Coronary artery bypass grafting

Aaina Mittal
Kamran Baig
Christopher Young

Abstract

Coronary artery bypass grafting (CABG) is a commonly performed and effective surgical procedure for the treatment of advanced coronary artery disease. It offers superior long-term outcomes in many patient groups compared with percutaneous coronary intervention (PCI). The use of arterial conduits is associated with better long-term graft patency than vein grafts. For elective procedures surgical mortality rates are low (<1%) despite them being used for patients who are older or have more complex disease. Procedure-related morbidities include myocardial dysfunction, bleeding requiring surgical re-exploration, wound infection, acute kidney injury, neurological dysfunction and respiratory complications. In selected patients, off-pump CABG, minimally invasive CABG and hybrid CABG/PCI procedures offer opportunities to reduce complication rates. Surgical risk assessment is supported by use of the EuroSCORE II tool and Society of Thoracic Surgeons risk model.

Keywords Conduits; coronary artery bypass; internal mammary artery; ischaemic heart disease; off-pump; radial artery; revascularization; saphenous vein

Key points

- Coronary artery bypass grafting (CABG) remains the revascularization option of choice for most patients with severe/complex multivessel and left main coronary artery disease
- The EuroSCORE II and Society of Thoracic Surgeons risk tools provide systematic, evidence-based predictions of operative mortality and complications
- Use of internal mammary and radial arteries as conduits for CABG results in better long-term graft patency than vein grafts
- Procedure-related morbidities include myocardial dysfunction, bleeding requiring surgical re-exploration, wound infection, acute kidney injury, neurological dysfunction and respiratory complications
- In selected patients and experienced centres, off-pump CABG, minimally invasive CABG and hybrid CABG/percutaneous coronary intervention procedures can be associated with reduced complication rates

Introduction

Coronary artery disease continues to be one of the leading causes of mortality worldwide. Coronary artery bypass grafting (CABG) is one of the most frequently performed and most effective surgical procedures for the treatment of advanced coronary artery disease. CABG offers superior long-term outcomes in many patient groups compared with percutaneous coronary intervention (PCI).

This chapter outlines the pathophysiology that CABG addresses, risk assessment tools used for preoperative planning, rationale behind the use of various conduits, surgical approaches including the use of minimally invasive approaches and postoperative complications.

Aaina Mittal ***BSc (Hons) MBBS MRCS*** *is a Speciality Registrar in Cardiac Surgery at St. Thomas' Hospital, London, UK. Competing interests: none declared.*

Kamran Baig ***BSc (Hons) MBBS MRCS MD FRCS (C-Th)*** *is a Consultant Cardiac Surgeon at St. Thomas' Hospital, London, UK. Competing interests: none declared.*

Christopher Young ***MBBS MD FRCS*** *is a Consultant Cardiac Surgeon at London Bridge Hospital, UK. Competing interests: none declared.*

Pathophysiology

Atherosclerotic plaques within vessels walls, progressive stenosis and flow limitation or obstruction precede the manifestations of coronary artery disease. Individuals can present with chronic symptoms of ischaemia on exercise, or acutely in the setting of plaque rupture, thrombosis or sudden occlusion from increasing luminal narrowing. PCI and CABG aim to restore blood flow, reperfuse affected territories and prevent future acute events.

PCI, and medical therapy where accessibility is limited, remains the mainstay of treatment in acute settings. CABG within 6 hours of non-transmural infarction and within 3 days of transmural infarction carries a high mortality risk. Emergency CABG is considered where PCI has failed or is unfeasible, in the presence of concurrent valvular disease and with mechanical complications such as ventricular wall rupture.

In chronic settings, the benefits of CABG over medical therapy or PCI are greatest in the highest risk patients (Table 1). The SYNTAX score is a clinical tool used in cardiology to quantify the complexity and severity of coronary artery disease based on coronary angiography findings, helping guide treatment decisions such as stenting or bypass surgery. The SYNTAX score is derived from detailed analysis of coronary angiography images, where the number, location, and complexity of lesions in coronary artery disease are systematically evaluated. It can be derived using online calculator (www.syntaxscore.org).

