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REVIEW

UP-TO-DATE CORONARY ARTERY BYPASS GRAFT SURGERY

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Abstract

The experimental and clinical efforts of Demikov and Kolesov between 1952 and 1964 related to coronary anastomosis between the internal thoracic artery and left anterior descending artery on a beating heart. Sones and Shirey (Cleveland, 1962) were pioneers of selective coronary angiography. The first coronary artery bypass grafting using a saphenous vein graft was performed by Garrett, Dennis, and DeBakey in Houston in 1964. Since that time, coronary surgery has become one of the most frequently performed surgical procedures in the world.

Coronarography can be considered the golden standard of diagnostics. Current supplements to coronarography are: functional assesment of the fractional flow reserve; intravascular ultrasound; and optical coherence tomography, for the estimation of atherosclerotic plaque. When combined, these techniques provide high-quality diagnoses. Diagnostic coronarography is followed by percutaneous coronary procedures, the results of which are comparable to those of coronary surgery.

Prerequisites of coronary artery bypass grafting (CABG) are grafts and vascular conduits. Alternative flow into ischaemic myocardial territory takes place across these vascular conduits. Usage of the left internal mammary artery is a proven superior standard in operative surgery, due to its better survival rates and prevention of massive myocardial reinfarction. Saphenous vein grafts are most frequently used in the myocardial territory that is not supplied by the left anterior descending artery. In 2018, we will have the final results of the ART trial, which is testing the usage of arterial grafts in coronary surgery. Preliminary results show superiority of the right internal mammary artery as a graft when compared with other arterial grafts (except the left internal mammary artery).

Nowadays, myocardial revascularisation with cardiopulmonary bypass is performed in 75-80% of cases. Off-pump coronary artery bypass (beating heart) surgery is performed in 20% of cases. Besides these procedures, there are less invasive procedures such as minimal invasive direct coronary bypass (MIDCAB), totally endoscopic coronary bypass (TECAB) and

myocardial laser revascularisation. Results of the perioperative application of stem cells and drugs for neoangiogenesis remain limited, in spite of some promising reports.

International guidelines from 2011, 2012 and 2013 give us an excellent framework for routine daily practice, but trials such as SYNTAX I and II (2013) and FAME I and II (2013, 2015) will provide new inputs to diagnostic procedures, decision making processes, development, and the need for modern CABG.

Key words: coronary artery bypass grafting, diagnostics, conduits, OPCAB, ONCAB

Introduction

After the pioneering works of Kolessov in 1964 to create anastomoses on a beating heart, the introduction of extracorporeal circulation as part of the operating arsenal has led to a progressive increase in the number of procedures. By the end of the 20th century, 500,000 operations were being performed in the United States each year. Improved diagnostic techniques, operative procedures, a system for extracorporeal circulation, improved anesthesia techniques, intensive care, post-operative treatment, recovery, rehabilitation and resocialisation of the patient, makes CABG a reasonably safe and promising procedure. In the 1990s percutaneous coronary procedures, angioplasty, and stenting of the coronary blood vessels were established. These treatments are comparable with coronary surgery, and as a result the number of operations decreased in the period 1999-2003. Since then, the number of coronary surgeries (CABGs) has stabilised at around 300,000 in the USA and 165,000 in Europe, although this figure can be slightly higher from year to year. The main difference between coronary surgery and percutaneous coronary cardiac procedures is that coronary surgery provides alternative blood flow in the ischaemic area while the PCI restitutes normal flow throughout the native vessel. By 2010, many cardiac surgeons and cardiologists had created guidelines for the treatment of ischaemic disease individually, which caused unbalanced decision making in the treatment of coronary patients. A cooperative approach works better, as all professionals have limitations, and should have the opportunity to be complemented by others. Since then, common European guidelines were written on the principle of consensus between cardiologists and cardiovascular surgeons.(1) Guidelines for the revascularisation treatment of coronary patients by cardiologists (2) and cardiovascular surgeons (3) were published in the USA in November 2011, with consensus among relevant professionals. The essence of the preamble is to guide the individual approach to each patient in terms of diagnostic conclusions and recommendations for treatment with the joint knowledge of cardiologists and cardiovascular surgeons, and the informed consent of patients for recommended procedures. In this paper, contemporary standards in coronary surgery in the fields of diagnostics, operative indications, graft choice and surgical methods will be presented.

