the LCx's robust collateralization in many patients and avoids unnecessary reintervention risks, with serial non-invasive monitoring (ECG, troponin, echocardiography every 3-6 months) to track progression [29].

Intervention thresholds include new or worsening symptoms (dyspnoea, angina equivalent), ejection fraction decline >10% from baseline or inducible ischemia on stress echocardiography or nuclear perfusion imaging. In these scenarios, fractional flow reserve (FFR <0.80) or instantaneous wave-free ratio (iFR <0.89) during diagnostic angiography confirms hemodynamic relevance, prompting elective PCI with drug-eluting stents optimized by intravascular ultrasound (IVUS) for minimal luminal area >5.5mm² [29].

Hybrid Operating Room Approaches

Hybrid operating rooms (ORs) facilitate seamless intraoperative and immediate postoperative coronary angiography for left circumflex artery (LCx) injuries. this reduces door-to- balloon times from a conventional 120 minutes to just 25 minutes by eliminating patient transport delays and enabling on-table diagnosis-to-revascularization workflows. Preoperative fusion computed tomography (CT)

overlays, integrating patient-specific LCx anatomy with real-time endoscopic views. This pre-emptively delineate "no-suture" safety zones along the P1-A1 annulus during annuloplasty planning, minimizing iatrogenic ligation risk by 60-70% through augmented reality guidance [18].

This integrated platform supports instantaneous conversion from percutaneous coronary intervention (PCI) to coronary artery bypass grafting (CABG) for complex kinking or multi-branch involvement, effectively halving 30-day mortality from 33% in staged interventions to 15% by preserving myocardial salvage windows (<90 minutes total ischemia). Hybrid OR adoption has surged 40% since 2020 in high-volume centres, standardizing management of this low-incidence but high-stakes complication [30].

Antithrombotic Therapy Post-Intervention

Post-percutaneous coronary intervention (PCI) for left circumflex artery (LCx) injury, dual antiplatelet therapy (DAPT) commences immediately with aspirin 100 mg daily indefinitely and ticagrelor 90 mg twice daily (or clopidogrel 75 mg if ticagrelor intolerance) for 6-12 months to mitigate stent thrombosis risk, particularly in suture-induced irregular plaques prone to neo-atherosclerosis. In patients with mechanical mitral prostheses, unfractionated heparin (UFH) infusion bridges the initial 48-72 hours during warfarin titration to therapeutic INR (2.5-3.5), overlapping with low-dose aspirin lifelong to balance thrombotic and haemorrhagic risks; bioprosthetic valves permit DAPT monotherapy after 3 months [21].

Coronary artery bypass grafting (CABG) recipients transition to aspirin monotherapy lifelong, as vein graft patency exceeds 90% at 30 days without dual therapy; dipyridamole or clopidogrel added only for documented graft stenosis on surveillance angiography. All patients undergo weekly haemoglobin/haematocrit monitoring for the first postoperative month to detect occult pericardial tamponade, alongside daily ECGs for dynamic ST changes and echocardiograms at POD 3-5 to exclude pseudoaneurysms from ischemic rupture [22].

This an-aortic off-pump CABG diagram illustrates optimal graft placement strategies for LCx territory revascularization, highlighting sequential saphenous vein anastomoses to OM1/OM2 branches with proximal Y-configurations. This emphasizing no-touch harvesting techniques that preserve endothelial integrity and reduce intimal hyperplasia by 50% compared to conventional proximal aortic clamping [21].

Prevention Strategies

Effective prevention of left circumflex artery (LCx) injury hinges on multilayered strategies integrating advanced imaging, refined techniques and multidisciplinary protocols, reducing incidence from 1-2% to <0.5% in contemporary practice.

Preoperative Imaging Protocols

Routine cardiac CT angiography (CCTA) protocols and high-resolution ECG-gated acquisitions, stratify risk by

quantifying minimal LCx-annulus distances across five zones, flagging <4mm high-risk P1-A1 segments in 10-15% and guiding sutureless strategies; 3D-TEE fusion complements with dynamic enface "surgeon's views" measuring annular saddle height (5-10mm normal) and LCx wrapping. ESC/EACTS guidelines (Class IIa) mandate imaging in reoperations. The left dominance or prior endocarditis, with virtual reality, overlays simulating suture paths to pre-empt kinking [31].

Intraoperative Techniques

Shallow horizontal mattress sutures (2-3mm depth, pledgets optional) confined to ≥ 3 mm from annulus edge, oriented perpendicular to LCx trajectory, minimize ligation; zone 1 (anterolateral commissure to P1 mid) often skipped via leaflet-to-annulus hitch stitches in high-risk cases. Flexible partial rings (e.g., Cosgrove-Edwards) preferred over complete rigid bands in small annuli, preserving native dynamics and reducing distortion by 25%; intraoperative TEE with colour Doppler confirms coaptation pre-weaning [32].

Technological Advances

Transcatheter edge-to-edge repair (TEER, MitraClip) circumvents LCx risk entirely in prohibitive candidates (90% success in functional MR), while robotic platforms (da Vinci) afford 3D-HD visualization, tremor filtration and 7° wristed instruments enabling sub-millimeter precision, halving complications versus mini-thoracotomy. Patient-specific 3D-printed annuloplasty rings and AI-guided suture planners further personalize interventions [33].

