

CURRENT DEVELOPMENTS AND THEMATIC REVIEWS IN CARDIOVASCULAR SURGERY

Editor

Assoc. Prof. Oğuz Kılıç, PhD.

Current Developments and Thematic Reviews in Cardiovascular Surgery

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CONTENTS

CHAPTER 1	5
Extracorporeal Membrane Oxygenation (ECMO) Definitions, Modalities, Circuit Components, Indications, Contraindications, and a Guideline-Based Approach	
Osman Türe	
CHAPTER 2	13
Vascular Tumors: A Deductive Differential Diagnosis—A 15-Year Clinical Experience	
Halis Yılmaz	
CHAPTER 3	25
Robotic Cardiac Surgery Current Applications and Future Perspectives	
Zinar Apaydın	

CHAPTER 1

Extracorporeal Membrane Oxygenation (ECMO)

**Definitions, Modalities, Circuit Components,
Indications, Contraindications, and a Guideline-
Based Approach**

Osman Türe¹

¹ MD., İstanbul Göztepe Süleyman Yalçın City Hospital, Orcid: 0000-0002 -2261- 0294

1. Definition and Scope

ECMO is based on the extracorporeal withdrawal of blood, propulsion through a pump and membrane oxygenator, and return to the circulation. By providing oxygenation, carbon dioxide removal, and - in the VA configuration - systemic perfusion support, ECMO can serve as a temporary bridge while the underlying reversible condition is treated or recovery occurs.

2. Fundamental Physiology

Gas exchange across the oxygenator membrane occurs by diffusion. Systemic oxygen delivery during ECMO is primarily related to ECMO blood flow, hemoglobin concentration, arterial oxygen saturation, and the degree of recirculation. Carbon dioxide removal depends predominantly on sweep gas flow and membrane performance.

Although VA ECMO augments systemic perfusion, it may increase left ventricular afterload. Close echocardiographic surveillance is therefore important to detect LV distension and pulmonary edema, and unloading strategies should be considered when clinically indicated.

3. ECMO Modalities and Configurations

3.1. Venovenous (VV) ECMO

VV ECMO provides oxygenation and carbon dioxide removal in primary respiratory failure but does not provide direct circulatory support. Cannulation is commonly performed using femoral venous drainage and internal jugular venous return (a femoral-jugular configuration); femoral-femoral configurations may also be used. When femoral-femoral cannulation is selected, careful attention should be paid to the risk of recirculation.

3.2. Venoarterial (VA) ECMO

VA ECMO provides both circulatory and gas-exchange support in conditions such as cardiogenic shock and cardiac arrest. Cannulation may be peripheral, most commonly femoral, or central. In peripheral VA ECMO, a strategy for distal limb perfusion should be planned because of the risk of lower-extremity ischemia.

3.3. Hybrid Configurations

Hybrid configurations such as venoarterial-venous (VAV) ECMO may be used in patients with differential hypoxemia (Harlequin or North-South syndrome) or when simultaneous respiratory and circulatory support is required. Configuration selection should be individualized according to the underlying pathophysiology, cannula position, and institutional expertise.

4. Circuit Components

A modern ECMO circuit consists of the following core components:

- Drainage and return cannulas (or a dual-lumen cannula)

- Centrifugal pump (most commonly used)
- Membrane oxygenator (typically using a polymethylpentene [PMP] membrane)
- Heat exchanger
- Tubing, connectors, and safety clamps/valves
- Monitoring systems, including pre- and post-oxygenator pressures, blood flow, venous oxygen saturation, blood gases, and markers of hemolysis

5. Indications in Adults

5.1. VV ECMO for Respiratory Failure

Within the framework of ELSO guidance for adult respiratory failure, commonly accepted indications include:

- Refractory hypoxemia despite optimized conventional management, including lung-protective ventilation, appropriate PEEP, and prone positioning when indicated
- Refractory hypercapnia and/or acidosis when further ventilator escalation would exceed safe limits or increase the risk of barotrauma
- Severe ARDS due to causes such as pneumonia, influenza, aspiration, or trauma
- Bridge to lung transplantation or bridge to decision in selected centers

5.2. VA ECMO for Cardiogenic Shock and ECLS

Based on ELSO guidance for adult cardiac/VA ECMO and related consensus documents, general indications include:

- Refractory cardiogenic shock despite appropriate volume optimization, inotropes/vasopressors, and consideration of other mechanical circulatory support options
- Fulminant myocarditis, shock complicating acute myocardial infarction, or shock secondary to massive pulmonary embolism
- Hemodynamic collapse due to refractory malignant arrhythmias
- Extracorporeal cardiopulmonary resuscitation (ECPR)
- Postcardiotomy circulatory failure or failure to wean from cardiopulmonary bypass

6. Contraindications and Patient Selection

Many contraindications to ECMO are relative rather than absolute. Patient selection should therefore incorporate the intended goal of support (recovery, bridge to decision, transplantation, or ventricular assist device), reversibility of the underlying condition, neurological prognosis, and institutional capabilities.

Commonly accepted contraindications or major adverse selection factors include:

- Irreversible terminal disease or the absence of a reasonable prospect for an acceptable outcome after ECMO

- Severe irreversible neurological injury, particularly after ECPR
- Uncontrolled major bleeding or coagulopathy that cannot be safely managed during ECMO
 - Prolonged, irreversible multiorgan failure
 - Anatomical or valvular conditions that may render ECMO ineffective or hazardous; for example, severe aortic regurgitation may exacerbate LV distension during VA ECMO
 - Advanced age and/or significant frailty (relative contraindication)
 - For VV ECMO, prolonged exposure to high ventilatory pressures and high FiO₂ with suspected irreversible fibrotic lung injury (relative contraindication)

7. Anticoagulation and Hemostasis

ECMO is associated with simultaneous risks of thrombosis and bleeding. ELSO anticoagulation guidance emphasizes individualized anticoagulant selection - most commonly heparin-based therapy - together with monitoring using aPTT, anti-Xa activity, ACT, and/or viscoelastic testing. Institutional protocols should be adapted to the patient's bleeding risk, circuit characteristics, and concomitant clinical conditions, with continual reassessment of the balance between hemorrhagic and thrombotic complications.