Material and methods

To explore these issues, we have used the MEDLINE and PubMed databases, and identified articles and studies for the period January 2009-July 2014. Keywords are: CABG, coronarography, vascular conduits, outcomes, clinical trials, fraction flow reserve, intravascular coronary imaging. Original articles, reviews, studies and guidelines were published in English. From the available literature, we have tried to present a good selection of information on diagnostic and therapeutic recommendations in coronary artery bypass surgery at the beginning of the 21st century.

Epidemiology of coronary atherosclerotic disease

In Bosnia and Herzegovina, morbidity and mortality from cardiovascular disease (CVD) began to rise after 1960, and rose three more times before 1990. Since the war of 1992-1995, the nation has seen a progressive increase in CVD morbidity and mortality rates. Morbidity has reached considerable proportions, with 253,367 patients diagnosed each year in the Federation, at an incidence of 10,880/100,000 (Institute of Public Health of Bosnia and Herzegovina from 2008 to 2010).

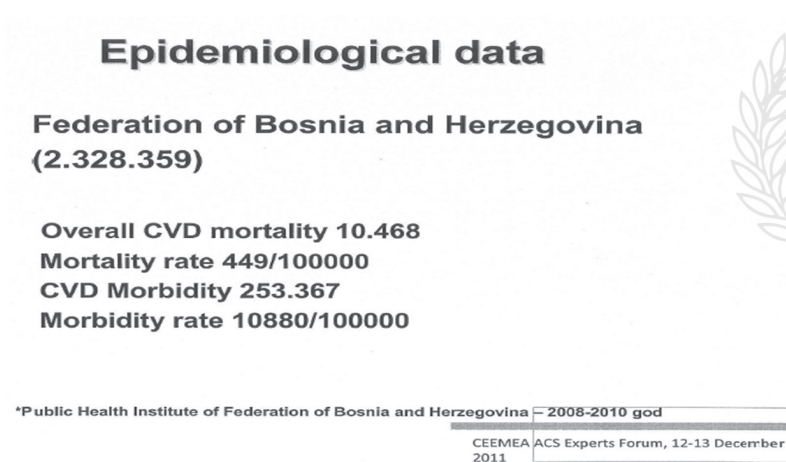


Figure 1. Epidemiology of cardiovascular mortality and morbidity in FBiH

Historical landmarks in the development of cardiac surgery

Alexis Carrel, 1910. Experimental anastomosis between the descending aorta and left coronary artery of a dog.

Claude Beck, 1930, Cleveland. Indirect revascularisation, sewing mediastinal structures or omentum to treat myocardial ischaemia.

Arthur Vinberg, 1946, Canada. Direct anastomosis of the left internal thoracic artery to the myocardium, resulting in the reversal of angina in the majority of patients.

Mason and Sones demonstrated a link between anastomosis and coronary flow by using angiography, and this operation became popular in the sixties.

Sones and Shirey, 1962, Cleveland. The first selective coronary angiography.

Longmire, 1958. First endarterectomy of coronary vessels. Poor results led to the abandonment of this technique, which included the first anastomosis of the right coronary artery (RIMA).

Garrett, Dennis, and DeBakey, 1964, Houston. First vein graft using the saphenous vein between the aorta and the LAD. The planned endarterectomy was proven to be too risky, so the operation is completed by bypass. In 1973 the patient was still alive, with an unobstructed bypass.

Vladimir Demikhov, 1952, Moscow. LIMA-LAD anastomoses on the beating heart of a dog.

Gibbon, 1952. Built the IBM Heart-Lung machine, the first successful use of extracorporeal circulation.

Kolessov, 1964, Leningrad. The first anastomosis LIMA-LAD through a left thoracotomy on a beating heart. A report on the experience of the 6 patients was published in 1967, in the American Journal of Surgery.

Green et al. Recommend the use of extracorporeal circulation in cardiac operations.

Bailey and Hirose, 1968. Recommended LIMA-LAD anastomosis and the use of a surgical loupe when creating anastomoses.

Rene Favaloro, 1968, Cleveland. Announced the results of 15 patients treated with aorto-coronary bypass graft using the saphenous vein.