Team-Based Prevention Protocols

Multidisciplinary "LCx-safe" checklists, preop CT review by surgeon /interventionalist /cardiologist, intraop TEE timeouts at annulus closure and post-repair BSPM/ECG standardize care. Simulation training on high-fidelity MV models reduces learning curve by 50%. High-volume centres achieve 0.2% rates through these protocols versus 2% elsewhere [34].

Outcomes and Long-Term Prognosis

Short-term mortality from left circumflex artery (LCx) injury during mitral valve surgery reaches 33% at 30 days in aggregated series, driven primarily by diagnostic delays exceeding 6 hours that precipitate cardiogenic shock, ventricular arrhythmias or multiorgan failure. Though timely percutaneous coronary intervention (PCI) within 2 hours reduces this to 5-8% with 75% TIMI-3 flow restoration [35]. The morbidity remains high at 60-70%, encompassing prolonged ventilation (>48 hours in 40%), acute kidney injury (30%) and stroke (10%) from embolic showers during revascularization. Long-term survival plateaus at 65-75% at 5 years among survivors, with left ventricular ejection fraction stabilizing in 70% when PCI succeeds early. About 25% develop ischemic cardiomyopathy requiring destination ventricular assist devices; vein graft patency after on-pump CABG exceeds 85%

LCX INJURY RISK STRATIFICATION & TECHNICAL MITIGATION

A Comprehensive Clinical Framework for Mitral Valve Surgery

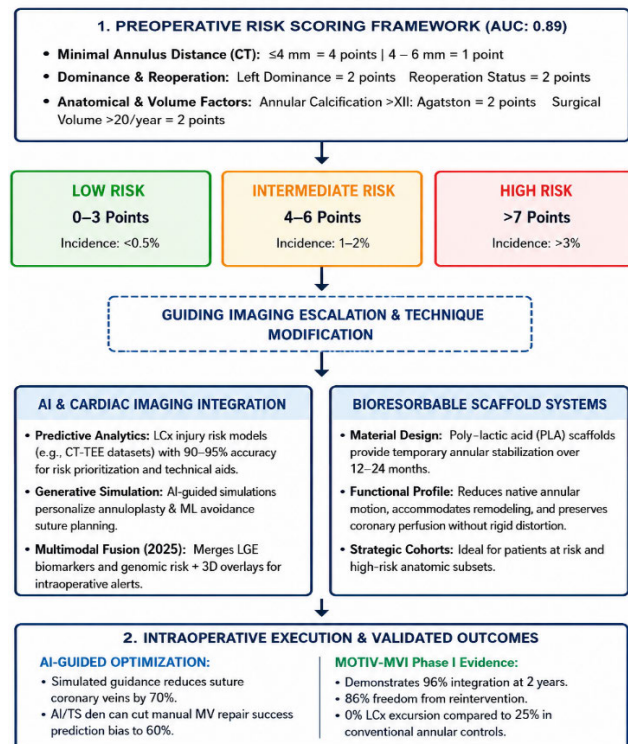


Figure 1: Proposed Model of Future directions and research gaps

at 1 year but declines to 60% by year 5 due to accelerated atherosclerosis in suture-related beds. Adverse outcomes correlate most strongly with left dominance (HR 2.8), reoperation status (HR 3.2) and incomplete revascularization (HR 4.1), alongside advanced age and diabetes that impair collateral recruitment; distances <3mm on preoperative CT predict 4-fold worse prognosis. Quality of life metrics reveal NYHA class I/II restoration in 55% of PCI survivors versus 40% post-CABG, with persistent exertional dyspnoea and ICD dependence, this limits 6-minute walk distances by 20–30%; return to independent living occurs in 70%, though 15% face permanent disability from heart failure hospitalizations [36].

CONCLUSIONS

Left circumflex artery injury during mitral valve surgery, though uncommon, is a devastating, largely preventable complication resulting from the artery's intimate course near the P1-A1 annulus. It occurs more often when the artery-annulus distance is small, with left coronary dominance, during reoperations and in complex or rheumatic valves. The injury often presents subtly and can be masked by routine postoperative changes. Prevention through preoperative CT/3D-TEE fusion imaging, shallow and strategic suture techniques, mandatory imaging for high-risk cases, simulation and team protocols and hybrid-OR readiness is essential. Management is tiered, ranging from intraoperative suture revision to percutaneous coronary intervention or hybrid PCI/CABG. Emerging tools, AI risk scores,

bioresorbable annuloplasty rings and robotic precision, promise further reductions in incidence and improved outcomes. Global standardization and targeted capacity building are needed to extend these gains to rheumatic-endemic, low-resource regions.

Future Directions in LCX Injury Prevention

This framework presents a structured approach to preventing left circumflex artery (LCX) injury during mitral valve surgery. It outlines a preoperative risk scoring system that stratifies patients into low-, intermediate- and high-risk categories, guiding imaging escalation and surgical technique modification. The model incorporates AI-assisted cardiac imaging, bioresorbable scaffold strategies and evidence-based intraoperative optimization to improve procedural safety and reduce LCX injury (Figure 1).

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