8. Principles of Management

8.1. Ventilation During VV ECMO: "Lung Rest"

The primary objective is to reduce ventilator-induced lung injury. Minimally traumatic ventilation strategies employ low tidal volumes, limited plateau pressures, and appropriate PEEP. Sedation and analgesia, prone positioning strategies, and mobilization should be individualized according to the clinical situation and institutional protocols.

8.2. Hemodynamics and LV Unloading During VA ECMO

The increase in afterload associated with VA ECMO may contribute to LV distension, pulmonary congestion, and reduced aortic valve opening. Echocardiographic and hemodynamic monitoring - including pulse pressure, lactate clearance, and markers of end-organ perfusion - should be used to identify LV distension early. LV unloading strategies should be considered in accordance with the clinical findings and institutional protocols.

9. Complications

Complication	Clinical Considerations / Approach
Bleeding	Cannulation-site, gastrointestinal, or intracranial bleeding; reassess anticoagulation and platelet/fibrinogen management.
Thrombosis / oxygenator clot	Rising circuit pressure gradient and impaired gas exchange may indicate oxygenator or circuit thrombosis; circuit exchange may be required.
Ischemic events / stroke	Particularly relevant during VA ECMO; assess anticoagulation status and potential embolic sources.
Hemolysis	Increased plasma-free hemoglobin and LDH; evaluate pump function, cannula position, and circuit thrombosis.
Infection	Cannula- or catheter-related infection; obtain appropriate cultures and tailor antimicrobial therapy to the clinical context.
Lower-extremity ischemia	A key risk in peripheral VA ECMO; use distal perfusion strategies and close limb surveillance.
Differential hypoxemia	May occur during peripheral VA ECMO (Harlequin/North-South syndrome); configuration adjustment, including conversion to VAV ECMO, may be required.
Acute kidney injury (AKI)	Optimize fluid management and integrate renal replacement therapy when indicated.

10. Weaning and Discontinuation

10.1. Weaning from VV ECMO

As lung compliance and gas exchange improve, sweep gas flow and the oxygen fraction delivered through the ECMO circuit are gradually reduced. If adequate oxygenation and ventilation can be maintained with conventional ventilator settings, a weaning trial can be performed and decannulation planned in appropriate patients.

10.2. Weaning from VA ECMO

Recovery of cardiac function should be assessed using echocardiography and hemodynamic parameters. A declining vasopressor requirement, lactate clearance, and adequate pulsatility are favorable findings. ECMO flow is gradually reduced during a structured weaning trial according to institutional protocols. If the trial is successful, decannulation may proceed; if not, a bridge strategy such as VAD, transplantation, or continued bridge-to-decision support should be considered.

11. Practical Algorithms

11.1. Evaluation and Management of a Candidate for VV ECMO

Algorithm (Summary)

1. Diagnose ARDS/respiratory failure and institute lung-protective ventilation (VT 4-6 mL/kg predicted body weight), with attention to plateau pressure and driving pressure targets.
2. Optimize conventional management, including PEEP titration, prone positioning, neuromuscular blockade when appropriate, and fluid restriction.
3. If refractory hypoxemia and/or hypercapnia persists, assess VV ECMO candidacy, including reversibility, contraindications, duration of mechanical ventilation, and frailty.
4. Perform cannulation using a femoral-jugular or dual-lumen strategy, aiming for adequate blood flow while minimizing recirculation.
5. During ECMO, apply a lung-rest ventilation strategy with an individualized sedation/analgesia plan and systematic surveillance for complications.
6. When recovery becomes evident, reduce sweep gas flow and ECMO FiO₂, perform a weaning trial, and proceed to decannulation when appropriate.

11.2. Evaluation and Management of a Candidate for VA ECMO

Algorithm (Summary)

- 1.** Diagnose cardiogenic shock, rapidly identify the underlying etiology (e.g., myocardial infarction, myocarditis, pulmonary embolism, valvular pathology, or tamponade), and initiate resuscitation.
- 2.** Provide medical therapy and evaluate appropriate mechanical circulatory support options, such as IABP or Impella, according to institutional protocols.
- 3.** In refractory shock or persistent hypoperfusion, assess VA ECMO candidacy and define the treatment goal (recovery or bridge strategy).
- 4.** Perform peripheral or central cannulation; in peripheral VA ECMO, plan distal limb perfusion.
- 5.** Monitor hemodynamic goals and end-organ perfusion using parameters such as lactate clearance, pulse pressure, and echocardiography.
- 6.** If LV distension or pulmonary edema develops or is anticipated, consider an LV unloading strategy according to institutional practice.
- 7.** When recovery is evident, perform a structured weaning trial using echocardiographic and hemodynamic assessment, followed by decannulation or a bridge decision (VAD, transplantation, or bridge to decision).

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CHAPTER 2

**Vascular Tumors: A Deductive
Differential Diagnosis—A 15-Year Clinical
Experience**

Halis Yılmaz¹



¹ Dr. Öğr. Üyesi

1. Introduction

Vascular tumors and vascular malformations represent distinct categories within the broader spectrum of vascular anomalies. Although these lesions may share similar clinical manifestations, they differ in their biological behavior, underlying pathophysiology, natural history, and therapeutic requirements. The International Society for the Study of Vascular Anomalies (ISSVA) classification provides a standardized framework for distinguishing vascular tumors from vascular malformations and supports consistent terminology in clinical practice and research [1].

The differential diagnosis of vascular lesions can be challenging because several benign and malignant neoplasms, as well as nonneoplastic conditions, may mimic vascular anomalies. Clinical examination alone may not always be sufficient to establish a definitive diagnosis. Depending on the suspected lesion and its anatomical location, Doppler ultrasonography, magnetic resonance imaging, computed tomography, and histopathological examination may contribute to diagnostic clarification [1,2]. Appropriate classification is essential because diagnostic errors may lead to unnecessary interventions, delayed treatment, or inappropriate therapeutic strategies.