Dudley Johnson, 1968. Published the first serious results of 301 patients treated in February 1967 with aorto-coronary bypass using saphenous vein grafts. 40% of patients received two bypasses. Based on the results of the first, five rules were recommended: do not limit the graft with the proximal portion of the artery; avoid the diseased part of the artery; the vein graft must be long enough, and should be grafted to the distal part of a healthy artery; always work end-to-side when performing anastomosis, and make sure the area is dry, as vascular anastomosis cannot be completed in a bloody environment; do not let the haematocrit fall below 35.

Thanks to the results and recommendations of Green, Loop and Crondina, LIMA becomes the graft of choice for coronary artery bypass surgery in the 1980s.

Carpantier, 1972, Paris. Proposed the radial artery as the preferred graft. This idea was quickly abandoned due to spasticity of the graft, but has been revisited in the past 15 years.

Denton Cooley et al, 1957, Houston. The first closure of a post-infarction ventricular septal defect.

Cardiac catheterisation – coronary angiography

Coronary angiography is the gold standard in the diagnosis of coronary artery disease, and the final level of its detection. It is also an important tool to assess the severity of the disease, and indication for revascularisation methods. The advantage of coronary angiography compared to other radiological methods is the possibility of simultaneous therapeutic intervention.

Negotiated assessment of coronary artery involvement divides segmental distribution of the coronary artery system into 16 or 27 segments. Division into 16 segments is widely accepted, and, most importantly, forms the basis of angiographic analysis and evaluation of the results of the SYNTAX study.(4)

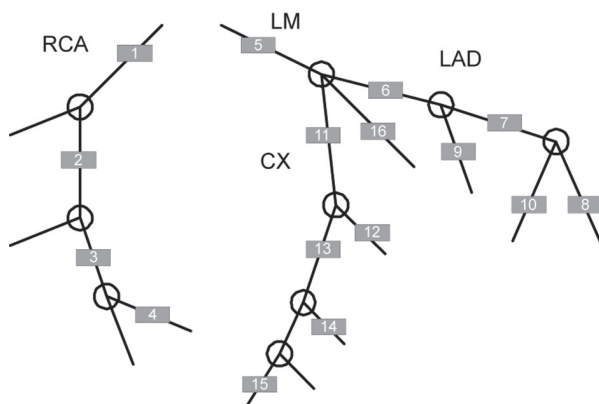


Figure 2. AHA segmental division of an artery

Angiography provides an overview of the frontal flow blood vessels. Stenosis can be concentric and eccentric, as well as in the lumen of the vessel. It was observed that angiographic imaging does not correlate with cross-sectional narrowing.

Average diameter loss	Cross-sectional area loss
$\frac{2}{3} = 67\%$ 	 90%
$\frac{1}{2} = 50\%$ 	 75%
$\frac{1}{3} = 33\%$ 	 50%

Figure 3. Relationship between angiographic and cross-sectional stenosis

Fractional flow reserve (FFR)

FFR is the preferred method in modern cath labs for the evaluation of coronary stenosis⁵. FFR is defined as the maximum myocardial flow distal to the stenosis divided by the value at which there is no epicardial stenosis. FFR can be considered separately in relation to the myocardium, epicardial coronary artery, and collateral flow. The formula for FFR is simplified as pressure distal to the stenosis divided by the pressure proximal to the stenosis. In normal conditions, the value is 1.0. FFR. A value of 0.6 means that the maximum myocardial flow through the stenosis is only 60% of what would be expected in the absence of stenosis. An FFR of 0.9 after percutaneous coronary intervention means that 90% of the maximum flow has been achieved. FFR has a high reproducibility because it does not show any significant changes in the pulse pressure and LV contractility.

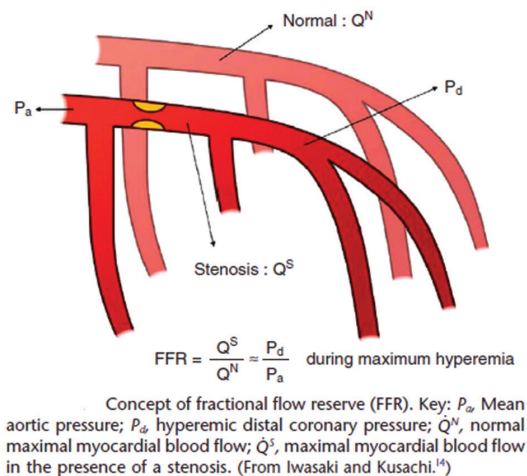


Figure 4. Fractional reserve blood flow

There is no strict correlation between myocardial stress tests and FFR. An FFR of less than 0.75 was defined as significant stenosis with inducible myocardial ischaemia. This implies the following values: sensitivity 88%, specificity 100%, positive predictive value of 100%, and accuracy of 93%. Measurement of FFR is now considered an extremely important indication tool, and is essential during coronary angiography. Tonino and his colleagues in the FAME study inaugurate the hypothesis that PCI with the measurement of FFR is superior to a conventional angiographic study in patients with three-vessel coronary artery disease. An FFR of less than 0.80 is an indication for intervention, and is of great importance for many studies.

