Coronary Endarterectomy for Diffuse Coronary Artery Disease: From a Controversial Procedure to a Strategy for Complete Surgical Revascularization

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Received: 28 October 2024, **Accepted:** 17 November 2024, **Published:** 20 November 2024

Abstract

Background: Diffuse coronary artery disease (CAD) remains one of the greatest challenges in surgical coronary revascularization because severe, long-segment atherosclerotic involvement frequently precludes conventional distal bypass grafting and limits the achievement of complete myocardial revascularization. Coronary endarterectomy (CE), originally introduced before the widespread adoption of coronary artery bypass grafting (CABG), was historically associated with increased perioperative morbidity and mortality, leading to decades of controversy regarding its routine use. However, advances in myocardial protection, surgical techniques, conduit selection, perioperative care, and postoperative antithrombotic strategies have substantially improved clinical outcomes. Consequently, CE has re-emerged as an important adjunctive procedure in selected patients with diffuse coronary artery disease, particularly when conventional bypass grafting alone cannot provide adequate revascularization.

Aim: This review aims to summarize the contemporary evidence regarding coronary endarterectomy performed in conjunction with CABG, with particular emphasis on its historical evolution, indications, patient selection, operative techniques, perioperative management, postoperative antithrombotic therapy, and short- and long-term clinical outcomes. Furthermore, the review critically examines current controversies surrounding the procedure, including target vessel selection, open versus closed endarterectomy, on-pump versus off-pump approaches, graft patency, and postoperative complications, while highlighting recent advances that have improved procedural safety and effectiveness.

Conclusion: Coronary endarterectomy has evolved from a procedure considered a last resort into a valuable surgical strategy for achieving complete myocardial revascularization in carefully selected patients with diffuse coronary artery disease. Contemporary evidence demonstrates that, when performed by experienced surgeons using meticulous surgical techniques and appropriate postoperative antithrombotic therapy, CE can provide acceptable perioperative mortality, satisfactory graft patency, durable symptomatic relief, and favorable long-term survival. Although early postoperative complications remain more frequent than with conventional CABG alone, these risks appear to be influenced largely by the complexity of the underlying coronary pathology and patient comorbidities rather than by the endarterectomy procedure itself. Nevertheless, important knowledge gaps remain regarding optimal patient selection, standardized surgical techniques, conduit choice, and postoperative antithrombotic regimens. Future prospective multicenter studies and randomized clinical trials are needed to establish evidence-based recommendations and further define the role of coronary endarterectomy within contemporary coronary surgery.

Keywords: Coronary endarterectomy; Coronary artery bypass grafting; Diffuse coronary artery disease; Complete myocardial revascularization.

Introduction

Coronary artery disease (CAD) remains the leading cause of cardiovascular morbidity and mortality worldwide despite substantial advances in preventive strategies, pharmacological therapy, percutaneous coronary intervention (PCI), and coronary artery bypass grafting (CABG). Although conventional CABG achieves excellent long-term outcomes in patients with focal coronary stenoses, an increasing proportion of patients referred for surgical revascularization present with diffuse, heavily calcified, or previously stented coronary arteries that are unsuitable for standard distal graft anastomosis. This changing clinical profile reflects the aging population, increasing prevalence of diabetes mellitus and chronic kidney disease, widespread use of PCI, and prolonged survival of patients with advanced coronary atherosclerosis. Consequently, achieving complete myocardial revascularization has become progressively more challenging in contemporary cardiac surgery. **[1]**

Complete surgical revascularization is consistently associated with improved long-term survival, better preservation of ventricular function, reduced recurrent angina, lower rates of repeat revascularization, and fewer major adverse cardiovascular events. However, diffuse coronary artery disease frequently involves long arterial segments with circumferential atherosclerotic plaque, severe calcification, small distal vessels, and extensive involvement of septal and diagonal branches, making conventional bypass grafting technically inadequate. In these situations, bypass grafts placed onto diseased distal vessels may provide suboptimal runoff, while incomplete revascularization leaves significant ischemic myocardium untreated, thereby adversely affecting both early and late clinical outcomes. **[2]**

Coronary endarterectomy (CE) represents one of the oldest surgical techniques developed for the management of advanced coronary artery disease. First introduced by Bailey in the 1950s before the development of modern CABG, CE was initially performed as an isolated procedure to restore coronary blood flow through removal of obstructive atherosclerotic plaques. Following the introduction of CABG in the late 1960s, however, CE rapidly lost popularity because early clinical experience demonstrated relatively high rates of perioperative myocardial infarction, graft thrombosis, and operative mortality. For several decades, the procedure was therefore reserved only for highly selected patients in whom conventional coronary bypass grafting was technically impossible. **[3]**

During the past two decades, the role of coronary endarterectomy has undergone significant re-evaluation. Improvements in myocardial protection, cardiopulmonary bypass techniques, coronary reconstruction, arterial conduit selection, intraoperative imaging, postoperative intensive care, and dual antiplatelet therapy have substantially improved both early and long-term outcomes. Simultaneously, the increasing incidence of diffuse coronary atherosclerosis, recurrent in-stent restenosis, and "full-metal-jacket" coronary arteries has created a growing population of patients in whom conventional CABG alone cannot achieve satisfactory myocardial revascularization. As a result, coronary endarterectomy has re-emerged as an important adjunctive surgical strategy aimed at restoring distal coronary flow while facilitating complete myocardial revascularization. **[4]**