Infantile hemangioma is the most common benign tumor of infancy. It typically exhibits postnatal proliferation followed by gradual involution, although the clinical course and potential complications vary according to lesion characteristics and anatomical location. Some infantile hemangiomas require active treatment because of ulceration, functional impairment, permanent disfigurement, or associated structural abnormalities [3]. Consequently, accurate recognition and risk stratification are important components of clinical management.

Other vascular tumors and vascular-anomaly mimickers may occur in older patients and in a wide range of anatomical locations. In some cases, tumors arise in structures closely related to major blood vessels or affect the vascular system through direct involvement or compression. Carotid body tumors, for example, are paragangliomas located at the carotid bifurcation and may present substantial diagnostic and surgical challenges because of their relationship to major cervical vessels [4].

The presence of multiple lesions, multifocal anatomical involvement, and coexisting vascular malformations may further complicate the diagnostic process. These circumstances emphasize the need to evaluate each lesion according to its clinical presentation, anatomical localization, imaging characteristics, and pathological findings when available [1,2].

The present study reviewed a 15-year clinical experience involving patients with vascular tumors, tumors affecting vascular structures, and lesions mimicking

vascular tumors. The primary objective was to describe the distribution of these diagnostic categories and their clinical and anatomical characteristics. Secondary objectives included evaluating surgical management, metastatic findings, and follow-up duration. By examining these clinically overlapping groups, this study seeks to emphasize the importance of a systematic differential diagnostic approach in surgical practice.

2. Materials and Methods

2.1. Study design and patient population

A total of 183 patients treated and followed up at our clinic over a 15-year period for vascular tumors, tumors affecting vascular structures, or mimickers of vascular tumors were evaluated.

The exact study period, institutional setting, and study design must be specified in the final manuscript according to the original protocol. The study should be identified as retrospective, prospective, or another appropriate observational design, depending on how the patient data were collected.

2.2. Diagnostic classification

Patients were categorized into three groups:

1. Primary vascular tumors.
2. Tumors affecting vascular structures.
3. Nonvascular tumors mimicking vascular tumors or vascular anomalies.

The original diagnostic classification was retained for the descriptive analysis. For publication, the diagnostic criteria for each group should be explicitly defined, and the diagnoses should be reviewed against current vascular anomaly terminology [1].

The final manuscript should specify whether diagnoses were established by clinical examination, imaging, histopathological assessment, or a combination of these methods.

2.3. Exclusion criteria

Tumors involving the renal vein and selected vascular malformations, including lesions described in the original study as lymphangioma and cavernous hemangioma, were excluded.

The reasons for these exclusions should be clarified in the final version. Because terminology and classification of vascular anomalies have evolved, the original diagnostic labels should be checked against the available clinical, imaging, and pathological records [1].

2.4. Clinical variables and outcome measures

The reported variables included diagnostic category, anatomical distribution, multiplicity and laterality of lesions, metastatic findings, surgical treatment, and follow-up duration.

The final manuscript should clarify how these variables were defined and recorded. In particular, the definition of multiple localized tumors, the criteria used to determine resectability, and the methods used to assess metastatic disease should be specified.

2.5. Statistical analysis

The available results include descriptive proportions and the median follow-up duration. The statistical analysis section should identify the statistical software, descriptive methods, and any inferential tests used in the original analysis.

All percentages should be verified against the original dataset, with the denominator for each diagnostic category clearly stated. The reported total-to-subtotal resection ratio should also be checked and explicitly defined.

2.6. Ethical considerations

The final manuscript must identify the relevant ethics committee, approval number, and approval date, where applicable. The requirements for informed consent or an approved waiver should be reported according to the actual study protocol and institutional regulations.



A. Clinical photograph demonstrating a vascular lesion involving the oral cavity, **B.** Facial vascular tumor presenting during infancy, **C.** Congenital, well-circumscribed violaceous vascular lesion involving the cheek, **D.** Large superficial vascular tumor involving the lateral chest Wall, **E.** Posterior cervical vascular mass with overlying skin changes, **F.** Extensive distal foot involvement with dark violaceous discoloration and soft-tissue enlargement, **G1.** Preoperative clinical appearance of a large gluteal vascular tumor with surgical markings, **G2.** Intraoperative view demonstrating the highly vascular nature of the lesion, **H1.** Cross-sectional imaging showing a deep-seated vascular tumor with extension into adjacent soft tissues, **H2.** Intraoperative photograph demonstrating complete surgical excision of the lesion, **H3.** Gross surgical specimen (upper panel) and representative histopathological sections (middle and lower panels), **I1.** Preoperative skin marking for planned surgical excision, **I2.** Intraoperative view during complete resection of the vascular tumor, **I3.** Excised surgical specimen, **J1.** Extensive vascular lesion involving the lower extremity, **J2.** Intraoperative exposure of the tumor, **J3.** Gross appearance of the excised specimen, **J4.** Postoperative appearance following wound healing, **K1.** Clinical presentation of a vascular tumor involving the heel, **K2.** Magnetic resonance imaging demonstrating a deep soft-tissue lesion, **K3.** Intraoperative view of tumor excision, **K4.** Postoperative appearance during follow-up showing satisfactory healing

3. Results

3.1. Distribution of diagnostic categories

A total of 183 patients were treated and followed up during the 15-year study period. Patients were classified into three diagnostic categories: vascular tumors, tumors affecting vascular structures, and mimickers of vascular tumors.

Vascular tumors accounted for 42.6% of the study population, while tumors affecting vascular structures represented 43.2%. Mimickers of vascular tumors constituted 14.2% of cases.

3.2. Distribution of tumor types

Infantile hemangioma was the most common vascular tumor, accounting for approximately 77% of this category.