Intravascular ultrasound (IVUS)

IVUS catheters reflect sound waves to visualise the arterial wall-dimensional computed tomography in a format that is analogous to a histological section of the

vessel. IVUS uses a significantly higher frequency (20-40 MHz) than that of the non-invasive echocardiography (2-5 MHz). This ensures high image resolution and expansion of the limited penetration of sound waves (4-8mm from the tip of the catheter). Interpretation of the IVUS display begins with the identification of the intima, media and adventitia structures in the blood vessel. Within these differentiated boundaries atherosclerotic plaque can form, develop, and lead to complications. IVUS provides electronic caliper measurements of dimensions and restriction zones, determining maximum stenosis and assessment of the segment located proximal and distal to the lesion. Plaque with extensive infiltration of lipids has a low reflectivity echo, while plaques with predominantly fibrous tissue are more echogenic structures. Calcified plaques have a bright border covered by a dark shadow that extends radially outwards. IVUS can detect calcified plaque in 60-80% of lesions, whereas only half these amounts can be detected by angiography. Clinical effectiveness of IVUS is also reflected in the identification of thrombotic masses and artery dissection, with or without intervention. IVUS provides accurate atherectomy, a clear display of stents and their position in relation to the arterial wall, and evaluation of in-stent stenosis.(6)

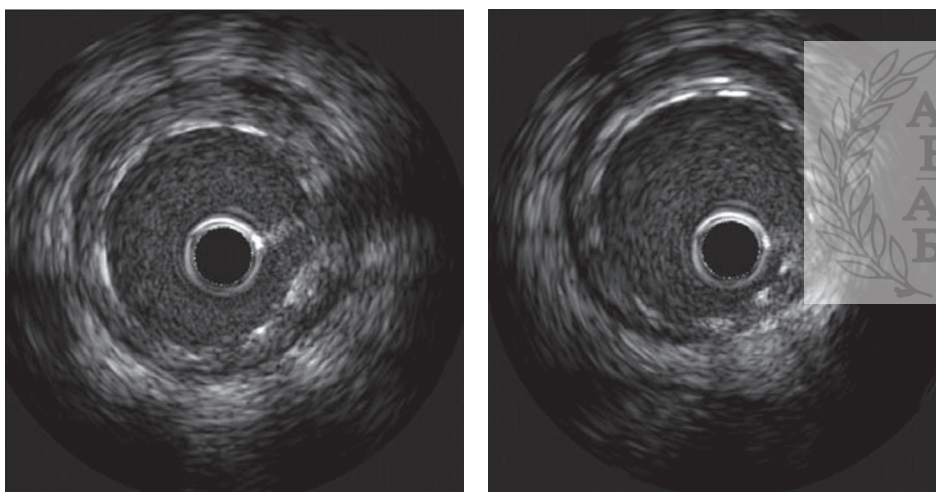


Figure 5. Intravascular ultrasound LMC

Optical coherence tomography (OCT)

OCT generates real-time tomographic imaging by reflecting infrared light. This use of optical echo can be considered as an optical analogue version of IVUS. The biggest advantage of a display based on the reflection of infrared light is that it has a higher resolution than conventional ultrasound. The intravascular OCT system consists of optical machinery which emits and receives infrared signals, a catheter for introducing light, a fibre optic catheter, and a computer processor. Experimental studies have shown that OCT can show structures measuring 10-50 microns, while

IVUS visualises structures of 150-200 microns. The diagnostic accuracy of OCT information has proved effective, with a sensitivity of 79% and specificity of 98% for fibrotic plaques. The importance of OCT is particularly demonstrated in evaluation of the thickness of the fibrous cap of atherosclerotic plaque in the coronary arteries.(7)

