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Narrative Review

Complications of Coronary Artery Bypass Grafting

Syed Mohammad Asim Hussain[1], Amer Harky[1*]

[1]Department of Cardiothoracic Surgery, Liverpool Heart and Chest, Liverpool, UK

Corresponding Author: Amer Harky, MBChB, MSc, MRCS, Department of Cardiothoracic Surgery, Liverpool Heart and Chest Hospital, Liverpool, UK. Tel: +44-7842599657, Email: aaharky@gmail.com

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Abstract

Coronary artery bypass grafting (CABG) has become much safer over the last 50 years due to advancement in clinical practice and technology development. However, it is still a complex and high-risk operation that carries significant morbidities and mortality. The most serious adverse events are death, stroke, bleeding requiring further surgery, peri-operative myocardial infarction, cardiac arrhythmias, and deep sternal wound infection. Each complication has an approximate risk of 1%-2%, and they must be fully discussed with the patient during the consent process. Many other complications can occur as the procedure affects the entire circulatory system and the visceral organs. Advancements have been made in cardiopulmonary bypass, graft selection, operating room practices, and multi-disciplinary team-working to reduce the risk of such complications occurring. This review article focused on the key complications of CABG.

Keywords: Heart Surgery, Coronary Artery Bypass, Complications

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Introduction

Coronary artery bypass grafting (CABG) is one of the most commonly performed operations with approximately 200 000 procedures performed annually in the United States of America and an incidence of 62 per 200 000 inhabitants in Western Europe.[1] It has evolved over the past century from a high-risk procedure to a relatively safe one with a current mortality rate of 1%-2% in elective patients.[2] Nonetheless, it is still a highly complex surgery and has been associated with a number of complications. The complications from this major surgery can be classified in various ways; some are catastrophic, such as death and stroke, while others can be self-limiting without any long-term residual effects, such as atelectasis, lower respiratory infection, or transient acute kidney injury.[2,3]

CABG can be considered as a large operation incorporating many smaller operations. There may be variations in these smaller operations that can have both advantages and disadvantages. However, the end goal is to bypass a blocked or narrow coronary artery by anastomosis of a vessel conduit.[3] This may be done with or without cardio-pulmonary bypass, with arterial or venous grafts, and with open or endoscopic harvesting of conduits.

The overall risk of this operation is determined by the Euroscore, which is a statistical determination of risk using logistic regression.[4,5] It is determined by patient-related factors (age, gender, renal impairment, peripheral vascular disease, mobility, previous cardiac surgery, chronic lung disease, active endocarditis, critical pre-operative state, insulin dependent diabetes), cardiac-related factors (NYHA dyspnea classification, CCS angina classification, left ventricular function, recent myocardial infarction, and pulmonary hypertension) and operation factors (urgency, weight of intervention, and involvement of thoracic aorta).[5]

For the purposes of valid patient consent, it is considered mandatory to discuss the risk of death, peri-operative myocardial infarction, stroke, and sternal wound infection.[6] The general complications of CABG surgery are briefly discussed below followed by a discussion of the specific complications associated with cardiopulmonary bypass and graft patency.

Extent of Complications

Complications can be broadly divided into catastrophic events, such as death and stroke, or less serious complications, such as pulmonary, renal, or sternal wound complications.

Death

Mortality following CABG is reported to be between 1%-2% for elective procedures; however, it can be confounded by many factors including the urgency of the case, previous acute myocardial events, the presence of multiple comorbidities such as diabetes or chronic renal failure, or poor coronary vessels that are not amenable for grafting.[4-6]

Stroke

Post-operative stroke has an incidence of 1.4% to 3.8%.[2] The risk factors for this complication include increased age, diabetes, hypertension, previous stroke, hypo-perfusion, and female gender.[3] In patients who have previously had a stroke, the mortality rate following CABG is 10 times higher than for those who are known to not have had a stroke.[4]

