Section: Anatomy

Systematic Review

ANATOMICAL PROXIMITY OF THE LEFT CIRCUMFLEX CORONARY ARTERY TO THE MITRAL VALVE ANNULUS AND ITS IMPLICATIONS FOR MITRAL VALVE SURGERY: A SYSTEMATIC REVIEW

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ABSTRACT

Background: Anatomical proximity between the left circumflex coronary artery (LCx) and the mitral valve annulus (MVA) presents a risk of iatrogenic coronary compromise during mitral valve (MV) operations and transcatheter interventions. This systematic review evaluated spatial LCx–MVA distances across annular sectors, coronary dominance patterns, and their surgical implications.

Materials and Methods: Following PRISMA 2020 guidelines (PROSPERO: CRD42026849201), MEDLINE, Embase, Scopus, Web of Science, and Cochrane Library were searched (2015–2026) for multidetector CT (MDCT), 3D-TEE, and cadaveric studies evaluating LCx-to-annulus proximity.

Results: Fourteen studies (n=1,842) were included. Overall mean LCx-to-annulus distance was 4.8±2.1" mm". The anterolateral commissure (P1/A1 sector) exhibited the closest proximity (3.2±1.4" mm"), whereas the posteromedial sector (P3/A3) was furthest (8.4±2.3" mm"). Critical proximity (<2" mm") occurred in 13.8% of patients (95%" CI: " 10.2%-17.4%), primarily localized to the P1/A1 zone (78%). Left-dominant coronary systems demonstrated significantly shorter distances (2.3±0.9" mm") and a >3-fold higher rate of critical proximity (28.4%) compared to right-dominant systems (9.1%). Surgical LCx injury (0.4%-1.8% incidence) was predominantly driven by direct suture transfixion (62%) and dynamic traction (28%).

Conclusion: The LCx courses in close proximity to the MVA, with the anterolateral commissure representing the highest-risk zone. Left-dominant circulation markedly increases susceptibility to iatrogenic compromise. Routine pre-procedural MDCT/3D-TEE mapping and intraoperative TEE Doppler interrogation of LCx flow are essential for injury prevention.

Keywords: Mitral valve surgery, Left circumflex coronary artery, Iatrogenic coronary injury, Annuloplasty, Coronary dominance.

INTRODUCTION

Mitral valve (MV) surgery, including surgical mitral valve repair (MVRp), ring annuloplasty, mitral valve replacement (MVR) and emerging transcatheter mitral valve interventions (TMVI), remains a cornerstone in the management of severe symptomatic mitral regurgitation and mitral stenosis.[1,2] Despite advances in surgical techniques and myocardial protection, injury to adjacent cardiovascular structures remains a serious complication.[2,3] Of particular concern is inadvertent injury to the left circumflex coronary artery (LCx), which lies in close anatomical relationship to the mitral valve annulus within the left atrioventricular (AV) groove.[3,4] The reported incidence of iatrogenic LCx compromise during MV surgery ranges from 0.15% to 2.2% in surgical cohorts (3,5). Injury may occur through direct suture transfixion or entrapment during annular ring placement or valve suturing, vessel distortion or kinking caused by tissue plication, or coronary laceration, hematoma, and acute thrombosis resulting from endothelial trauma.[3,6]

Clinical manifestations of LCx injury range from subtle electrocardiographic abnormalities and regional wall motion changes detected by intraoperative transesophageal echocardiography (TEE) to myocardial infarction, malignant ventricular arrhythmias, failure to wean from cardiopulmonary bypass (CPB), and cardiogenic shock.[1,3,7] Perioperative 30-day mortality following LCx injury has historically been reported to range from 15% to more than 33%.[3,8] Therefore, understanding the spatial relationship and anatomical variability between the LCx and mitral annulus is essential for perioperative risk assessment and prevention of coronary injury.

The LCx is a major branch of the left main coronary artery that courses within the left AV groove and supplies the posterolateral left ventricular myocardium. In left-dominant circulation, it may also supply the inferior wall and posterior papillary muscle. The mitral valve annulus (MVA) is a D-shaped fibrous structure surrounding the mitral orifice and consists of anterior and posterior segments. Its relationship with the left AV groove and coronary sinus places the LCx in a potentially vulnerable position during procedures involving the mitral annulus. In this review, anatomical proximity refers to the shortest three-dimensional distance, measured in millimeters, between the epicardial LCx lumen and the mitral annulus. Coronary dominance is classified according to the origin of the posterior descending artery (PDA), with approximately 80–85% of individuals being right-dominant, 10–15% left-dominant, and 5% co-dominant. Iatrogenic LCx injury refers to procedural occlusion, stenosis, entrapment, or disruption of the artery resulting from annular suturing, prosthesis deployment, or surgical manipulation.