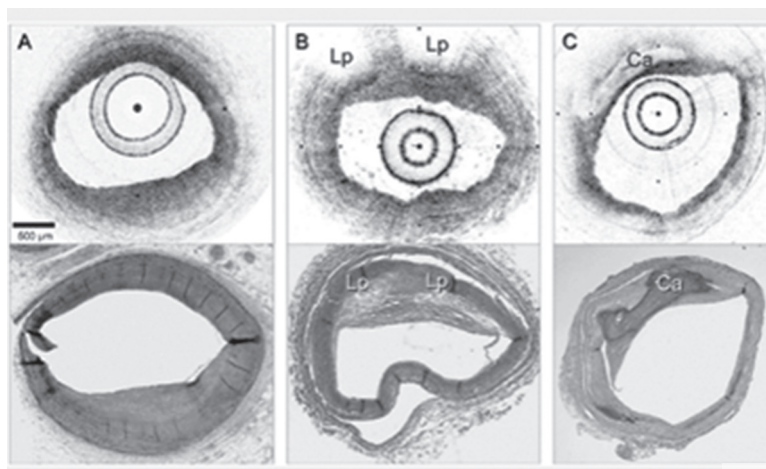


Figure 6. OCT with histology showing vessels

Coronary CT

The sensitivity and specificity of CT coronary angiography is over 95%, depending on the number of detectors (64, 128 or 256). However, at its current stage of technological development CT coronary angiography does not offer the possibility of simultaneous percutaneous coronary procedures. Heart rate must be less than 65 beats per minute. An elevated calcium score greater than 400 complicates the interpretation of stenosis of the coronary arteries, and reduces the specificity of the examination. The CT technique has excellent negative predictive value, ie. it can effectively exclude coronary disease.(8) It has become the method of choice in evaluating the patency of coronary stents and of grafts in bypass surgery. A bypass generally creates a wider lumen, which has less mobility during the cardiac cycle than the coronary arteries. Coronary anomalies are indications of choice for this type of test.

Treatment of ischaemic heart disease

There are three modalities of treatment: optimal medical therapy, percutaneous coronary procedures, and surgical treatment.

Optimal medical therapy (OMT)

OMT is the control of risk factors and the use of anti-ischaemic drugs as a non-aggressive method of treatment.(9)

Percutaneous coronary procedures

In December 2011, recommendations were published for the first time to differentiate when percutaneous coronary intervention should be applied, and when surgical intervention is more appropriate. Results and findings from individual and randomised trials show the following (10):

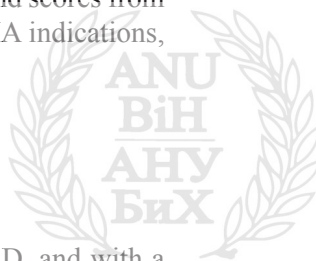
- PCI reduces the incidence of anginal disorders
- PCI has not been shown to improve survival in stable patients with OMT
- PCI has demonstrated its value in acute coronary syndrome
- PCI did not reduce the long-term risk of myocardial infarction
- PCI may increase the short-term risk of myocardial infarction
- PCI can be a successful complement to CABG in hybrid procedures
- PCI can be used in dealing with graft stenosis

Coronary artery bypass grafting (CABG)

Indications for surgery

Since December 2011, indications for surgery have been determined by guidelines for surgical myocardial revascularisation. These are based on results and scores from the EBM SYNTAX study.(11) This paper will present only the class IA indications, about which there is consensus for surgical treatment (12):

- Left main stenosis (narrowing of the left main coronary artery)
- Left main equivalent (proximal LAD and Cx)
- Three-vessel disease
- Two-vessel disease with proximal LAD and EF<50%
- One-vessel and two-vessel disease without involvement of the LAD, and with a large territory at risk
- Severe refractory AP with full OMT
- Failed PCI with haemodynamic, ischaemic ventricular dysfunction or electrical instability
- Persistent or recurrent ischaemia refractory to OMT with acceptable anatomy and significant territory at risk
- A condition that requires surgical repair post AMI, VSD, or acute mitral regurgitation
- Cardiogenic shock in patients younger than 75 years who have ST elevation, LBBB, or posterior AMI within 18 hours of onset of symptoms.
- Life-threatening ventricular arrhythmias in the presence of LM stenosis >50%, and/or vessel disease
- Impaired left ventricular function with LM and two-vessel or three-vessel disease
- Life-threatening ventricular arrhythmias with LMS or LM equivalent
- Foreign body in a critical position
- Haemodynamic instability and coagulopathy without/with previous sternotomy
- Previous CABG procedures