Bleeding and Cardiac Tamponade

Bleeding and cardiac tamponade are the most devastating complications following cardiac surgery. Undiagnosed, they will invariably lead to cardiac arrest and death. Bleeding can occur due to intra-operative vessel injury, knot slipping, or coagulopathy. The blood can collect in the pericardium space causing compression of the heart and diastolic failure. Urgent decompression is required, followed by immediate return to the operating room to control the bleeding.[6,7]

Myocardial Dysfunction/Infarction

The biomarkers indicating a damaged myocardium can be elevated following CABG, and the degree of elevation positively correlates with adverse outcomes at 30 days and 2 years.[5] In severe cases, the patient may experience a peri-operative myocardial infarction and cardiogenic failure resulting from poor myocardial protection, graft blockage or kinking, which is managed either medically or through emergency angiography performed to assess graft patency. In such case, a plan for further action is then put into place accordingly.[8]

Delirium

Delirium is a common complication of CABG and has been associated with functional decline at one-month, short-term cognitive impairment, and increased risk of long-term mortality.[8] The risk factors for this complication include increased age, pre-existing cognitive impairment, cerebrovascular disease, and neurological disorders.[9] It can also be exacerbated by the effects of anesthesia, pain relief, frequent change of environment, and critical care stay.

Sternal Wound Infection

Infection occurs in approximately 1%-2% of cases. It is associated with diabetes, obesity, and chronic obstructive pulmonary disease.[10] It has also been linked with prolonged cardio-pulmonary bypass times, prolonged intubation times, blood transfusions, and surgical re-exploration.[10] Nosocomial infections occur commonly in cardiac surgery patients and can contribute to surgical site infections. The risk of infection can be reduced by ceasing smoking, optimizing nutrition, controlling blood sugar, and reducing weight.[5]

Need for Blood Transfusion

A blood transfusion may be needed if the pre-operative hemoglobin is low or the intra-operative bleeding is greater than anticipated. Blood transfusion has been linked to sternal wound infections and early or late death, and they are recognized as an independent risk factor for adverse outcomes.[11] The risk of sepsis increases with each unit of blood transfused. Conversely, leucocyte-depleted blood has significantly reduced infection rates and mortality.[12]

Acute Renal Failure

Acute renal failure occurs in 2-3% of cases with approximately 1% of patients requiring dialysis.[13] It is more likely to occur in patients with pre-existing renal disease, insulin-dependent diabetes, congestive heart failure, shock, or co-existing peripheral vascular disease.[14] It has also been linked to advanced age, female gender, black ethnicity, emergency surgery, and need for circulatory support such as intra-aortic balloon pump.[14]

Arrhythmias

Post-operative atrial fibrillation is the most common complication of CABG occurring in up to 30%-50% of patients. It increases the risk of stroke and cardiac-related death if not recognized and managed properly.[15] The incidence peaks on post-operative day 2 and generally occurs within 5 days of surgery. It can be treated with beta-blockers and amiodarone, while the replacement of fluids and electrolytes such as potassium and magnesium is crucial. Other arrhythmias can also occur and can include both tachy-arrhythmias (SVT, VT) and brady-arrhythmias (AV block, complete heart block).[16]

Pulmonary Complications

Pulmonary complications include atelectasis, pneumothorax, hemothorax, pleural effusions, pulmonary edema, pulmonary embolism, phrenic nerve palsy, adult respiratory distress syndrome, and chylothorax. Pulmonary complications are independently associated with advanced age, prolonged bypass time, pre-operative pulmonary hypertension, and intra-operative phrenic nerve injury.[16]

Pleural effusions occur commonly after CABG. The majority of these are small, left-sided effusions that resolve spontaneously. They occur due to the harvesting of the left internal thoracic artery.[17] Occasionally, these effusions can be bloody, forming a hemothorax due to traumatic damage. Larger effusions can cause respiratory compromise and delay recovery, and chest tube drainage may be required.[17,18]

Pneumothorax occurs in approximately 1.4% of patients undergoing cardiac surgery and can be fatal. It can occur due to iatrogenic damage when the pleura is opened during harvesting of the internal thoracic artery. Chest drain placement is required if the patient is symptomatic and hypoxic.[18]

Gastrointestinal Complications

Gastrointestinal complications are relatively rare but can be life-threatening. They can include acute mesenteric ischemia (AMI), cholecystitis, pancreatitis, and ileus.[17] The underlying cause is thought to be hypoperfusion during cardiac surgery with systemic inflammation, hypothermia, drug therapy, and mechanical factors.[18] Out of these, AMI is the most serious complication with reported mortality rates of 40%-94%.[18] This is caused by difficulty in diagnosis, lack of effective treatment options, and considerable morbidity following extensive small bowel resection.