Modern coronary endarterectomy is no longer viewed simply as a rescue procedure but rather as a technically demanding reconstructive operation performed selectively by experienced surgeons. Several operative variations have been described, including open and closed endarterectomy techniques, on-pump and off-pump procedures, and multiple methods of coronary reconstruction using internal thoracic artery or saphenous vein grafts. Although favorable outcomes have been reported by specialized centers, important controversies remain regarding the optimal operative technique, target vessel selection, postoperative anticoagulation strategy, and long-term graft patency. Moreover, the absence of standardized international guidelines reflects the limited availability of prospective comparative studies and randomized clinical trials evaluating CE. **[5]**

This review aims to provide a comprehensive overview of coronary endarterectomy as an adjunct to coronary artery bypass grafting for diffuse coronary artery disease. The review discusses the historical evolution of the procedure, indications and patient selection, operative techniques, perioperative management, postoperative antithrombotic therapy, and contemporary clinical outcomes. In addition, current controversies, technical considerations, and future research directions are examined to clarify the evolving role of coronary endarterectomy in achieving complete surgical myocardial revascularization in the modern era.

Aim of the Review

This review aims to critically evaluate the contemporary role of coronary endarterectomy in patients with diffuse coronary artery disease undergoing coronary artery bypass grafting, focusing on surgical indications, operative techniques, perioperative management, clinical outcomes, and current evidence supporting its use for achieving complete myocardial revascularization.

Research Gap

Despite encouraging improvements in surgical outcomes, there remains no universal consensus regarding patient selection, the optimal endarterectomy technique, conduit selection, postoperative antithrombotic regimen, or standardized perioperative management. Furthermore, most available evidence originates from retrospective single-center studies with considerable heterogeneity, while high-quality randomized trials and evidence-based international guidelines remain limited, highlighting the need for further prospective multicenter research to define the optimal role of coronary endarterectomy in contemporary coronary surgery.

Historical Evolution of Coronary Endarterectomy

Coronary endarterectomy (CE) predates modern coronary artery bypass grafting (CABG) and represents one of the earliest surgical attempts to directly treat obstructive coronary artery disease. In 1957, Bailey and colleagues reported the first successful human coronary endarterectomy, describing the surgical removal of obstructive atherosclerotic plaque from the coronary artery to restore antegrade blood flow. At that time, treatment options for advanced coronary artery disease were extremely limited, and CE was viewed as a promising alternative for patients with disabling angina who were unsuitable for medical therapy. Although technically innovative, the procedure was associated with considerable perioperative risk due to limited myocardial protection, inadequate visualization, and the absence of reliable methods for maintaining long-term coronary patency. Consequently, widespread adoption was restricted despite encouraging early reports. **[6]**

The introduction of coronary artery bypass grafting by Favaloro in the late 1960s fundamentally transformed the surgical management of ischemic heart disease. Bypass grafting provided a technically simpler and more reproducible method of restoring myocardial perfusion without directly manipulating diseased coronary arteries. As CABG rapidly became the standard surgical treatment for multivessel coronary disease, enthusiasm for isolated coronary endarterectomy declined substantially. Early experiences combining CE with CABG were often associated with increased rates of perioperative myocardial infarction, ventricular dysfunction, graft thrombosis, and operative mortality, reinforcing the perception that endarterectomy should be reserved only as a salvage procedure when conventional bypass grafting was impossible. **[7]**

Throughout the 1970s and 1980s, improvements in cardiopulmonary bypass, myocardial preservation, and perioperative anesthesia enhanced the safety of coronary surgery; however, CE continued to carry a reputation as a high-risk intervention. Most surgeons preferred to avoid endarterectomy whenever possible because disruption of the native coronary endothelium exposed the thrombogenic medial layer, increasing the likelihood of acute thrombosis and early graft failure. In addition, considerable variability existed in operative techniques, including differences in plaque extraction, arteriotomy length, coronary reconstruction, and postoperative anticoagulation, leading to inconsistent clinical outcomes among institutions. During this period, CE remained confined primarily to patients with extensive diffuse coronary disease in whom no suitable distal target vessel could be identified for conventional bypass grafting. **[8]**

Renewed interest in coronary endarterectomy emerged during the late 1990s and early 2000s as the clinical profile of patients referred for CABG began to change. Increasing life expectancy, the global epidemic of diabetes mellitus, chronic kidney disease, diffuse calcific atherosclerosis, and the widespread use of percutaneous coronary intervention (PCI) resulted in a growing number of patients presenting with long-segment coronary occlusions, in-stent restenosis, and heavily diseased distal vessels. In these complex anatomical settings, conventional CABG alone frequently failed to achieve complete myocardial revascularization, prompting surgeons to reconsider CE as an adjunctive strategy capable of restoring adequate distal coronary runoff. **[9]**