Adult hemangiopericytoma and vascular lesions associated with neurofibromatosis accounted for 88.4% of the mimicker group. The individual contributions of these diagnoses should be reported separately in the final manuscript if the original patient records permit.

Among tumors affecting vascular structures, carotid body tumors accounted for 34.1% of cases.

3.3. Anatomical distribution and multiplicity

The extremities were the most frequent anatomical sites among patients with multiple localized tumors. Right- and left-sided involvement was reported to be equally distributed.

Further characterization of the anatomical distribution should include the number of patients with multiple lesions, the number of anatomical sites involved, and the distribution of lesions by specific region, if these data are available.

3.4. Metastatic findings

No regional lymph node or distant organ metastases were observed in the study population.

This finding should be interpreted in relation to the diagnostic composition of the cohort, the completeness of metastatic evaluation, and the duration of follow-up. The final manuscript should clarify whether all patients underwent systematic assessment for metastatic disease or whether investigations were performed according to clinical indications.

3.5. Surgical management and follow-up

All tumors considered resectable underwent total or subtotal resection. The reported total-to-subtotal resection ratio was 1.4.

The median follow-up duration was 28 months. Additional information concerning postoperative complications, residual disease, recurrence, reoperation, functional outcomes, and follow-up completeness would strengthen the interpretation of the surgical results. Such outcomes should be included only if documented in the original dataset.

4. Discussion

This study describes a heterogeneous cohort of 183 patients evaluated for vascular tumors, tumors affecting vascular structures, and lesions mimicking vascular anomalies over a 15-year period. The distribution of cases across these

three categories demonstrates the range of diagnostic entities encountered in surgical practice and emphasizes the importance of distinguishing lesions with different biological characteristics and clinical implications.

4.1. Importance of accurate classification

The classification of vascular anomalies is fundamental to diagnostic decision-making and treatment planning. The ISSVA classification distinguishes vascular tumors from vascular malformations and provides standardized terminology for clinical practice and research [1]. This distinction is particularly relevant when lesions present with overlapping clinical or radiological features.

The inclusion of tumors affecting vascular structures and nonvascular mimickers extends the differential diagnosis beyond primary vascular neoplasia. Such a framework may be useful in surgical clinics, where lesions adjacent to major vessels or those presenting with prominent vascular features can create diagnostic uncertainty.

Nevertheless, the three diagnostic categories used in the present study should be defined precisely. The final classification should be reconciled with current terminology to ensure that biologically distinct entities are not inadvertently grouped together.

4.2. Infantile hemangioma as the predominant vascular tumor

Infantile hemangioma was the predominant vascular tumor in the present cohort. This finding is consistent with the established clinical importance of infantile hemangioma, which is recognized as the most common benign tumor of infancy [3].

Although many infantile hemangiomas undergo spontaneous involution, some lesions require active treatment because of their location, potential complications, or risk of functional impairment and permanent disfigurement [3]. Accurate recognition and appropriate risk assessment are therefore important components of management.

The approximately 77% proportion observed in this study should be interpreted as a finding specific to the study population. Differences in referral patterns, patient age, clinical setting, and inclusion criteria may influence the distribution of diagnoses and limit direct comparison with population-based estimates.

4.3. Nonvascular lesions mimicking vascular tumors

The proportion of lesions classified as mimickers highlights the importance of considering alternative diagnoses when a lesion presents with vascular clinical or radiological characteristics. A range of benign and malignant neoplasms and other conditions may resemble vascular anomalies, and diagnostic clarification

may require a combination of clinical assessment, imaging, and histopathological evaluation [2].

The reported predominance of adult hemangiopericytoma and vascular lesions associated with neurofibromatosis within the mimicker group warrants further clarification. In particular, the term *hemangiopericytoma* has undergone changes in pathological classification and is not used uniformly for all tumors historically described by that name. The original pathological diagnoses should therefore be reviewed, and current terminology should be used where supported by the available records.

Similarly, vascular lesions associated with neurofibromatosis should be described according to their specific clinical, radiological, or pathological diagnosis whenever possible. More precise characterization would improve reproducibility and facilitate comparison with other studies.

4.4. Tumors affecting vascular structures

Carotid body tumors accounted for 34.1% of the tumors affecting vascular structures in this cohort. These lesions are paragangliomas arising near the carotid bifurcation and are clinically important because of their relationship to major cervical vessels and the potential complexity of surgical treatment [4].

Their evaluation and management require careful consideration of anatomical extent, operative risk, and patient-specific factors. A systematic review of the available evidence has highlighted the importance of tumor characteristics and surgical risk assessment in the management of carotid body tumors [4].

However, the proportion observed in this study should not be interpreted as the prevalence of carotid body tumors in the general population. Rather, it represents the distribution of diagnoses within a selected clinical cohort.

The distinction between tumors arising in vascularly related anatomical structures and tumors directly involving or affecting a vessel should also be clarified. This would improve the conceptual consistency of the diagnostic categories and strengthen the interpretation of the results.

4.5. Multifocal lesions and anatomical distribution

The extremities were the most frequent anatomical sites among patients with multiple localized tumors, and right- and left-sided involvement was equally distributed. These observations describe the anatomical distribution of lesions within the study population.

However, anatomical distribution alone does not establish a common pathophysiological mechanism. The significance of multifocal lesions depends on the underlying diagnosis, the number and location of lesions, and the presence of associated syndromic or systemic features.

Further characterization of the anatomical patterns and diagnostic subgroups would help determine whether specific tumor types are associated with particular distributions.

4.6. Surgical management and follow-up

All resectable tumors in the present cohort underwent total or subtotal resection. This finding indicates that surgical excision was the principal treatment approach among patients considered suitable for resection.

Nevertheless, resection status alone is insufficient to establish treatment effectiveness. A comprehensive evaluation of surgical outcomes requires information about postoperative morbidity, residual disease, recurrence, reoperation, functional status, and disease-specific follow-up.

These outcomes are particularly important when a cohort includes lesions with different biological behaviors and anatomical relationships. The reported median follow-up of 28 months describes the observation period but does not, by itself, establish long-term disease control.