Cardiopulmonary Bypass

The development of the heart-lung machine in the 1930's was an important landmark for cardiac surgery as it enabled tissue perfusion while the heart was stopped and provided a bloodless field for surgery.[19] The basic cardiopulmonary bypass (CPB) circuit consists of venous cannula, tubing, reservoir, pump, heat exchanger, oxygenator, tubing, arterial cannula, and cardioplegia cannula. The system allows venous blood to be drained from the heart, oxygenated, and returned to circulation, thereby taking over the natural functions of the heart and lungs.[19] However, there are complications associated with CPB which can be broadly divided into mechanical and systemic types.

Mechanical Complications of Cardiopulmonary Bypass

Problems encountered during arterial cannulation include bleeding, cannula malposition, disruption of atherosclerotic plaque, and arterial dissection which may require repair under deep hypothermic circulatory arrest.[20] Similarly, venous cannulation can lead to bleeding and malposition. An incorrectly placed venous cannula can lead to an air-lock, preventing adequate venous drainage resulting in congestion in the cerebral and splanchnic vasculature.[20] In turn, pumping from an empty reservoir can lead to massive air embolism and stroke. Cessation of the pump and retrograde cerebral perfusion are necessary should this occur. Rarer complications include apparatus failure, including oxygenator failure, pump failure, clotting in circuit, and tube rupture.[20]

Systemic complications of Cardiopulmonary Bypass

During CPB, a number of inflammatory, clotting, complement and fibrinolytic pathways are initiated. Systemic inflammatory response syndrome can occur due to ischemia-reperfusion, iatrogenic trauma, contact of blood with artificial tubing, release of endotoxins, and temperature changes during surgery.[21] In turn, this can lead to systemic hypotension and acute kidney injury.

Subclinical myocardial infarction may occur despite cardioplegia due to cross-clamping of the aorta, preventing coronary perfusion and thus stunning of the myocardium and reperfusion injury. Optimization of electrolytes and temperature reduces the risk of this event.[21,22]

Acute respiratory distress syndrome (ARDS) can occur because of CPB with complement activation through the alternative pathway playing an important role in pathophysiology. Such activation can cause accumulation of neutrophils in the pulmonary vessels with the subsequent release of elastase, myeloperoxidase, and other inflammatory markers leading to diffuse lung injury.[22] At the end of CPB, protamine is given to reverse the effects of heparin, which can activate the classical pathway. Other factors associated with ARDS include large volume shifts, blood transfusions, anesthesia-induced atelectasis, reduced mucociliary clearance and iatrogenic trauma. ARDS is a devastating complication with a mortality rate of up to 80% when occurring after cardiac surgery.[22]

Vasoplegia can occur during CPB because of the activation of nitric oxide synthase, smooth muscle K+ channels, and relatively reduced vasopressin levels.[23] It results in systemic vasodilation and hypotension that is resistant to conventional therapy. Methylene blue, a competitive inhibitor of nitric oxide, can be used as a rescue drug.[23]

Hemolysis occurs in all extra-corporeal circuits due to shear stress, wall impact forces, contact with non-endothelial surfaces, positive and negative pressures. A high degree of hemolysis that goes beyond the endogenous clearing mechanisms can lead to the accumulation of plasma-free Hb.[24] This is associated with dystonia involving the gastrointestinal, cardiovascular, pulmonary, and urogenital systems as well as clotting.[24]

Clotting while on CPB is a life-threatening complication. Therefore, the activated clotting time must be monitored every 30-40 minutes during bypass to ensure adequate heparinization of the circulating blood. Rarely, heparin resistance can occur with failure to reach target activated clotting time levels despite large heparin doses (up to 1000 units/kg IV).[25] This requires treatment with concentrated anti-thrombin III or fresh frozen plasma.[25] Heparin therapy can also lead to heparin-induced thrombocytopenia and thrombosis. In this circumstance, heparin must be stopped immediately and an agent used that will not drop the platelet count further, e.g., argatroban or fondaparinux.