Indications include proximal left anterior descending (LAD) or left main stem disease, increasing complexity of coronary artery disease (a high SYNTAX score), number of vessels affected, larger territory at risk, left ventricular dysfunction and comorbidities, particularly diabetes.[1]

CABG reduces the need for repeat revascularization compared with PCI. This may be because while PCI acts at the site of a specific lesion, CABG treats the specific lesion identified on

Indications for CABG

	Grade of Recommendation
Left main coronary stenosis	1A
Multivessel coronary disease with diabetes	1A
Multivessel coronary disease without diabetes	1A
Multivessel coronary disease with impaired left ventricular function (EF <35%)	1A
Single or double vessel disease involving proximal LAD	1A

Other indications: mechanical complications of myocardial infarction including post-infarction ventricular septal defect, papillary muscle or ventricular wall rupture.
EF, ejection fraction.
Source: Vrints et al. (2024).[1]

Table 1

current angiography as well as future lesions that might arise, as it provides an alternative route for blood flow, rather than through the already diseased vessel. This is supported by the evidence that long-term PCI outcomes are primarily determined by the progression of coronary artery disease forming new flow-obstructing lesions in the previously treated vessel, rather than re-stenosis of a treated lesion.

Risks assessment

Risk assessment tools are used in cardiac surgery to provide patients and relatives with systematic, evidence-based predictions of operative mortality and complications, and to help with surgical planning, optimization and resource allocation.

EuroSCORE II is a cardiac surgery risk prediction model that estimates operative mortality.[2] It was developed as the initial EuroSCORE tool overestimated mortality in the setting of modern practice in cardiac surgery. It takes into account: patient-related factors such as age, sex and co-morbidities; cardiac-related factors such as the New York Heart Association class, left ventricular function and presence of pulmonary hypertension; and operation-related factors such as urgency, concomitant procedures and reoperations.

EuroSCORE II is the most widely used risk assessment tool internationally.[2] It has a good discriminative accuracy, best for high-risk patients, but can overestimate the mortality risk, especially in younger patients.

The Society of Thoracic Surgeons (STS) risk model is more comprehensive and includes demographic, clinical and procedure-specific factors. The STS score has the advantage of predicting both mortality and major complications, and it is frequently recalibrated using data from the STS Adult Cardiac Surgery Database.

Conduits

The use of the left internal mammary artery (LIMA), particularly its grafting to the LAD, is the gold standard; it is backed by a large body of evidence in increasing survival and event-free survival after CABG.[3] Patency rates for LIMA grafts at 10 years and 15 years are 93% and 88%, respectively.

The right internal mammary artery (RIMA) is not as widely used, despite a patency of 80–90% at 10 years being reported. This is probably because of the lack of definitive evidence on its survival advantage and consensus on its use as the second conduit.

The endothelium of the internal mammary artery (IMA) is particularly resistant to the formation of atherosclerotic plaques, has a lower proliferative response to inflammatory factors, demonstrates a higher production of vasodilators and undergoes remodelling over time to adapt to increased flow.

Pedicled IMA harvesting includes the surrounding soft tissue, providing mechanical protection. Skeletonized harvesting involves dissection free of surrounding tissue, which preserves a greater sternal blood supply, reducing the risk of sternal wound infection.

Saphenous vein grafts (SVGs) are the most commonly used conduit. They are easily available, provide long lengths that can be used for multiple grafts, and have less technically challenging harvesting. They can be harvested via open dissection or stripping, or endoscopically, which is more popular as it reduces the risk of wound infection. SVGs are vulnerable to intimal hyperplasia and progressive atherosclerosis. Although SVGs provide good early outcomes, graft failure occurs at a rate of almost 50% at 10 years.

Radial artery (RA) use is increasing. After confirming viability through an adequate ulnar circulation, it is harvested with an open or endoscopic approach from the patient's non-dominant arm. Vasospasm is prevented with regular use of pharmacological agents such as amlodipine. Patency of RA grafts to suitable targets at 10 years was 89% in the RAPCO trial.[4]

Configurations of these grafts are demonstrated in Figures 1–3.