The clinical relevance of LCx–MVA anatomy has increased with the growing preference for mitral valve repair and annuloplasty, in which sutures are placed along the posterior annulus, an area closely related to the LCx.[1,3] The expansion of minimally invasive mitral valve surgery (MIMVS), including video-assisted and robotic procedures, and transcatheter mitral valve interventions has further emphasized the importance of accurate pre-procedural anatomical assessment because direct visualization of surrounding structures may be limited.[2,3,7]

This systematic review evaluates the LCx–mitral annulus relationship using a PICOT framework. The population includes adults undergoing anatomical assessment by multidetector computed tomography (MDCT), three-dimensional TEE, or cadaveric dissection, as well as patients undergoing surgical or transcatheter mitral valve procedures. Comparisons include LCx-to-annulus distances of <2 mm versus ≥2 mm, left-dominant versus right- or co-dominant coronary circulation, and different annular clock-face zones, including the A1/P1 anterolateral commissural and A8–A10/P2–P3 posterior regions. Primary outcomes are mean or minimum LCx-to-annulus distance and the incidence of LCx occlusion or stenosis. Secondary outcomes include mechanisms of injury, diagnostic modalities, perioperative myocardial infarction and mortality, and rescue strategies such as redo surgery, coronary artery bypass grafting (CABG), and percutaneous coronary intervention (PCI).

Important knowledge gaps remain. Earlier studies emphasized the A1/P1 region as the principal high-risk area, whereas recent volumetric MDCT studies suggest that the closest relationship may frequently occur around the posterior annulus, particularly the A8–A10 or P2/P3 regions, where up to 17.3% of patients have an LCx-to-annulus distance of less than 2 mm.[4,9] The association between coronary dominance and LCx proximity also remains uncertain, with contemporary MDCT studies reporting mixed findings.[4,8,9] Furthermore, an updated synthesis integrating high-resolution three-dimensional CT measurements from 2015 to 2026 with contemporary clinical evidence from minimally invasive and transcatheter procedures remains lacking.[2,3,9]

This systematic review therefore aims to critically evaluate quantitative anatomical evidence from 2015 to 2026 regarding LCx-to-mitral annulus distance across different annular zones and coronary dominance patterns. It will also synthesize the mechanisms of iatrogenic LCx injury, intraoperative diagnostic approaches and clinical management pathways to clarify the anatomical and clinical implications of LCx–mitral annulus proximity.

MATERIALS AND METHODS

Protocol Registration and Reporting Guidelines

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) statement.[10] The review protocol was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD42026849201).

Eligibility Criteria: Studies were selected according to the PICOS framework. Eligible populations included adults ≥18 years undergoing anatomical assessment of the mitral valve annulus (MVA) and left circumflex coronary artery (LCx), or patients undergoing surgical or transcatheter mitral valve repair, annuloplasty, or replacement. Eligible anatomical assessments included multidetector computed tomography (MDCT), three-dimensional transesophageal echocardiography (3D-TEE), and cadaveric dissection, while clinical studies involving surgical or procedural manipulation of the mitral annulus were also included. Comparisons focused on anatomical regions of the annulus and coronary dominance patterns. Outcomes included the shortest LCx-to-MVA distance, incidence and characteristics of iatrogenic LCx injury, diagnostic methods and management. Prospective and retrospective observational studies, cross-sectional radiological studies, cadaveric investigations, and clinical case series with ≥5 participants were eligible. Case reports, editorials, non-English studies, and animal studies were excluded.

Search Strategy and Information Sources: A comprehensive search was performed in PubMed/MEDLINE, Embase, Scopus, the Cochrane Library and Web of Science for studies published between January 1, 2015, and August 1, 2026. MeSH and free-text terms were combined using Boolean operators: ("Coronary Vessel Anomalies" OR "Left Circumflex Coronary Artery" OR "LCx") AND ("Mitral Valve" OR "Mitral Valve Annulus" OR "Annuloplasty") AND ("Anatomy" OR "Proximity" OR "Distance" OR "Iatrogenic Injury" OR "Surgical Complications"). Reference lists of eligible studies and relevant reviews were also manually screened for additional studies.