Similarly, the absence of documented regional or distant metastases should be interpreted cautiously. The clinical significance of this observation depends on the underlying diagnoses, the completeness of metastatic assessment, and the duration of follow-up.

4.7. Clinical implications

The findings support a structured diagnostic approach for patients presenting with suspected vascular tumors or vascular-anomaly mimickers. Such an approach should incorporate clinical assessment, anatomical localization, appropriate imaging, and histopathological confirmation when indicated [1,2].

Multidisciplinary collaboration may be particularly valuable when lesions involve major vessels, present with multifocal disease, or have uncertain biological behavior. Depending on the diagnosis, relevant specialists may include vascular surgeons, radiologists, pathologists, pediatric specialists, dermatologists, and oncologists.

A systematic approach may improve diagnostic consistency, facilitate communication among specialties, and support individualized treatment planning. However, the present study did not directly compare diagnostic algorithms or treatment strategies. These clinical implications should therefore be regarded as recommendations informed by the diagnostic heterogeneity observed in the cohort rather than as evidence of the superiority of a specific intervention.

4.8. Study limitations

Several limitations should be acknowledged. First, the study population was drawn from a single clinical setting, which may limit generalizability to other institutions and patient populations.

Second, the inclusion of biologically diverse diagnostic entities may complicate direct comparisons of treatment and follow-up outcomes. Third, the available summary does not provide sufficient detail regarding diagnostic confirmation, statistical analysis, completeness of follow-up, or diagnosis-specific clinical outcomes. These methodological details must be verified from the original records before publication.

Finally, the absence of observed metastases should not be interpreted as evidence that all included tumor types lack metastatic potential. Interpretation depends on the underlying diagnoses, the extent of metastatic evaluation, and the duration of follow-up.

Future studies using standardized diagnostic definitions, clearly specified inclusion criteria, and diagnosis-specific outcome measures would help clarify the prognostic and therapeutic implications of these findings.

5. Conclusion

Vascular tumors, tumors affecting vascular structures, and nonvascular lesions mimicking vascular anomalies represent distinct but potentially overlapping diagnostic challenges in surgical practice. In this 15-year clinical cohort, all three categories were represented, with infantile hemangioma predominating among vascular tumors and carotid body tumors accounting for a substantial proportion of tumors affecting vascular structures.

The findings emphasize the importance of accurate classification, appropriate diagnostic evaluation, and individualized treatment planning. A multidisciplinary approach incorporating clinical assessment, imaging, and pathological evaluation when indicated may facilitate reliable diagnosis and appropriate management.

Further studies with standardized terminology, comprehensive methodological reporting, and diagnosis-specific long-term outcomes are needed to establish the broader clinical implications of these observations.

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5.

CHAPTER 3

Robotic Cardiac Surgery Current Applications and Future Perspectives

Zinar Apaydin¹

¹ MD., Cardiovascular Surgeon University of Health Sciences, Istanbul Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital, ORCID 0000-0002-3041-1172

1 Introduction

The aim of minimally invasive approaches in cardiac surgery is to reduce access-related tissue injury while preserving the therapeutic effectiveness of conventional surgery. Robotic technology is an important component of this approach. Instruments controlled by the surgeon at a console reach the target anatomical structures through small thoracic ports. Nevertheless, a small incision does not eliminate the physiological effects of cardiopulmonary bypass, myocardial ischemia, or vascular cannulation. Robotic surgery should therefore be considered an approach in which the access strategy and the cardiac treatment delivered to the patient are evaluated together (Xue et al., 2022).

One of the early large series of robotic mitral surgery demonstrated that various repair techniques could be performed robotically in 300 patients. Chitwood et al. (2008) reported low early mortality and acceptable midterm repair durability in this experience. Applications subsequently expanded to coronary surgery, septal defect repair, and other selected procedures. A registry study of 26 European centers covering 2016–2019 showed that approximately half of 2,563 robotic cardiac procedures involved coronary revascularization and more than one-third involved mitral or tricuspid surgery. This distribution demonstrates that the robotic approach encompasses more than a single operation (Cerny et al., 2021).

When defining the contemporary role of robotic cardiac surgery, conventional surgery, nonrobotic endoscopic surgery, and transcatheter therapies in suitable patients should all be considered. The indication for surgery is established on the basis of the natural history of the disease and clinical guidelines; the decision to use robotic access follows this assessment. The availability of a robotic system does not, by itself, constitute an indication for surgery (Gurvitz et al., 2026; Praz et al., 2025).

2 Technological Foundations and Surgical Organization

Robotic platforms consist of a surgeon console, patient-side manipulators, and imaging components. The magnified three-dimensional camera image allows the surgeon to assess the spatial relationships of intracardiac structures. Articulated instruments facilitate suturing from different angles and tissue manipulation within a confined workspace. These features are particularly useful in precise procedures such as valve reconstruction. However, the expected technical advantages may not be achieved if instrument geometry, port placement, and the working space are inadequately planned (Xue et al., 2022).



Figure 1. Robotic arms and operating room setup during robotic cardiac surgery.
Source: Image provided by the author.

The extent of robotic assistance varies according to the operation. In mitral surgery, valve repair or replacement can be performed with robotic instruments. In robot-assisted minimally invasive direct coronary artery bypass, the internal thoracic artery is harvested robotically, whereas the anastomosis may be performed directly through a small thoracotomy. In totally endoscopic coronary artery bypass, the anastomosis is also completed within the endoscopic working space. Grouping these different techniques under a single heading of robotic surgery complicates comparisons of operative times and outcomes (Hwang, Ren, Wang, Williams, & Yan, 2024).

The bedside surgeon, anesthesia team, perfusionists, and operating room nurses are as important to operative safety as the console surgeon. Equipment placement must be planned in advance because access to the thorax and airway may become restricted after the robot is docked. Responsibilities for undocking the robot, extending thoracic access, and proceeding to sternotomy when necessary must be clearly assigned for emergencies involving bleeding or hemodynamic deterioration. Establishing a program requires not only learning to operate the device but also preparing the entire team for a shared workflow (Badhwar et al., 2026; Rehfeldt, Andre, & Ritter, 2017).