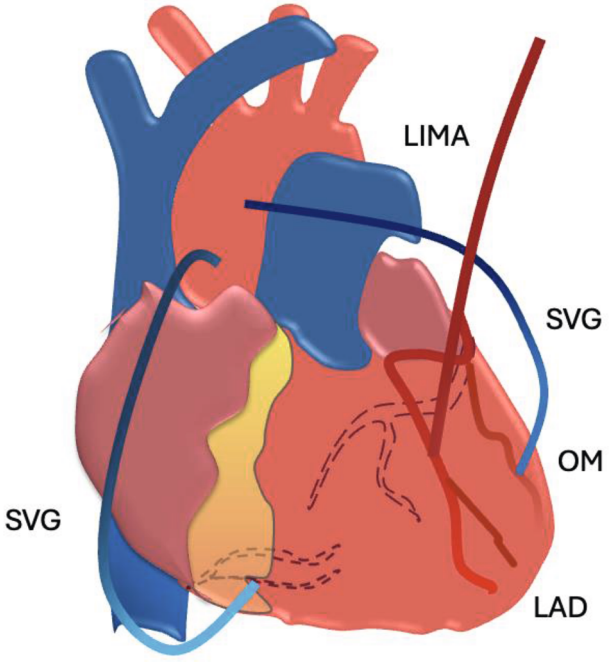

Figure 1 The most conventional CABG configuration in many centres: SVG to PDA, SVG to OM, pedicled LIMA to LAD. OM, obtuse marginal artery; PDA, posterior descending artery. Image courtesy of Dr Prasanthi Sivakumaran.

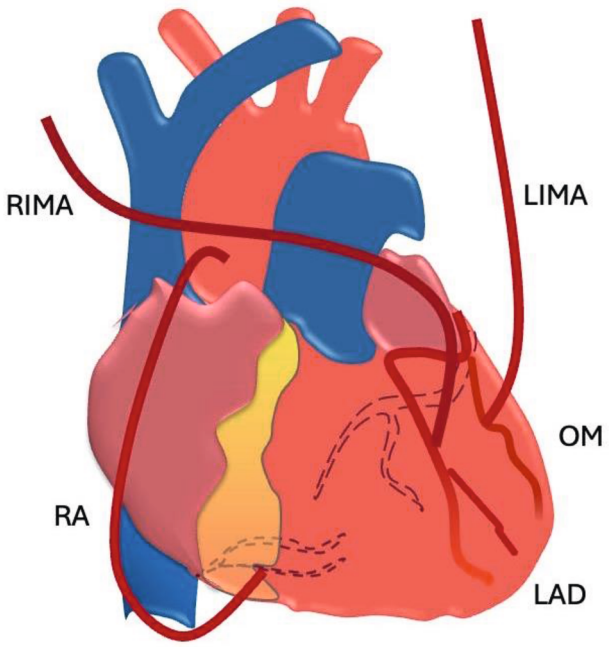

Figure 2 Total arterial grafting. Pedicled RIMA to LAD, pedicled LIMA to OM, RA to PDA. OM, obtuse marginal artery; PDA, posterior descending artery. Image courtesy of Dr Prasanthi Sivakumaran.

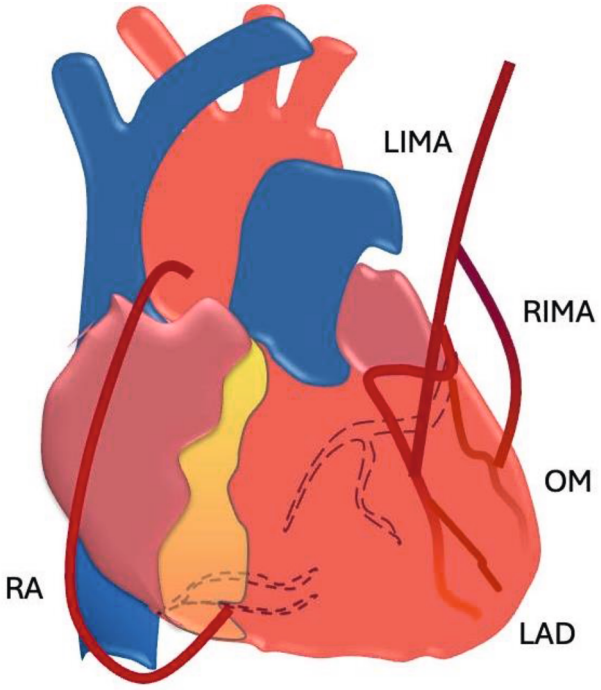

Figure 3 Total arterial grafting with a Y graft. Free RIMA to OM; Y grafted to LIMA, pedicled LIMA to LAD, RA to PDA. OM, obtuse marginal artery; PDA, posterior descending artery. Image courtesy of Dr Prasanthi Sivakumaran.