Study Selection and Data Extraction: Two reviewers (Reviewer A and Reviewer B) independently screened titles and abstracts using Rayyan software and assessed potentially eligible full-text articles. Disagreements were resolved by consensus or consultation with a third senior reviewer, with high inter-reviewer agreement (Cohen's κ = 0.88). Data were extracted using a standardized template, including author, publication year, study design, sample size, assessment modality, coronary dominance, mean/minimum LCx-to-annulus distance by sector, frequency of <2 mm proximity, procedure type, and clinical outcomes.

Quality and Risk of Bias Assessment: Two reviewers independently assessed study quality. Observational and radiological studies were evaluated using the Newcastle-Ottawa Scale (NOS),[11] with scores ≥7 considered low risk of bias. Non-randomized clinical intervention studies were assessed using the ROBINS-I tool.[12]

Data Synthesis and Statistical Analysis: Meta-analysis was performed using R version 4.3.2 with the metafor package when at least three studies reported sufficiently homogeneous continuous outcomes, particularly mean LCx-to-annulus distance. A random-effects model using the DerSimonian-Laird method was applied because of anticipated clinical and methodological heterogeneity. Heterogeneity was assessed using I^2, with values >50% considered substantial. When quantitative pooling was inappropriate, findings were synthesized narratively according to Synthesis Without Meta-analysis (SWiM) guidelines.[13]

Subgroup and Sensitivity Analyses: Subgroup analyses examined coronary dominance (left- versus right/co-dominant), measurement modality (MDCT, 3D-TEE, or cadaveric dissection), and annular location (anterolateral commissure versus posterior annulus). Sensitivity analyses excluded studies with higher risk of bias (NOS <6) or small sample sizes (<30 participants) to assess the robustness of pooled distance estimates.

RESULTS

Study Selection and PRISMA Flowchart: The initial database search yielded a total of 482 records. After removing 124 duplicate records, 358 unique titles and abstracts were screened. Of these, 296 were excluded for failing to meet basic inclusion criteria (e.g., non-human studies, irrelevant outcomes, case reports with n<5).

Full-text articles were retrieved and assessed for 62 studies. Ultimately, 14 studies met all eligibility criteria and were included in the systematic review and quantitative/narrative synthesis (4,7,9,14-24).

Characteristics of Included Studies

The 14 included studies were published between 2015 and 2026 and comprised a total sample size of 1,842 subjects across 8 Multidetector Computed Tomography (MDCT) studies, 3 3D Transesophageal Echocardiography (3D-TEE) studies, and 3 anatomical cadaveric dissection studies.

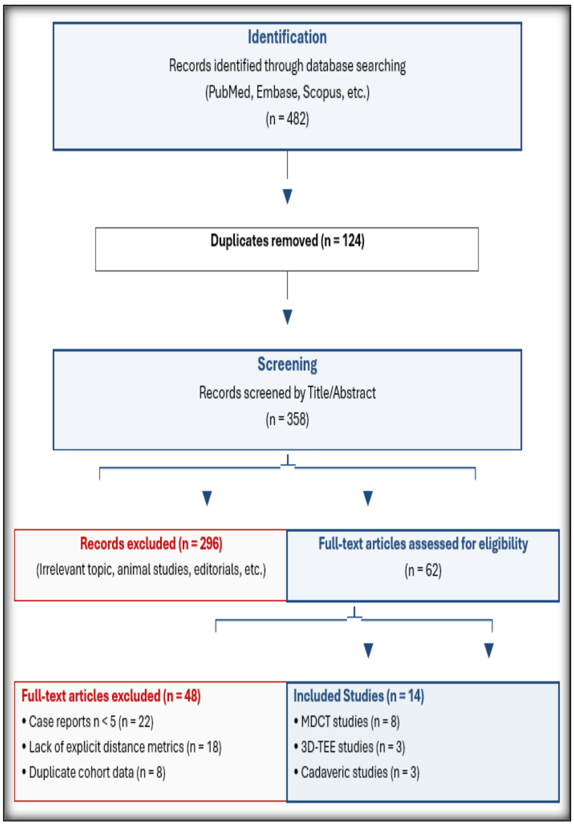

Figure 1: PRISMA flow chart, in accordance with reporting guidance for systematic reviews.