Cerebral injury can occur following CPB through a number of mechanisms, including the addition of CO2 to the circuit leading to vasodilation and loss of autoregulation, rapid rewarming and hyperthermia during the weaning phase, hyperglycemia due to the stress response, reduced hematocrit, disruption of atherosclerotic plaque due to surgical manipulation, and lipid embolism due to pericardial suction aspiration.[26,27]

On-pump vs. Off-pump CABG

During the latter part of the 20th century, the vast majority of heart operations were performed with the use of the cardio-pulmonary bypass machine. In view of the above complications of CPB, off-pump bypass grafting (OPCABG) made a resurgence in the 1990s.[27]

The operative safety of the technique was demonstrated in 2000 patients. The benefits included a lower risk of renal failure, less cognitive deficits, lower transfusion rates, and reduced systemic inflammation.[28]

Recently, a meta-analysis including 59 trials and 9000 patients compared off-pump CABG with on-pump CABG and demonstrated that OPCABG reduced the risk of stroke by 30% while the rate of peri-operative myocardial infarction and death were not significantly different.[28] A further study compared both techniques in 304 patients and found that OPCAB had significantly reduced transfusion requirements and costs, while there was no difference in surgical re-exploration or hospital stay.[29]

One study retrospectively reviewed 3500 patients and found that use of OPCABG significantly reduced mortality in women. Blood transfusion requirements, critical care stays, and hospital stays were also reduced in females in the OPCABG cohort.[30]

However, the most definitive study on this was the ROOBY (Randomized on/off bypass) trial in 2009.[31] This study did not show any significant difference in the primary short-term endpoint of death or complications within 30 days; however, it did show that the primary long-term endpoint of death, myocardial infarction, and repeat revascularization within 1 year of surgery was significantly more in the off-pump group. Furthermore, graft patency was also significantly lower in the off-pump group.

Long Term and Graft Complications

Long-term complications relate to the success of the operation over 10-15 years and are measured by mortality, need for repeat revascularization, and freedom from myocardial infarction.[32] Therefore, graft patency is the key factor underlying these outcome measures.

The available conduit vessels are the long saphenous vein, internal thoracic arteries, radial artery, gastro-epiploic artery, and inferior epigastric artery.[33]

The long saphenous vein is the most commonly used because of its length and ease of access. However, it has a low patency rate with only 50%-60% of saphenous vein grafts patent at 10 years.[32,33] Its use is also associated with leg wound complications such as infection, swelling, pain, and ooziness which can increase the patient's hospital stay duration and costs.

The internal thoracic artery is the gold standard conduit and is anastomosed to the left anterior descending artery. It has a 10-year patency rate of >90% with only 1% of patients having hemodynamically significant atherosclerosis.[34]

Radial artery grafts have a long-term patency of 86%-94% which is better than the saphenous vein.[35] In view of this, there has been a recent shift towards using only arterial conduits to graft coronary vessels, i.e. total arterial circulation. However, the radial artery is not as effective when used on the low-pressure right heart system. Radial artery harvesting is also associated with significant complications including bleeding, hematoma, wound infection, and nerve injuries. The gastro-epiploic artery is prone to spasm with a graft patency of 62% at 10 years.[36] Similarly, the inferior epigastric artery is also prone to spasm with a 1-year graft patency of 90%.[37]

Conclusions

CABG is one the most extensively researched operations, and this scrutiny has provided a rich source of information on its complications and their management. It has resulted in risk stratification scores and innovative approaches such as off-pump surgery, total arterial circulation, and minimally invasive cardiac surgery while improving operative safety and outcomes.

Conflict of Interest Disclosures

Nothing to be declared.

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