Conventional approach

A median sternotomy is the most common approach, accounting for 90% of CABG operations. The incision extends in variable lengths from the sternal notch to the xiphisternum. Conduits are harvested, the pericardium is divided and pericardial sutures improve exposure. The ascending aorta is palpated for atherosclerosis or extensive calcification. Heparin is administered for systemic anticoagulation, aiming for an activated clotting time >450 seconds.

If suitable, the distal ascending aorta is cannulated, along with a two-stage cannula in the right atrial appendage, with purse strings to enable later closure. An aortic root cannula is placed in the ascending aorta, often at the site of a proximal anastomosis to provide antegrade cardioplegia and a root vent.

A retrograde cardioplegia cannula can be inserted via the right atrium and sited in the coronary sinus, which provides additional protection of the myocardium, especially in cases of severe coronary artery stenosis or aortic insufficiency. The conduits are prepared and may be secured at the sternal edges ready for grafting. The locations on the coronary arteries for grafting may be marked.

Cardiopulmonary bypass (CPB) is initiated. Normothermia or cooling may be preferred. Flow is reduced while an aortic cross-clamp is placed between the aortic cannula and root cannula. Cardioplegia using cold blood, a potassium-rich solution, is administered, aiming to achieve asystole.

An arteriotomy is performed in a part of each coronary artery to be grafted in a region that is least diseased but proximal enough to be of benefit and graftable. Distal anastomosis of the conduit onto the coronary artery is performed using direct, sequential or composite (Y or T) techniques; it can also involve endarterectomy where safely possible for extensive lesions. Cardioplegia doses are repeated as required. The IMA—LAD graft is usually performed last.

Proximal anastomosis of free grafts to the ascending aorta can be performed on or off cross-clamping. The single-clamp technique leads to a longer cross-clamp time, while the partial clamp technique causes more aortic manipulation. The grafts are deaired.

After removal of the cross-clamp, a stable heart rhythm with or without the insertion of pacing wires, normal temperature, ventilation and acceptable biochemistry should be achieved before weaning the patient off CPB.

After venous decannulation and correction of any significant surgical bleeding, protamine is given to reverse the effects of the heparin. Aortic decannulation follows on reduced blood pressure. Haemostasis is achieved before sternal closure, routinely with stainless steel wires but novel techniques have emerged including sternal plate fixation, zip ties and cable tie systems.

Surgical considerations

Surgical variations arise from surgeon preference, patient factors and emerging evidence.

Off-pump coronary artery bypass is a successful technique in the hands of experienced surgical and anaesthetic teams.[5] With insufficient surgeon experience, there are reports of increased mortality and a need for repeat revascularization. Manipulation of the beating heart can cause haemodynamic compromise, lead to incomplete revascularization and lower graft patency. With sufficient surgical experience and higher risk patients, some

studies have found a lower in-hospital mortality and incidence of stroke, acute renal or respiratory dysfunction, and infections.

Minimally invasive direct coronary artery bypass surgery is performed through a left anterolateral mini-thoracotomy, primarily for LIMA—LAD single-bypass grafting. It reduces the wound complications that occur with a sternotomy, while offering the benefits of surgical CABG. Total endoscopic coronary artery bypass is a promising effective technique but has limited applicability in current practice.

Hybrid revascularization combines the advantages of PCI and minimally invasive CABG to achieve complete revascularization and can be utilized for high-risk patients or those with PCI to the culprit lesion that later requires LIMA-LAD grafting.

Coronary reoperations are challenging because of adhesions during sternal reopening, difficult myocardial protection owing to stenotic existing grafts and patent arterial grafts reducing the effectiveness of cardioplegia, aortic atherosclerosis, diffuse native vessel disease and lack of bypass conduits. Mortality is higher, quoted at 3—7% in the literature.

Complications

The morbidity and mortality of CABG are both decreasing. Mortality is now typically <1% for elective CABG (0.49% in 2025 National Adult Cardiac Surgery Audit report).[6] With an ageing demographic, the focus now is on reducing the rate of postoperative morbidity.

Heart failure and *myocardial dysfunction* are the leading causes of death for most patients undergoing CABG. Low cardiac output syndrome significantly increases mortality and morbidity. Predictors of low cardiac output syndrome include older age, impaired left ventricular function, CPB, emergency surgery and incomplete revascularization. Most patients have some level of myocardial stunning postoperatively, many require inotropic support, and some require mechanical support such as an intra-aortic balloon pump.