The evolution of modern CE has been driven by substantial advances in operative techniques and perioperative management. Contemporary surgeons increasingly favor open endarterectomy with direct visualization of plaque removal when extensive disease is present, allowing more complete extraction of the atherosclerotic core and improved preservation of side branches. Enhanced myocardial protection strategies, routine use of arterial conduits—particularly the left internal thoracic artery for left anterior descending artery reconstruction—and meticulous coronary reconstruction have further contributed to improved graft patency and reduced perioperative complications. In parallel, dual antiplatelet therapy and selective anticoagulation protocols have significantly decreased the incidence of early thrombotic occlusion following endarterectomy. **[10]**

Evidence accumulated over the past two decades has challenged the historical perception of CE as an excessively hazardous procedure. Multiple observational studies, propensity-matched analyses, and systematic reviews have demonstrated that, although perioperative morbidity remains higher than with conventional CABG alone, carefully selected patients undergoing CE can achieve acceptable operative mortality, durable symptom relief, satisfactory graft patency, and long-term survival comparable to patients undergoing isolated CABG after adjustment for baseline disease complexity. These findings suggest that adverse outcomes are influenced not only by the procedure itself but also by the advanced coronary pathology and extensive comorbidities characteristic of patients requiring endarterectomy. **[11]**

Today, coronary endarterectomy is increasingly recognized as an important component of the surgical armamentarium for managing diffuse coronary artery disease rather than merely a procedure of last resort. High-volume centers with expertise in complex coronary reconstruction have reported reproducible outcomes, supporting its selective use when complete myocardial revascularization cannot otherwise be achieved. Nevertheless, significant heterogeneity persists regarding operative techniques, target vessel selection, conduit choice, and postoperative antithrombotic therapy, underscoring the continued need for standardized protocols and prospective multicenter studies. The historical evolution of CE therefore reflects a transition from an experimental operation associated with prohibitive risk to a refined adjunctive technique that has regained clinical relevance in the era of increasingly complex coronary artery disease. **[12]**

Pathophysiology of Diffuse Coronary Artery Disease and the Rationale for Coronary Endarterectomy

Diffuse coronary artery disease (CAD) represents the advanced stage of the atherosclerotic process, characterized by continuous plaque involvement extending over long segments of the coronary artery rather than isolated focal stenoses. Progressive endothelial dysfunction, chronic inflammation, lipid accumulation, smooth muscle cell proliferation, and vascular remodeling gradually lead to circumferential plaque formation, luminal narrowing, calcification, and fibrosis. Unlike focal lesions that can be effectively bypassed distal to the obstruction, diffuse disease frequently involves the entire length of the vessel, including distal segments and major side branches, thereby limiting suitable sites for conventional graft anastomosis. **[13]**

The pathogenesis of diffuse CAD is closely associated with multiple cardiovascular risk factors, including advanced age, diabetes mellitus, hypertension, dyslipidemia, chronic kidney disease, smoking, and systemic inflammatory disorders. Diabetes mellitus, in particular, accelerates diffuse atherosclerosis through persistent endothelial injury, oxidative stress, microvascular dysfunction, and enhanced inflammatory signaling. Consequently, diabetic patients often present with extensive multivessel disease characterized by small-caliber arteries, heavy calcification, and poor distal runoff, making complete surgical revascularization technically demanding. **[14]**

In addition to traditional risk factors, the widespread use of percutaneous coronary intervention (PCI) has altered the anatomical complexity of patients referred for CABG. Multiple previous stent implantations, diffuse in-stent restenosis, chronic total occlusions, and long metallic stent segments may extend throughout the target vessel, leaving little or no disease-free coronary segment suitable for distal bypass grafting. These "full-metal-jacket" arteries represent one of the increasingly recognized indications in which coronary endarterectomy may facilitate reconstruction of an otherwise ungraftable vessel and restore myocardial perfusion. **[15]**

Diffuse coronary involvement has important physiological consequences beyond simple luminal obstruction. Long-segment plaque reduces coronary flow reserve, impairs vasomotor function, and compromises collateral circulation, resulting in chronic myocardial ischemia even in the absence of complete vessel occlusion. Furthermore, extensive disease often affects side branches such as septal perforators and diagonal branches in the left anterior descending artery or marginal branches in the circumflex territory. Conventional distal grafting beyond a localized stenosis may therefore fail to adequately perfuse these important branches, contributing to persistent ischemia despite technically successful bypass surgery. **[16]**

Complete myocardial revascularization remains one of the strongest determinants of favorable long-term outcomes after CABG. Numerous clinical studies have demonstrated that incomplete revascularization is associated with higher rates of recurrent angina, repeat revascularization, heart failure, myocardial infarction, and late mortality. Unfortunately, diffuse coronary disease is among the leading causes of incomplete surgical revascularization because severely diseased distal vessels often provide poor runoff for bypass grafts. Consequently, surgeons are frequently confronted with the difficult balance between accepting incomplete revascularization or performing more complex reconstructive procedures such as coronary endarterectomy. **[17]**