- Previous occlusion and bypass, and class I coronary artery disease

Methods of surgical treatment

1. Coronary artery bypass with the use of extracorporeal circulation (on-pump CABG/ONCAB) (13)
2. Coronary artery bypass without the use of extracorporeal circulation (off-pump CABG/OPCAB) (14)
3. On-pump beating heart CABG
4. Minimally invasive coronary surgery (15)
5. Transmyocardial revascularisation (16)
6. CABG with simultaneous instillation of stem cells
7. Hybrid revascularisation (17)

The tactics and strategy of surgical intervention are focussed on two objectives: to achieve optimal revascularisation; and optimal intraoperative myocardial protection.

Prerequisites for vascular conduits (grafts) in coronary surgery

Internal mammary artery (LIMA)

Using LIMA grafts to bypass the LAD provides proven superiority in short- and long-term survival.(18,19) Excellent biological characteristics, incomparable long-term patency and improved clinical results are some outcomes of LIMA graft use, which has become the first choice for myocardial revascularisation. LIMA shows considerable resistance to the development of atherosclerosis as well as to the possible violation of the endothelium of the saphenous vein during preparation. Electron microscopy studies do not show thrombogenic intimal defects that are commonly seen in vein grafts. Non-fenestrated internal elastic lamina is likely to inhibit cellular migration by preventing intimal hyperplasia. The middle layer is thin, with few muscle cells showing a decreased proliferative response to mitogens and pulsatile mechanical force. The endothelium of the LIMA is a significant autoproducer of vasodilators such as nitric oxide and prostacyclin. The LIMA showed a favorable response to certain drugs used perioperatively. It is vasodilated under the influence of milrinone and does not tolerate vasoconstriction in response to norepinephrine. Nitroglycerine also causes LIMA vasodilation. Endogenous secretion of vasodilators carried in the blood stream has a positive effect on the coronary vasculature distal to the anastomosis. It is important to note significant remodelling of the LIMA represents adaptation to flow demands. The consequence may be an increase in the lumen of the LIMA to 1.5 to 2.5 times its normal size. Two basic preparation techniques for LIMA are pedicled and skeletonised harvesting. In the case of using both internal mammary arteries (LIMA and RIMA), skeletonised harvesting is preferred because it provides better opportunities for sternum healing, especially among women, obese patients and patients with diabetes. RIMA is somewhat more prone to atherosclerosis compared to LIMA in patients of an advanced age (28% of 6%). RIMA is also sensitive to the effects of medication, which is important as it is more commonly used

as a free graft. The patency rate of skeletonised harvesting is undeniably high; more than 90% of LIMA grafts after 10 years, which is superior to that of all other grafts.

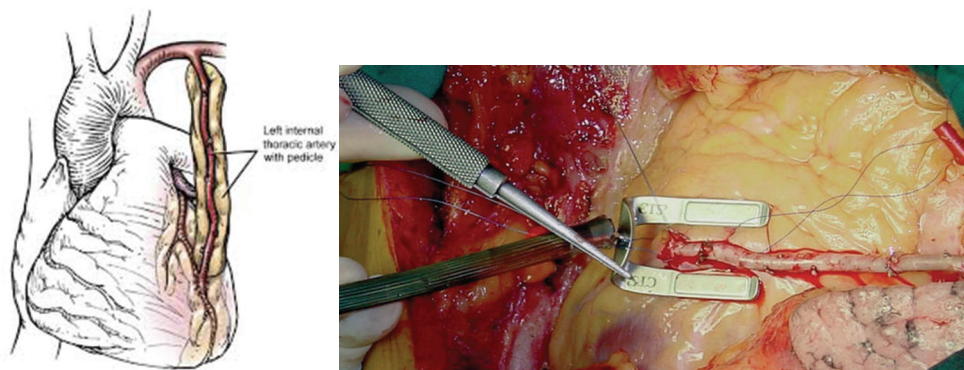


Figure 7. Pedicled and skeletonised LIMA

The radial artery

Use of radial artery grafts was first described in 1970. Artery spasm was common, and fixed by mechanical dilatation. Initial results were poor, so this graft was quickly abandoned. Akar postulated that the preparation technique is responsible for spasm and occlusion of the graft. Pedicled harvesting and pharmacological preparation of the graft was recommended, making this type of graft gain importance. In some studies it proved superior to the saphenous vein graft, although is still open to discussion.(20) Graft patency was 90% for 9 months, and 65% after 10 years.