Re-exploration for *bleeding* is required in around 2.2% patients.[6]

Adverse neurological outcomes range from stroke and transient delirium to cognitive decline. The rate of postoperative stroke is around 1%. Major strokes are thought to be related to manipulation of the aorta, and micro-embolic infarcts are more likely to arise from the use of CPB and surgical techniques. Risk factors for neuropsychiatric complications include preoperative cognitive impairment, stroke history, increased intraoperative time, postoperative arrhythmia and a longer stay on the intensive therapy unit.

Deep sternal wound infection (DSWI) after CABG is a very serious complication, but rates in the UK are low — 0.3% in 2023/24.[5] The use of a skeletonized mammary artery, bilateral mammary arteries, gentamicin-impregnated collagen sponge during closure, preoperative antimicrobial interventions and tight postoperative glycaemic control aims to reduce the rate.

Acute kidney injury after cardiac surgery is associated with worse outcomes, including increased mortality rate. The rate of serious kidney injury (requiring renal dialysis or support therapy) after CABG in England between 2022 and 2025 has ranged from 0.98% to 1.45%.

Significant *respiratory complications* occur in almost 4% of patients, some requiring re-escalation of care and longer periods of ventilation. ◆

KEY REFERENCES

1 Vrints C, Andreotti F, Koskinas KC, et al. 2024 ESC Guidelines for the management of chronic coronary syndromes. *Eur Heart J* 2024; **45:** 3415—537.

2 Silverborn M, Nielsen S, Karlsson M. The performance of EuroSCORE II in CABG patients in relation to sex, age, and surgical risk: a nationwide study in 14,118 patients. *J Cardiothorac Surg* 2023; **18:** 40.

3 Gaudino M, Bakaeen FG, Sandnre S, et al. Expert systematic review on the choice of conduits for coronary artery bypass grafting: endorsed by the European Association for Cardio-Thoracic Surgery (EACTS) and The Society of Thoracic Surgeons (STS). *J Thorac Cardiovasc Surg* 2023; **166:** 1099—114.

4 Buxton B, Hayward P, Raman J, et al. Long-term results of the RAPCO trials. *Circulation* 2020; **142:** 1330—8.

5 Shroyer AL, Grover FL, Hattler B, et al. On-pump versus off-pump coronary-artery bypass surgery. *N Engl J Med* 2009; **361:** 1827—37.

6 National Institute for Cardiovascular Outcomes Research National Adult Cardiac Surgery Audit (NACSA). 2025. https://www.nicor.org.uk/national-cardiac-audit-programme/cardiac-surgery-audit-nacsa (accessed 5 January 2026).

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TEST YOURSELF

To test your knowledge based on the article you have just read, please complete the questions below. The answers can be found at the end of the issue or online here.

Question 1

A 45-year-old man presented with limiting angina. He also had type 1 diabetes and hyperlipidaemia. Three-vessel coronary artery disease was found on invasive angiography and he was awaiting bypass graft surgery. Total arterial revascularization was planned using pedicled left internal mammary artery (LIMA) and right internal mammary artery (RIMA) grafts, and a free radial artery (RA) graft with one graft to each of the major coronary arteries.

What is the most likely graft configuration?

A. LIMA to left anterior descending (LAD), RIMA to circumflex, RA to right coronary
B. LIMA to LAD, RIMA to right coronary, RA to circumflex
C. LIMA to circumflex, RIMA to LAD, RA to right coronary
D. LIMA to circumflex, RIMA to right coronary, RA to circumflex
E. LIMA to right coronary, RIMA to LAD, RA to right coronary

Question 2

A 75-year-old man was due to undergo elective coronary artery bypass grafting (CABG). He had no significant co-morbidities. As part of the consent procedure he asked about the likelihood of perioperative complications including death.

What should he be advised is the most common cause of death after CABG surgery?

A. Bleeding
B. Heart failure
C. Kidney failure
D. Neurological complications
E. Respiratory complications

Question 3

A 68-year-old woman presented with limiting angina and was found to have three-vessel coronary artery disease on invasive angiography. She had a background of hypertension, type 2 diabetes and hyperlipidaemia.

Investigations

- Estimated glomerular filtration rate was 62 ml/minute/1.73 m^2 (>90)
- Echocardiography showed left ventricular inferior wall hypokinesia with an ejection fraction of 48%

What feature most strongly supports revascularization with coronary artery bypass grafting rather than percutaneous coronary intervention?

A. Diabetes
B. Hyperlipidaemia
C. Hypertension
D. Left ventricular dysfunction
E. Renal impairment