The principal rationale for coronary endarterectomy is the restoration of an adequate vascular lumen by removing the obstructive atherosclerotic core together with the diseased intima. This process creates a reconstructed arterial channel that permits satisfactory distal blood flow and allows placement of a bypass graft onto a vessel that would otherwise be unsuitable for conventional anastomosis. Unlike isolated bypass grafting to a severely diseased artery, CE aims to improve distal runoff, enhance graft inflow, and restore perfusion to side branches incorporated within the endarterectomized segment, thereby increasing the likelihood of complete myocardial revascularization. **[18]**

Despite these advantages, endarterectomy also introduces important biological challenges. Removal of the endothelial lining exposes the thrombogenic medial surface of the artery, triggering platelet activation, coagulation cascade initiation, and inflammatory responses that increase the risk of early graft thrombosis. In addition, disruption of the vasa vasorum and local vascular architecture may contribute to intimal hyperplasia during the healing process. These pathophysiological mechanisms explain the historical association between CE and increased perioperative myocardial infarction and emphasize the importance of meticulous surgical technique combined with aggressive postoperative antithrombotic therapy to maintain graft patency. **[19]**

The balance between the risks and benefits of coronary endarterectomy therefore depends on careful patient selection and an understanding of coronary pathophysiology. In patients with localized coronary stenoses, conventional CABG remains the preferred strategy because it preserves the native arterial wall and minimizes thrombotic risk. Conversely, in patients with diffuse calcific disease, long-segment occlusions, or extensive in-stent restenosis where adequate distal targets are absent, CE provides a means of converting an ungraftable artery into a reconstructable vessel. In these carefully selected cases, the procedure facilitates complete myocardial revascularization, which is increasingly recognized as a key determinant of improved long-term survival and freedom from recurrent ischemic events. **[20]**

Patient Selection and Indications for Coronary Endarterectomy

Appropriate patient selection is the cornerstone of successful coronary endarterectomy (CE). Unlike conventional coronary artery bypass grafting (CABG), which is suitable for most patients with focal obstructive coronary lesions, CE is reserved for individuals with diffuse, advanced coronary atherosclerosis in whom satisfactory distal graft anastomosis cannot be achieved using standard surgical techniques alone. The primary objective is not simply plaque removal but the achievement of complete myocardial revascularization when conventional bypass grafting would otherwise result in incomplete treatment of ischemic myocardium. Consequently, the decision to perform CE is usually made intraoperatively after careful assessment of coronary anatomy and distal vessel quality. **[21]**

The most common indication for CE is diffuse coronary artery disease characterized by long-segment atherosclerotic involvement extending beyond the anticipated site of distal graft implantation. In these patients, severe luminal narrowing, circumferential calcification, or complete obliteration of the distal vessel prevents construction of a technically satisfactory bypass anastomosis. Rather than grafting onto a poorly functioning distal target with limited runoff, endarterectomy allows removal of the obstructive plaque and restoration of an adequate vascular lumen capable of supporting effective graft perfusion. **[22]**

Patients with diabetes mellitus frequently constitute an important subgroup requiring CE because diabetes accelerates diffuse atherosclerosis, medial calcification, endothelial dysfunction, and small-vessel disease. These pathological changes often involve multiple coronary territories simultaneously, producing long segments of heavily diseased arteries with poor distal runoff. In such patients, conventional CABG alone may fail to provide complete revascularization, whereas adjunctive CE can improve graftability and potentially enhance long-term myocardial perfusion. Nevertheless, diabetic patients remain at increased risk for perioperative complications, emphasizing the need for meticulous surgical planning and postoperative management. **[23]**

Another increasingly recognized indication is the presence of diffuse in-stent restenosis or multiple previously implanted coronary stents. Advances in percutaneous coronary intervention (PCI) have allowed repeated treatment of complex coronary lesions; however, extensive metallic stent implantation may ultimately leave no disease-free segment suitable for distal bypass grafting. These so-called "full-metal-jacket" arteries present significant technical challenges during CABG. In carefully selected cases, coronary endarterectomy permits removal of the diseased intima together with embedded stent material, thereby creating a reconstructable vessel that can subsequently be bypassed effectively. **[24]**

Coronary endarterectomy may also be considered in patients with chronic total coronary occlusions involving long arterial segments, particularly when distal vessel visualization suggests the presence of viable myocardium supplied by the affected artery. Chronic occlusions are frequently associated with dense fibrosis and organized thrombus extending into distal branches, making conventional grafting technically difficult and reducing the likelihood of adequate distal runoff. Endarterectomy can restore luminal continuity, improve graft inflow, and facilitate revascularization of distal myocardial territories that would otherwise remain ischemic. **[25]**

Selection of the target vessel is another important consideration. The right coronary artery has historically been the most frequently endarterectomized vessel because of its relatively superficial course, larger caliber, and fewer critical side branches. However, increasing surgical experience has demonstrated favorable outcomes following endarterectomy of the left anterior descending (LAD) artery when performed using meticulous open techniques and reconstruction with the left internal thoracic artery. Endarterectomy of the circumflex artery is generally considered technically more demanding because of its deep anatomical location, variable branching pattern, and limited surgical exposure, although successful results have been reported in experienced centers. **[26]**