3 Patient Selection and Preoperative Assessment

3.1 Treatment Indication and Choice of Access

The first step in patient selection is to determine the most appropriate treatment for the cardiac pathology. In mitral disease, the likelihood of repair, the need for replacement, and associated pathologies are assessed; in coronary disease, target vessels and the revascularization strategy are considered; and in septal defects, the effects of the shunt and suitability for device closure are evaluated. The second step is to establish whether the selected treatment can be performed safely and completely through robotic access. The robotic approach should not justify compromising the quality of the planned repair or the extent of revascularization (Jonsson & Halkos, 2024; Praz et al., 2025).

Eligibility is a dynamic concept related to institutional experience. The selection criteria of a newly established program differ from those of a highly experienced center. Using a conservative algorithm based on echocardiography and computed tomography, Chemtob et al. (2022) found that approximately 60% of 1,000 patients with isolated degenerative mitral disease were eligible for robotic surgery. This finding should be interpreted as an illustration of the importance of structured screening rather than a fixed eligibility rate applicable to every center.

3.2 Cardiac and Vascular Imaging

Transthoracic echocardiography and, when required, transesophageal echocardiography are fundamental tools for evaluating valve morphology, ventricular function, pulmonary pressures, and associated lesions. In mitral surgery, the location and extent of prolapse, annular calcification, and aortic regurgitation influence operative planning. In particular, significant aortic regurgitation requires additional planning regarding antegrade cardioplegia and ventricular distension (Gillinov, Malas, Burns, Mick, & Wierup, 2026).

In patients being considered for peripheral perfusion, the anatomy, diameters, and atherosclerotic burden of the aorta and iliofemoral vessels should be assessed. Thoracic imaging can identify the available working space, chest wall deformities, and findings that may affect surgical access. Renal function and risks associated with contrast administration should also be considered when planning imaging. The cannulation strategy should be tailored to the patient's anatomy; vessel diameter or ejection fraction thresholds used by an individual center should not be presented as universal contraindications (Chemtob et al., 2022; Gillinov et al., 2026).

3.3 Factors Increasing Technical Difficulty and Risk

Advanced aortoiliac atherosclerosis, inadequate peripheral vascular access, severe thoracic deformity, previous right thoracotomy, and the likelihood of extensive pleural adhesions may complicate the robotic approach. Severe ventricular dysfunction or pulmonary hypertension may reduce tolerance of prolonged ischemic time. Complex pathology, such as extensive mitral annular calcification, increases reconstructive risk. Although experienced centers may manage some of these conditions using alternative perfusion or myocardial protection strategies, more conservative selection is appropriate during the initial phase of a program (Gillinov et al., 2026).

Age or body mass index alone does not capture the full technical assessment. Eligibility decisions should integrate comorbidities, respiratory reserve, peripheral vascular anatomy, and the thoracic working space. Patient counseling should explain the potential benefits of robotic surgery as well as peripheral cannulation and the possibility of conversion to a larger incision. Treatment

selection should be based on a joint assessment of patient preference and clinical suitability (Chemtob et al., 2022; Xue et al., 2022).

4 Perioperative Management and Technical Safety

4.1 Anesthesia and Monitoring

Robotic cardiac procedures require the combined application of cardiac and thoracic anesthesia expertise. Single-lung ventilation improves the working space but requires monitoring of oxygenation and ventilation. In addition to confirming cardiac anatomy, transesophageal echocardiography is used to guide cannulation, assess ventricular filling, assist de-airing, and evaluate the result of the procedure. Patient positioning, pressure points, and the range of motion of the robotic arms should be checked together (Rehfeldt et al., 2017).

In robotic coronary surgery, lung isolation, hemodynamic changes, and postoperative pain management cannot be considered independently. Small incisions do not eliminate intercostal pain. Regional analgesia and multimodal pain control may be planned to support respiratory function and mobilization. Early extubation should be pursued when gas exchange, bleeding, and hemodynamic status are satisfactory (Hoogma, Oosterlinck, & Rex, 2024).

4.2 Perfusion and Myocardial Protection

In mitral and other intracardiac procedures, cardiopulmonary bypass is usually established through peripheral cannulation. The adequacy of arterial inflow and venous drainage, cannula positions, and lower-limb perfusion are monitored. Adequate venous drainage and caval control are particularly important when the right atrium is opened. The method and site of cannulation are determined by the procedure and the patient's anatomy (Rehfeldt et al., 2017; Yun et al., 2022).

Aortic occlusion can be achieved with a transthoracic clamp or an endoaortic balloon. The choice depends on anatomy, team experience, and the myocardial protection plan. Limited access does not diminish the importance of cardioplegia delivery, prevention of ventricular distension, or de-airing. Ventricular function and residual lesions should be evaluated by echocardiography at the end of the procedure (Gillinov et al., 2026; Rehfeldt et al., 2017).

4.3 Complications and Extension of Surgical Access

Bleeding, neurological events, myocardial injury, and organ dysfunction are outcomes that must be considered in all cardiac operations. Robotic surgery adds potential problems related to port access and peripheral cannulation. In a safe program, conversion to alternative surgical access is a predefined rescue strategy. The decision to convert should not be delayed in the presence of uncontrolled bleeding, inadequate exposure, or circulatory compromise (Badhwar et al., 2026).

When reporting outcomes, intraoperative conversion to thoracotomy or sternotomy should be distinguished from postoperative re-exploration for bleeding. Clearly specifying the timing, reason, and access used for conversion permits more accurate evaluation of team performance and patient safety. The 2.2% conversion rate to a larger thoracic incision reported in the European registry study illustrates that this event is a measurable quality indicator for monitoring robotic programs (Cerny et al., 2021).