Gastroepiploic artery

Use of this artery is less common, although it can be used in redo surgery in the absence of other acceptable grafts, or as a second or third arterial conduit in total arterial revascularisation of the heart. Preparation of the graft requires a longer operating time, increasing the possibility of abdominal complications. There is currently no consensus on the long-term benefits of total arterial revascularisation.

Great saphenous vein (GSV)

Despite the identification of its numerous negative characteristics, the GSV remains the most commonly used vein for grafts in bypass surgery, due to its ease of preparation, rapid availability of sufficient length, resistance to spasm, and satisfactory long-term results.(21) Early use of aspirin and statins reduces occlusion of grafts in the first year after surgery. In the future, gene therapy is likely to be able to modify the venous vascular endothelium to avoid the development of intimal hyperplasia. Vein harvesting is performed by either open, semi-open, or endoscopic methods. The open method traumatises the skin, and has higher levels of complications and post-operative wound pain. The semi-open method, with its smaller cutdowns, can reduce pain and wound complications but increases surgical manipulation of the graft.

Minimally invasive preparation of the GSV with endoscopic techniques is gaining popularity, although its effect on the morphology of the vein's endothelial structure, function and long-term patency are questionable.(22) Conversion of endoscopic to open technique occurs in 5 to 7% of cases. Air and fat embolisms of the lungs have been reported. Long-term patency of the venous graft appears low, as 20% of grafts are occluded in the first year. Annual graft occlusion occurs at a level of 2%, meaning that after 10 years, 60% of grafts are patent, although recent studies using a non-touch preparation technique refute these results.(23,24,25)

Surgical revascularisation with the use of extracorporeal circulation (On-pump CABG/ONCAB)

Preparation for cardiopulmonary bypass ends cannulation of the aorta and right atrium at a typical site. After this, lines for cardioplegia and venting are installed. The aorta is crossclamped, a cardioplegic solution is given, and the heart is arrested in diastole. We can consider this the conventional approach to bypass surgery. Cardiopulmonary bypass now constitutes 75-80% of all bypass procedures in the world, and is seen as a proven treatment.(26)

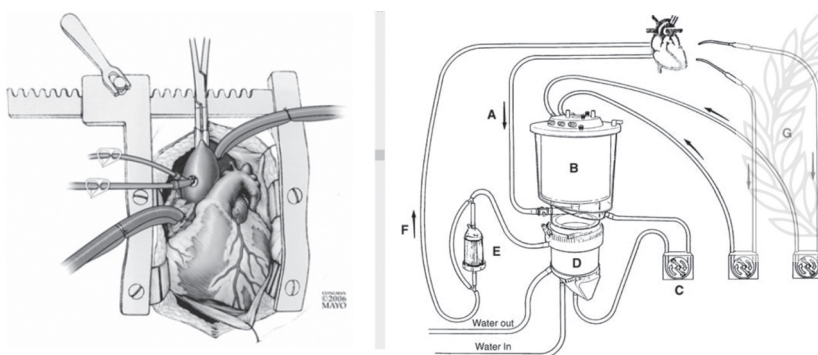


Figure 8. CABG with the use of extracorporeal circulation

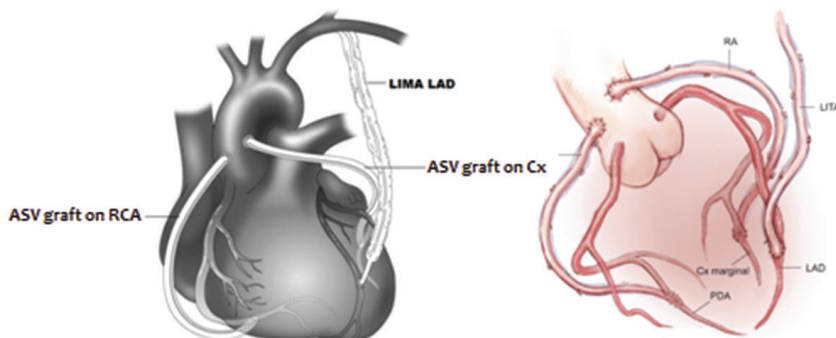


Figure 9. Conventional CABG (LIMA and SVG) and total arterial revascularisation

CABG without the use of extracorporeal circulation (off-pump CABG/OPCAB)