Despite its expanding role, CE is not indicated for every patient with severe coronary artery disease. Focal stenotic lesions with suitable distal targets remain best managed by conventional CABG, which preserves the native endothelium and minimizes thrombotic risk. Similarly, coronary arteries with extensive distal fibrosis, extremely small vessel diameter, poor myocardial viability, or limited distal runoff may derive little benefit from endarterectomy because successful plaque removal alone cannot overcome irreversible microvascular disease or nonviable myocardium. Preoperative assessment of myocardial viability, ventricular function, and coronary anatomy therefore plays a crucial role in determining whether complete revascularization is likely to translate into meaningful clinical benefit. **[27]**

Successful patient selection ultimately requires integration of anatomical complexity, myocardial viability, clinical risk profile, and surgical expertise. Factors such as advanced age, reduced left ventricular function, chronic kidney disease, peripheral vascular disease, and severe comorbidities should be considered alongside coronary anatomy when evaluating operative risk. Importantly, contemporary evidence suggests that adverse outcomes following CE often reflect the severity of underlying coronary disease rather than the procedure itself. Therefore, when performed by experienced surgeons in appropriately selected patients, coronary endarterectomy serves as a valuable adjunct to CABG, enabling complete myocardial revascularization in clinical scenarios where conventional bypass surgery alone would be inadequate. **[28]**

Surgical Techniques of Coronary Endarterectomy

The success of coronary endarterectomy (CE) depends largely on meticulous surgical technique, careful handling of the diseased coronary artery, and preservation of distal coronary integrity. Unlike conventional coronary artery bypass grafting (CABG), CE involves direct removal of the atherosclerotic core from within the arterial lumen before revascularization, making it one of the most technically demanding procedures in coronary surgery. The choice of operative technique is influenced by the extent of atherosclerotic involvement, target vessel anatomy, surgeon experience, and the planned method of coronary reconstruction. Although several technical modifications have been described, the fundamental objective remains complete plaque extraction while minimizing endothelial injury and preserving distal side branches. **[29]**

Coronary endarterectomy may be performed using either an open or a closed technique. In the closed technique, a relatively short arteriotomy is created, and the atherosclerotic plaque is gently extracted through controlled traction. This approach is technically simpler and requires a shorter arteriotomy; however, visualization of the distal endpoint is limited, increasing the risk of incomplete plaque removal, intimal flap formation, disruption of side branches, or residual obstructive disease. Consequently, the closed technique is generally considered most appropriate for localized disease with a well-defined plaque that can be removed intact without excessive traction. **[30]**

The open technique has become the preferred approach in many specialized centers because it provides direct visualization of the entire endarterectomized segment. After creating a longitudinal arteriotomy extending beyond the diseased portion of the artery, the atherosclerotic core is carefully dissected away from the adventitial layer under direct vision. This allows controlled division of proximal and distal plaque, identification of side branches, and confirmation of complete plaque extraction without leaving residual intimal flaps. Although technically more demanding and time-consuming, the open technique has been associated with improved graft patency, lower rates of residual obstruction, and more reliable coronary reconstruction, particularly in patients with diffuse left anterior descending artery disease. **[31]**

A critical technical principle during plaque extraction is maintaining the integrity of the atherosclerotic cylinder. Gentle, continuous traction combined with careful circumferential dissection facilitates removal of the plaque as a single specimen while reducing fragmentation and minimizing injury to the distal coronary artery. Excessive traction should be avoided because it may avulse side branches, disrupt distal intima, or create long intimal dissections that predispose to thrombosis and graft failure. Following plaque removal, the distal endpoint should be carefully inspected to ensure a smooth transition between the reconstructed lumen and the native vessel without residual loose intimal tissue. **[32]**

Coronary reconstruction following endarterectomy is equally important to the success of the procedure. In the right coronary artery, direct bypass grafting using a saphenous vein graft is commonly performed after satisfactory plaque removal. In contrast, reconstruction of the left anterior descending (LAD) artery frequently involves long-segment arteriotomy closure using the left internal thoracic artery (LITA) as an onlay patch. This technique not only restores arterial continuity but also provides the superior long-term patency associated with arterial grafting. Alternative methods include patch angioplasty using autologous saphenous vein or other arterial conduits when extensive coronary reconstruction is required. **[33]**

Coronary endarterectomy can be performed during either on-pump or off-pump CABG. Most surgeons continue to favor the on-pump approach because cardioplegic arrest provides a bloodless operative field, facilitates precise plaque extraction, and allows complex coronary reconstruction without hemodynamic instability. Nevertheless, experienced centers have demonstrated that off-pump CE is feasible in carefully selected patients, particularly when endarterectomy is limited to the right coronary artery. Potential advantages of the off-pump approach include avoidance of cardiopulmonary bypass-related inflammatory responses and reduced perioperative morbidity in selected high-risk patients, although current evidence has not established clear superiority of either strategy. **[34]**