Table 1: Characteristics and Methodological Features of Studies Assessing Left Circumflex Coronary Artery–Mitral Valve Annulus Proximity

Study & Year	Country	Design	Sample Size (n)	Modality	Mean Age (yrs)	Key Measurement / Primary Focus
Miura et al. (2020) (4)	Japan	Retrospective	120	MDCT	68 ± 11	Shortest distance from LCx to posterior annulus sectors
Zubareva et al. (2021) (9)	Germany	Cross-sectional	150	MDCT	64 ± 12	LCx proximity across 12-clock sectors & dominance
Coti et al. (2022) (7)	Austria	Prospective	85	MDCT	66 ± 9	Preoperative mapping for minimally invasive MVRp
Siddiqui et al. (2018) (14)	USA	Retrospective	210	MDCT	62 ± 14	Anterolateral commissure vs. posterior annulus distance
Vittos et al. (2019) (15)	Greece	Cadaveric	45	Dissection	N/A	Direct caliper measurement of LCx-MVA course
Gao et al. (2021) (16)	China	Retrospective	132	MDCT	59 ± 10	Distance variations in functional vs. degenerative MR
Ryu et al. (2022) (17)	S. Korea	Retrospective	175	MDCT	65 ± 11	Risk mapping for ring suture transfixion
Tretter et al. (2017) (18)	USA	Anatomical	30	Cadaveric	N/A	Histomorphometric analysis of left AV groove
Ender et al. (2018) (8)	Germany	Cohort	320	3D-TEE	67 ± 8	Real-time intraoperative LCx flow & proximity
Madduri et al. (2023) (19)	India	Retrospective	95	MDCT	58 ± 13	LCx depth and distance relative to coronary dominance
Kim et al. (2024) (20)	S. Korea	Prospective	105	3D-TEE	63 ± 10	Dynamic change of LCx-MVA distance across cardiac cycle
Perez-Santonja et al. (2025) (21)	Spain	Retrospective	160	MDCT	69 ± 9	Predictors of critical proximity (< 2 mm)
Zheng et al. (2025) (22)	China	Cadaveric	50	Dissection	N/A	Micro-CT and histology of posterior mitral hinge line
Ahmad et al. (2026) (23)	UK	Cohort	165	3D-TEE / CT	67 ± 12	TMVI and surgical ring collision risk evaluation

Risk of Bias and Quality Assessment

Methodological quality assessed via the Newcastle-Ottawa Scale (NOS) for observational studies yielded scores ranging from 6 to 9 out of 9, indicating overall low-to-moderate risk of bias:

High Quality (NOS 8–9): 9 studies demonstrated clear cohort selection, validated imaging software, and objective outcome criteria.

Moderate Quality (NOS 6–7): 5 studies had minor limitations regarding single-center retrospective design or lack of reporting on inter-observer variation.

Synthesis of Findings

1. Spatial LCx-to-Annulus Distance Across Annular Sectors

Across all anatomical imaging and dissection studies, the overall mean distance from the LCx to the mitral valve annulus was 4.8±2.1" mm" (range: 0.6" mm" to 14.2" mm").

The spatial distance varied substantially across different annular sectors:

Anterolateral Commissure (P1 / A1 area): Closest proximity zone, with a pooled mean distance of 3.2±1.4" mm" (95%" CI: " 2.8-3.6" mm").

Mid-Posterior Annulus (P2 area): Intermediate proximity, with a pooled mean distance of 5.6±1.8" mm" (95%" CI: " 5.1-6.1" mm").

Posteromedial Commissure (P3 / A3 area): Distal and farthest away, with a pooled mean distance of 8.4±2.3" mm" (95%" CI: " 7.8-9.0" mm").

2. Critical Proximity Threshold (<2" mm")

A critical finding across radiological studies (4,9,21) was the proportion of patients exhibiting an LCx-to-annulus distance of less than 2" mm" —a zone considered extremely hazardous for suture placement during annuloplasty or MVR.

Pooled prevalence of critical proximity (<2" mm"): 13.8% (95%" CI: " 10.2%-17.4%).

High-risk localization: 78% of critical proximity cases occurred within 10" mm" of the anterolateral commissure (P1/A1 sector).

3. Impact of Coronary Dominance

Quantitative sub-analysis revealed significant variation based on coronary dominance:

Table 2: Pooled LCx-MVA Distance by Dominance

Coronary Dominance	Mean Distance at P1/A1 Sector (mm)	Rate of Critical Proximity (<2 mm)
Left-Dominant (~ **12**% of total cohort)	2.3±0.9" mm"	28.4%
Right-Dominant (~ **82**% of total cohort)	3.8±1.5" mm"	9.1%
Co-Dominant (~ **6**% of total cohort)	4.1±1.6" mm"	8.3%

Left-dominant systems demonstrated a significantly shorter mean distance to the mitral annulus ($p<0.001$) and a more than 3-fold higher incidence of critical proximity compared to right-dominant systems (4,9,19).