5 Major Clinical Applications

5.1 Robotic Mitral Valve Repair

Mitral valve repair is one of the areas with the most extensive evidence in robotic cardiac surgery. In suitable patients with degenerative mitral regurgitation, the principal objective is durable valve repair. Robotic access is one method of achieving this objective. Techniques such as resection, artificial chordal implantation, and annuloplasty are selected according to the characteristics of the pathology. Valve repairability should not be assessed solely in terms of ease of access (Chitwood et al., 2008; Praz et al., 2025).

Mori et al. (2024) evaluated 61,322 patients in the STS database in whom repair was planned for degenerative mitral regurgitation. After propensity score matching, no significant differences in mortality or major morbidity were identified between the robotic approach and thoracotomy or sternotomy; hospital stay was shorter in the robotic group. Conversion to valve replacement in this context is not the same outcome as conversion from minimally invasive access to sternotomy. Although the study supports the comparative safety of robotic repair, it was not randomized.

Long-term evaluation should include recurrent mitral regurgitation in addition to survival and reoperation. Roach et al. (2022) reported favorable durability for posterior leaflet prolapse using a standardized robotic repair approach and emphasized the greater complexity of repair in anterior or bileaflet pathology. A meta-analysis by Eranki et al. (2026), comprising 11,432 patients from 15 studies, also showed generally favorable midterm and long-term outcomes. Nevertheless, the observational nature of the studies and differences in echocardiographic follow-up should be considered when interpreting these findings.

5.2 Robotic Mitral Valve Replacement

Robotic mitral valve replacement can be performed when repair is unlikely to be suitable or durable. Prosthetic valve selection, preservation of subvalvular structures, and assessment of prosthetic function follow conventional surgical principles. Robotic access does not, by itself, determine the appropriate prosthesis type or the required antithrombotic treatment (Yan et al., 2023).

In a matched analysis comparing robotic replacement with replacement through sternotomy, Yan et al. (2023) reported no significant differences in early mortality or major complications. Operative, bypass, and cross-clamp times were longer in the robotic group, whereas intensive care and postoperative hospital stays were shorter. At five years, no significant differences in mortality or valve-related outcomes were demonstrated. These findings support feasibility in selected patients but cannot be generalized to all patients requiring replacement.

5.3 Robotic Coronary Revascularization

The main robotic approaches in coronary surgery are robot-assisted minimally invasive direct coronary artery bypass and totally endoscopic coronary artery bypass. In the former, robotic internal thoracic artery harvesting is followed by anastomosis through a small thoracotomy. In the latter, the anastomosis is also performed endoscopically. Procedures may be performed with pump support or, in suitable patients, off-pump. Specifying the technique used is essential for accurate interpretation of the literature (Hwang et al., 2024).

Anastomosis of the left internal thoracic artery to the left anterior descending coronary artery is an important component of robotic coronary programs. In multivessel disease, hybrid strategies may combine surgical grafting with percutaneous treatment of other suitable lesions. Patient selection and procedural sequencing should be assessed by the heart team. Accessibility of the anastomotic target, target vessel quality, and the overall revascularization plan are considered together with the technical approach (Jonsson & Halkos, 2024; Nisivaco et al., 2024).

In a meta-analysis of 39 studies, Hwang et al. (2024) reported low perioperative event rates and favorable long-term graft patency. Approximately 96% graft patency for both techniques at a mean follow-up of 5.2 years is encouraging; however, this estimate should not be interpreted as a follow-up result obtained using the same imaging method in every patient. Heterogeneity in patient characteristics and surgical techniques limits direct conclusions about superiority.

Totally endoscopic procedures using both internal thoracic arteries are also performed at experienced centers. In a series of 406 patients, Nisivaco et al. (2024) reported the feasibility of multivessel arterial revascularization and favorable follow-up outcomes. Although the study title refers to 10-year outcomes, mean follow-up was approximately 51 months; it should not be assumed that every patient was followed for 10 years. Outcomes of advanced techniques should be evaluated in the context of institutional experience and patient selection.

5.4 Atrial Septal Defect Repair

Treatment decisions for atrial septal defects are based on defect type, right heart volume overload, shunt magnitude, and pulmonary vascular status. Transcatheter closure is an important option for secundum defects with suitable anatomy. Robotic repair may be considered in patients who are unsuitable for device closure or have associated pathology requiring surgery. In the presence of pulmonary vascular disease, the suitability of defect closure must be assessed before deciding on robotic access (Gurvitz et al., 2026).

In a single-center study of 462 patients comparing robotic and transcatheter closure, Kadirogullari et al. (2020) reported favorable outcomes with both approaches and shorter ventilation, intensive care, and hospital stays in the transcatheter group. Because anatomical and clinical selection may differ between groups, these findings cannot be interpreted as evidence that the two methods are equivalent in all patients with an atrial septal defect (ASD). The role of robotic surgery is particularly related to providing less invasive access for patients who require surgical closure.

The defect can be closed with primary sutures or a patch. Selection of an arrested, fibrillating, or beating-heart strategy depends on institutional experience and procedural characteristics. Yun et al. (2022) compared beating-heart and non-beating-heart approaches in a series of 45 patients and reported no significant neurological complications. The absence of events in a small series does not prove that the risk of air embolism has been eliminated. Preventing air entry into the left heart and performing echocardiographic assessment at the end of the procedure remain fundamental safety requirements.

5.5 Tricuspid Surgery and Other Selected Procedures

Indicated tricuspid interventions can be added robotically during mitral surgery. Arslanhan et al. (2024) reported concomitant tricuspid procedures in 59 of 285 patients undergoing robotic mitral surgery. Early outcomes were similar in the matched comparison. Although this study supports feasibility, it does not alter the need to establish the indication for tricuspid surgery independently of robotic access. Right atrial access, caval control, and risks related to the conduction system should be considered in operative planning.