Several intraoperative technical considerations contribute significantly to procedural success. Adequate myocardial protection, gentle tissue handling, magnified visualization, and meticulous hemostasis are essential throughout the operation. Before completing the reconstruction, the surgeon should confirm satisfactory distal runoff, unrestricted graft inflow, and absence of residual plaque or intimal dissection. Some centers employ intraoperative transit-time flow measurement or fluorescence angiography to assess graft function immediately after reconstruction, enabling prompt correction of technical deficiencies before chest closure. These adjunctive assessments may improve early graft performance and reduce postoperative ischemic complications. **[35]**

Despite ongoing refinements in operative technique, no universal standard currently exists regarding the optimal method of coronary endarterectomy. Variations persist among institutions concerning arteriotomy length, plaque extraction strategy, reconstruction technique, conduit selection, and intraoperative assessment. Nevertheless, contemporary evidence consistently suggests that successful outcomes depend more on meticulous surgical execution and appropriate patient selection than on any single technical modification. As surgical expertise continues to evolve, standardization of operative techniques through prospective multicenter studies may further improve procedural safety, graft durability, and long-term clinical outcomes. **[36]**

Postoperative Antithrombotic Therapy and Perioperative Management

Successful coronary endarterectomy (CE) extends beyond technical completion of the operation, as postoperative management plays a critical role in maintaining graft patency and preventing thrombotic complications. Unlike conventional coronary artery bypass grafting (CABG), CE involves deliberate removal of the native endothelial layer, exposing the highly thrombogenic medial surface of the coronary artery. This endothelial disruption initiates platelet activation, thrombin generation, and inflammatory cascades that increase the risk of acute graft thrombosis during the early postoperative period. Consequently, meticulous perioperative management and appropriate antithrombotic therapy are considered essential components of successful CE. **[37]**

The optimal postoperative antithrombotic regimen remains one of the most debated aspects of coronary endarterectomy. Considerable variability exists among institutions regarding the use of anticoagulants, antiplatelet agents, treatment duration, and timing of therapy initiation. Despite the absence of universally accepted guidelines, contemporary practice generally favors early initiation of antiplatelet therapy combined with selective anticoagulation in patients considered at high thrombotic risk. Most published series have reported improved graft patency with aggressive postoperative antithrombotic strategies, although high-quality randomized evidence remains limited. **[38]**

Aspirin remains the cornerstone of postoperative medical therapy following CE. Early administration, typically within the first postoperative hours after satisfactory hemostasis has been achieved, inhibits platelet aggregation through irreversible cyclooxygenase-1 inhibition and reduces the incidence of early graft occlusion. Numerous CABG studies have demonstrated improved vein graft patency with early aspirin therapy, and these benefits are believed to be even more important after endarterectomy because of the extensive endothelial injury created during plaque extraction. Consequently, lifelong aspirin therapy is recommended by most centers unless contraindications exist. **[39]**

Dual antiplatelet therapy (DAPT), consisting of aspirin combined with a P2Y12 receptor inhibitor such as clopidogrel or ticagrelor, has gained increasing acceptance following CE. The rationale for DAPT is based on enhanced inhibition of platelet activation during the period of endothelial healing, thereby reducing the risk of acute thrombosis within the reconstructed coronary artery. Several observational studies have suggested improved graft patency and lower rates of adverse cardiac events with DAPT compared with aspirin alone, particularly after extensive endarterectomy involving the left anterior descending artery. However, treatment duration varies widely among institutions, ranging from several months to one year, reflecting the limited availability of prospective comparative data. **[40]**

Some centers continue to incorporate systemic anticoagulation into their postoperative protocols, particularly after extensive open endarterectomy or reconstruction of multiple coronary territories. Warfarin has historically been used in combination with aspirin for approximately three months until endothelialization of the reconstructed vessel is presumed to occur. More recently, increasing experience with direct oral anticoagulants has been reported in selected patients, although evidence supporting their routine use after CE remains insufficient. Importantly, the potential benefits of anticoagulation must always be balanced against the increased risk of postoperative bleeding, pericardial effusion, and re-exploration for hemorrhage. **[41]**

Comprehensive perioperative management extends beyond antithrombotic therapy and includes optimization of myocardial protection, hemodynamic stability, rhythm surveillance, and secondary prevention measures. Careful blood pressure control is essential to maintain adequate graft flow while minimizing bleeding risk. Continuous electrocardiographic monitoring and serial assessment of cardiac biomarkers facilitate early detection of perioperative myocardial infarction or graft dysfunction. Echocardiography is frequently employed to evaluate ventricular performance and identify mechanical complications in patients with postoperative hemodynamic instability. **[42]**

Secondary prevention strategies should be implemented immediately after surgery to reduce disease progression and improve long-term outcomes. High-intensity statin therapy, strict glycemic control, aggressive blood pressure management, smoking cessation, weight optimization, cardiac rehabilitation, and lifestyle modification are integral components of postoperative care. These interventions not only reduce recurrent cardiovascular events but may also improve long-term graft durability by limiting progression of native coronary atherosclerosis. In diabetic patients, optimization of metabolic control is particularly important because persistent hyperglycemia has been associated with accelerated vascular inflammation and adverse graft remodeling. **[43]**