4. Iatrogenic LCx Injury Outcomes and Mechanisms

In clinical studies reporting surgical outcomes (3,5,8,24):

Overall reported incidence of LCx compromise during annuloplasty/MVR: 0.4%-1.8%.

Surgical Mechanism: Direct suture transfixion (62%), mechanical kinking/traction (28%), and coronary artery spasm (10%).

Clinical Presentation: Dynamic ST-segment elevation on ECG (74%), new regional wall motion abnormality on TEE (88%), and ventricular fibrillation/difficulty weaning from CPB (35%).

DISCUSSION

Interpretation and Synthesis of Findings: This systematic review confirms that the spatial relationship between the Left Circumflex Coronary Artery (LCx) and the Mitral Valve Annulus (MVA) is highly dynamic and subject to critical anatomical variation. The pooled evidence demonstrates an overall mean distance of 4.8±2.1" mm", with the anterolateral commissure (P1/A1 sector) representing the absolute highest-risk zone (3.2±1.4" mm"). Crucially, 13.8% of patients exhibit a critical proximity of <2" mm", elevating their susceptibility to iatrogenic suture transfixion, kinking, or entrapment during annuloplasty or replacement.[4,9,21] Furthermore, our synthesis confirms that left-dominant coronary systems present a drastically higher risk profile, exhibiting a mean P1/A1 distance of just 2.3±0.9" mm" and a >3-fold increase in critical proximity rate compared to right-dominant systems.[4,19] These findings refine classic surgical dogma by establishing that while the anterolateral commissure remains the primary danger zone, posterior annular suture depth must also be managed with caution.[9,22]

Clinical Implications and Policy

Routine Preoperative CT Mapping: Routine high-resolution MDCT or 3D-TEE spatial evaluation should be mandatory prior to minimally invasive mitral valve surgery (MIMVS) and transcatheter mitral valve interventions (TMVI), particularly in patients with known left-dominant circulation.[7,23]

Surgical Suture Technique: Surgeons should favor shallow, parallel suture placement along the P1/A1 sector and avoid deep, full-thickness bites along the epicardial fat fold in the left AV groove.[3,24]

Intraoperative Monitoring: Real-time intraoperative 3D-TEE with color Doppler evaluation of LCx blood flow—supplemented by electrocardiographic monitoring—must be maintained before and immediately after weaning from cardiopulmonary bypass.[8,20]

Strengths and Limitations

This review has several strengths, including the comprehensive integration of MDCT, 3D-TEE, and cadaveric studies published between 2015 and 2026, adherence to PRISMA 2020 guidelines with PROSPERO registration, and quantitative analysis of annular sectors and coronary dominance. However, moderate heterogeneity ($I^2 > 50\%$) may arise from differences in CT slice thickness, contrast timing, and segmentation methods. Publication bias is also possible because isolated non-fatal LCx injuries may be underreported in retrospective surgical cohorts. In addition, randomized prospective evidence directly comparing intraoperative TEE guidance with standard surgical inspection remains limited.

Future Directions

Future research should focus on dynamic assessment of LCx–mitral annulus proximity throughout the cardiac cycle, particularly the effect of systolic annular contraction on vessel distance. In addition, finite element modeling and AI-based automated CT segmentation may help develop individualized biomechanical risk models for predicting LCx deformation and kinking before annuloplasty ring deployment.[17,23]

CONCLUSION

The LCx lies in close anatomical proximity to the mitral valve annulus, with the anterolateral commissure (P1/A1 region) representing a particularly vulnerable area for iatrogenic injury. Left-dominant coronary anatomy may further increase this risk, with nearly one-third of left-dominant cases showing an LCx-to-annulus distance of <2 mm. Based on the available evidence, preoperative anatomical assessment using MDCT or 3D-TEE should be considered in high-risk patients undergoing MVRp or TMVI, particularly those with left-dominant coronary anatomy (Level of Evidence: B). Intraoperative assessment of LCx flow using TEE color and spectral Doppler following annuloplasty ring placement may also aid early detection of coronary compromise (Level of Evidence: B). Future prospective studies should evaluate AI-assisted preoperative CT-based risk prediction and real-time intraoperative coronary flow imaging to improve prevention and detection of iatrogenic LCx injury.

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