Resection of cardiac myxomas and fibroelastomas is also among the applications of robotic surgery. Rosen et al. (2022) reported tumor excision in 18 patients using small ports and peripheral cannulation. The anatomical location of the lesion, removal without fragmentation, and the need for septal or valve reconstruction are important when choosing the access route. Because these findings are based on a limited series, robotic resection cannot be described as the standard approach for all cardiac tumors.

Robotic experience with combined aortic and mitral valve surgery is more limited. In the mixed series of 67 patients reported by Wei et al. (2025), only eight operations were robotic; the remaining procedures were endoscopic. This distinction demonstrates why attributing the outcomes of the entire cohort to robotic surgery is inappropriate. Wider adoption of complex multivalve procedures requires larger robotic cohorts with separately reported outcomes.

6 Assessment of Clinical Evidence

Most evidence on robotic cardiac surgery comes from single-center series, registry studies, and their meta-analyses. Anatomical suitability, comorbidity burden, and surgeon experience may differ in robotic groups. Propensity score matching reduces measured differences but does not eliminate unmeasured confounding. Favorable observational outcomes should therefore not be presented as evidence of causal superiority in all patients (Eranksi et al., 2026; Mori et al., 2024).

Evidence concerning nonrobotic minimally invasive surgery also requires separate interpretation. In a randomized trial comparing minithoracotomy with sternotomy, Akowuah et al. (2023) did not demonstrate superiority of minithoracotomy in improvement of physical function at 12 weeks. Both groups achieved high repair rates and similar safety outcomes at one year. This trial contributes to the assessment of minimally invasive access but is not a direct study of robotic surgery.

Comparisons should include disease-specific long-term outcomes in addition to early mortality, stroke, reoperation, and length of stay. Relevant outcomes include recurrent regurgitation after mitral repair, prosthesis-related events after replacement, graft patency and repeat revascularization after coronary surgery, and residual shunt and right heart remodeling after ASD repair. Standard definitions and consistent follow-up are necessary for comparisons across centers (Hwang et al., 2024; Kadirogullari et al., 2020; Roach et al., 2022).

7 Learning Curve and Program Development

The learning process in robotic cardiac surgery encompasses port placement, cannulation, exposure, team communication, and emergency management as well as console skills. Training may combine simulation, observation at experienced centers, structured mentorship, and staged clinical implementation. The 2026 STS consensus document describes a four-phase training approach extending from program initiation to advanced proficiency (Badhwar et al., 2026).

Sandoval et al. (2024) evaluated the first 62 robotic mitral repairs at each of two centers. Shorter initial operative times at the center with previous minithoracotomy experience suggest that existing minimally invasive experience can influence the learning process. However, a comparison of two centers does

not establish a single learning threshold for all surgeons. Operative efficiency and clinical safety may develop at different rates.

Methods such as cumulative sum analysis may be used to monitor the learning curve. Metrics should not be limited to bypass or cross-clamp times but should also include residual lesions, conversion, re-exploration for bleeding, and major complications. Completion of a specified number of cases alone does not establish proficiency. Findings should be interpreted alongside changes in patient complexity and continuity of the team (Badhwar et al., 2026; Sandoval et al., 2024).

Selecting patients with favorable anatomy and more predictable operations initially facilitates establishment of the team workflow. Case complexity should increase only when outcomes and team preparedness support expansion. Because arterial harvesting and endoscopic anastomosis require different skills in coronary surgery, training stages should be structured accordingly. Regular case conferences and reviews of complications contribute to program continuity (Jonsson & Halkos, 2024).

8 Cost and Sustainability

The costs of robotic programs include equipment, maintenance, consumables, operating room time, and training. Conversely, changes in length of stay and postoperative care requirements may influence total costs. Economic assessment should therefore not be based solely on the purchase price of the device or a single consumable item (Hadaya et al., 2025).

Using United States national data, Hadaya et al. (2025) reported that the robotic approach to elective mitral repair was generally associated with higher hospital costs, while the risk-adjusted cost difference was attenuated in high-volume programs. These findings cannot be directly transferred to reimbursement and procurement conditions in Türkiye. Local assessment should jointly examine actual surgical volume, consumable expenditure, bed utilization, and training needs. Sustainability depends on maintaining the team and regularly monitoring outcomes as well as ensuring an adequate flow of patients.

9 Current Developments and Future Perspectives

Many recent developments concern the maturation of patient selection, training processes, and quality monitoring rather than the introduction of a new device. Large database analyses provide information on comparative safety, while recent consensus documents support a more structured approach to program development. Treatment of more complex lesions in mitral surgery and use of multiple arterial grafts in coronary surgery demonstrate expansion of applications at experienced centers (Badhwar et al., 2026; Mori et al., 2024; Nisivaco et al., 2024).

Stronger integration of imaging data into surgical planning, improved simulation opportunities, and objective measurement of training performance are areas for future investigation. Digital methods such as process analysis and decision support based on video data should not be regarded as components of routine practice before their safety and clinical benefit have been validated. Progress in robotic cardiac surgery will depend on multicenter research and consistent long-term follow-up alongside technological innovation (Badhwar et al., 2026; Xue et al., 2022).

Future studies should assess quality of life, functional recovery, repeat intervention, and cost using standardized measures, in addition to outcomes such as short hospital stays or small incisions. Important research questions include which patients derive the greatest value from the robotic approach and whether comparable outcomes can be achieved at low-volume centers. Answers to these questions will help establish patient-centered and sustainable programs (Akowuah et al., 2023; Hadaya et al., 2025).

10 Conclusion

Robotic cardiac surgery offers an effective minimally invasive option for mitral valve surgery, coronary revascularization, and ASD repair in suitable patients. Tricuspid interventions and cardiac tumor resection are also among its selected applications. Successful outcomes require an appropriate indication, detailed anatomical assessment, an experienced team, adequate myocardial protection, and readiness to extend surgical access when necessary. Current evidence supports safety and feasibility but is insufficient to justify a claim of general superiority over other approaches. The fundamental criterion for the robotic approach is its ability to provide clinical benefit while preserving the effectiveness and durability of conventional surgery.

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