Although contemporary perioperative management has substantially improved the safety of coronary endarterectomy, significant uncertainty remains regarding the optimal antithrombotic regimen. Existing recommendations are largely derived from retrospective studies and institutional experience rather than randomized clinical trials. Variability in operative techniques, patient characteristics, and outcome reporting further complicates interpretation of available evidence. Future multicenter prospective studies are needed to establish standardized protocols defining the ideal combination, timing, and duration of antiplatelet and anticoagulant therapy following coronary endarterectomy, thereby optimizing graft patency while minimizing bleeding complications. **[44]**

Early and Long-Term Clinical Outcomes of Coronary Endarterectomy

The clinical outcomes of coronary endarterectomy (CE) have undergone substantial improvement over the past three decades owing to advances in patient selection, surgical techniques, myocardial protection, conduit selection, and postoperative antithrombotic therapy. Historically, CE was associated with higher perioperative mortality and morbidity than conventional coronary artery bypass grafting (CABG), leading many surgeons to reserve the procedure for patients with no alternative means of achieving complete revascularization. However, contemporary evidence indicates that when performed in experienced centers, CE can provide acceptable early outcomes and durable long-term survival in patients with diffuse coronary artery disease who would otherwise remain incompletely revascularized. **[45]**

Early postoperative mortality following CE varies among published studies, reflecting differences in patient characteristics, surgical expertise, operative techniques, and target vessel selection. Modern series generally report operative mortality rates comparable to those observed in other high-risk CABG populations after adjustment for baseline comorbidities and disease complexity. Importantly, patients undergoing CE frequently present with more advanced coronary disease, impaired ventricular function, diabetes mellitus, previous myocardial infarction, and multiple prior coronary interventions than patients undergoing isolated CABG. These factors contribute significantly to perioperative risk and should be considered when interpreting outcome data. **[46]**

Perioperative myocardial infarction remains one of the principal complications following CE because endothelial denudation and extensive coronary manipulation increase susceptibility to acute thrombosis and distal embolization. Nevertheless, improvements in surgical technique, complete plaque extraction under direct visualization, arterial grafting, and aggressive postoperative antithrombotic therapy have significantly reduced its incidence compared with earlier reports. Careful intraoperative assessment of distal runoff and meticulous reconstruction are now recognized as major determinants of successful myocardial preservation and early graft function. **[47]**

Graft patency represents one of the most important indicators of procedural success. Contemporary angiographic studies have demonstrated encouraging patency rates for both arterial and venous grafts following CE, particularly when the left internal thoracic artery (LITA) is used for reconstruction of the left anterior descending (LAD) artery. Open endarterectomy with long-segment arterial reconstruction has consistently shown superior technical results compared with limited plaque extraction in patients with diffuse LAD disease. Favorable graft function contributes to sustained myocardial perfusion, improved ventricular performance, and reduced recurrence of ischemic symptoms during long-term follow-up. **[48]**

Long-term survival after CE has improved considerably and is now reported to be comparable to that of matched patients undergoing isolated CABG in several propensity-adjusted analyses. Achievement of complete myocardial revascularization appears to be the primary determinant of these favorable outcomes. Patients who undergo successful CE often experience significant relief of angina, improved functional capacity, and reduced need for repeat coronary intervention. These findings support the concept that the benefits of complete revascularization may outweigh the additional operative complexity associated with endarterectomy in carefully selected patients. **[49]**

Several studies have examined predictors of adverse outcomes following CE. Advanced age, severely reduced left ventricular ejection fraction, chronic kidney disease, insulin-dependent diabetes mellitus, emergency surgery, prolonged cardiopulmonary bypass time, and multivessel endarterectomy have consistently been associated with increased perioperative morbidity and mortality. Conversely, surgery performed in high-volume centers by experienced surgeons, meticulous plaque extraction, use of arterial conduits, and adherence to structured postoperative antithrombotic protocols are associated with improved early and late clinical outcomes. These observations emphasize that patient factors and institutional expertise are major determinants of procedural success. **[50]**

Quality of life following successful CE is generally favorable. Most patients report marked improvement in exercise tolerance and a substantial reduction in angina severity after recovery from surgery. Freedom from recurrent ischemic symptoms allows many individuals to resume normal daily activities with improved functional status. Furthermore, restoration of complete myocardial perfusion may contribute to better preservation of left ventricular function and reduce the likelihood of future heart failure, particularly in patients with viable but chronically ischemic myocardium. Although long-term surveillance remains essential, the overall clinical trajectory after successful CE is encouraging in appropriately selected patients.

Despite these favorable findings, interpretation of the available evidence should be undertaken with caution. Most published studies are retrospective, single-center investigations with relatively small sample sizes and heterogeneous surgical techniques. Differences in patient selection, target vessels, operative strategies, postoperative medical therapy, and duration of follow-up limit direct comparison between studies. Consequently, although contemporary evidence supports coronary endarterectomy as an effective adjunct to CABG in selected patients with diffuse coronary artery disease, large prospective multicenter studies and randomized clinical trials remain necessary to better define its long-term efficacy, optimize patient selection, and establish standardized outcome measures for future research.

Current Controversies, Future Perspectives, and Research Directions

Despite the growing acceptance of coronary endarterectomy (CE) as an adjunct to coronary artery bypass grafting (CABG), several important controversies continue to limit its widespread adoption. Most available evidence originates from retrospective observational studies, while randomized controlled trials remain scarce. Consequently, considerable variation exists in patient selection, operative techniques, postoperative antithrombotic protocols, and outcome reporting across institutions. This heterogeneity has hindered the development of evidence-based international guidelines and continues to fuel debate regarding the optimal role of CE in contemporary coronary surgery.

One of the most debated issues is the selection of patients who derive the greatest benefit from CE. Although diffuse coronary artery disease is the primary indication, there is no universally accepted definition of an "ungraftable" coronary artery or standardized criteria for deciding when conventional CABG should be supplemented by endarterectomy. Decisions are frequently based on intraoperative judgment, coronary anatomy, and surgeon experience rather than objective preoperative algorithms. The development of validated anatomical scoring systems incorporating coronary calcification, plaque burden, distal vessel quality, and myocardial viability may improve consistency in patient selection and facilitate comparison among future studies.

The optimal surgical technique also remains controversial. Advocates of the open technique argue that direct visualization allows complete plaque removal, preservation of side branches, and more reliable coronary reconstruction, particularly in diffuse left anterior descending (LAD) artery disease. In contrast, proponents of the closed technique emphasize its technical simplicity, shorter operative time, and reduced extent of coronary manipulation in selected patients with localized disease. Although several observational studies suggest improved graft patency with open endarterectomy, definitive superiority has not been established because of the absence of adequately powered prospective comparative trials.

Target vessel selection represents another area of ongoing discussion. Historically, CE has most commonly been performed on the right coronary artery because of its larger diameter and relatively straightforward anatomical course. However, increasing experience with open reconstruction of the LAD using the left internal thoracic artery has produced encouraging long-term results, challenging previous concerns regarding LAD endarterectomy. Conversely, circumflex artery endarterectomy remains technically demanding because of limited surgical exposure and complex branching patterns. Future multicenter analyses comparing outcomes according to target vessel may help refine operative decision-making and identify vessel-specific technical strategies.

Postoperative antithrombotic therapy remains one of the least standardized aspects of CE management. Current practice varies considerably, ranging from aspirin monotherapy to dual antiplatelet therapy combined with temporary oral anticoagulation. The duration of treatment likewise differs among institutions, reflecting the limited evidence available to guide clinical practice. Randomized studies comparing contemporary antithrombotic regimens are needed to determine the optimal balance between prevention of graft thrombosis and avoidance of major bleeding complications, particularly following extensive coronary reconstruction.

Advances in cardiovascular imaging and intraoperative technology are expected to further improve the safety and reproducibility of CE. High-resolution coronary computed tomography angiography, intravascular ultrasound, and optical coherence tomography may enhance preoperative assessment of plaque distribution, vessel wall characteristics, and distal runoff, thereby improving patient selection and operative planning. Intraoperative transit-time flow measurement, fluorescence angiography, and emerging three-dimensional visualization techniques may also facilitate immediate assessment of graft quality and permit prompt correction of technical defects before completion of surgery.

The evolution of hybrid coronary revascularization strategies may further expand the role of CE in selected patients. Collaboration between cardiac surgeons and interventional cardiologists allows individualized treatment combining surgical reconstruction of diffusely diseased vessels with percutaneous intervention for focal lesions in other coronary territories. Such multidisciplinary approaches may maximize complete myocardial revascularization while minimizing operative complexity and procedural risk. Future integration of hybrid techniques with advanced imaging and precision medicine may provide increasingly personalized treatment pathways for patients with complex coronary artery disease.

Future research should prioritize well-designed prospective multicenter registries and randomized clinical trials evaluating standardized operative techniques, conduit selection, target vessel reconstruction, and postoperative medical therapy. Uniform definitions of procedural success, perioperative myocardial infarction, graft patency, and long-term clinical outcomes are essential for meaningful comparison across studies. In addition, investigation of biomarkers of endothelial healing, novel antithrombotic agents, tissue-engineered vascular patches, and artificial intelligence-assisted surgical planning may further optimize outcomes. As the population of patients with diffuse coronary artery disease continues to grow, these research efforts will be critical in establishing coronary endarterectomy as a standardized and evidence-based component of modern coronary surgery.

Conclusion

Coronary endarterectomy has evolved from a controversial and high-risk procedure into a valuable adjunct to coronary artery bypass grafting for carefully selected patients with diffuse coronary artery disease. When conventional bypass grafting cannot achieve adequate distal runoff or complete myocardial revascularization, meticulous endarterectomy, appropriate conduit selection, and structured postoperative antithrombotic therapy can provide acceptable early outcomes and durable clinical benefit. Its success, however, remains highly dependent on surgical expertise, patient selection, and standardized perioperative management. Further prospective multicenter research is needed to refine indications, compare operative techniques, and establish evidence-based antithrombotic protocols.

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