CABG procedures have been documented to improve the patient's chance of survival and quality of life, and to eliminate symptoms. The number of OPCAB procedures was increasing until 2003, but has since stabilised at a level of 20%. The aims of these procedures are: graft patency at least equivalent to that of conventional techniques; to reduce morbidity and mortality, particularly in high-risk groups; ensure a quick return to good functional capacity; and economic benefit. Selection of patients depends primarily on the technical skills of surgeons, and angiographic characteristics of the coronary anatomy. This includes patients with a satisfactory caliber of vessels, focal stenosis of the target vessel sufficiently distant from the AV groove, and vessels for which there is no probability of endarterectomy. High-risk patients who are likely to benefit from OPCAB are those with: severe LV dysfunction; renal insufficiency; severe atherosclerosis of the aorta; or COBP. Haemodynamically or electrically unstable patients are often unable to tolerate the manipulation OPCAB requires, and are generally not considered candidates for this type of surgery. Maintaining temperature control is of great importance. There are conflicting reports about the safety of immediate extubation after surgery.

Optimal exposure of vessels is of paramount importance. The LIMA seam contributes to initial exposure, while later techniques include additional seams, and are perfected by the use of mechanical stabilisers. The order of anastomosis creation in OPCAB surgery is crucial. Collateralised vessels are grafted before those that give collaterals. First, an anastomosis LIMA-LAD is created, then the proximal anastomosis, then the distal, followed by grafts, in this order: diagonal artery; RCA; PDA; PLA; first OM; and RIM.

Despite the fact that OPCAB eliminates CPR, it does not eliminate all the complications that occur in coronary surgery, although some are significantly decreased. Non-touch aorta OPCAB avoids manipulation of the aorta, and reduces the possibility of neurological deficit. Controlled studies showed no difference in mortality after one to three years. Randomised studies have shown a decreased need for blood transfusions, inotropic support, fewer respiratory infections, and a lower incidence of atrial fibrillation. However, we did not find statistical significance of differences in: post-operative ischaemia; use of IABP; ARF; wound infection or mediastinitis; or recurrence of angina. ONCAB conversions are reported to occur in an average of 8% of patients, with a subsequent mortality rate of 6-15%.

Surgical revascularisation with the use of extracorporeal circulation on the beating heart (on-pump beating heart CABG)

Extracorporeal circulatory support for beating heart surgery is a useful tool. Unstable patients with: AMI; barely reduced EF; acute coronary occlusion; and coronary dissection leading to cardiovascular collapse, are all ideal candidates for this type of

operation, where it is possible to simultaneously create anastomoses on a beating heart. Easier manipulation of the heart and greater control of blood loss during surgery are some advantages of extracorporeal circulation. This technique is most likely the future of cardiac surgery in severe cases.

Minimally invasive myocardial revascularisation (MIDCAB)

MIDCAB is an insufficiently defined term, referring mainly to the exclusion of CPB surgical standards. Other important features are the practice of median sternotomy as a surgical approach, and the use of endoscopic methods of operation and preparation of grafts. OPCAB is partially MIDCAB, where a median sternotomy is the preferred approach. MIDCAB began as a single LIMA-LAD anastomosis through an antero-lateral thoracotomy, with the use of endoscopy in the preparation of grafts to avoid over-expansion of the ribs in the approach. Use of the harmonic scalpel in the preparation of grafts represents a particular development in this technique. MIDCAB has been further developed via computer software that enables telemanipulation (robotic surgery). This is used in total endoscopic coronary artery bypass (TECAB) grafting. It is possibly the least invasive approach to revascularisation on a beating heart. Operators need access ports for scope and manipulation. The transition from the limited indication of the total endoscopic revascularisation will require more time, due to limitations in the adequacy of instruments, software, and computers, and the steep learning curve for surgeons. Despite its high technology, TECAB remains technically demanding, and is initially used on an arrested heart with femorofemoral bypass, aortic endo-clamping and cardioplegic arrest. It is shown that initial studies exhibit the same graft patency as standard procedures. The level of conversion to the standard procedure is high. Ignoring the surgical exposure in these experimental techniques in situations of three-vessel disease has led to complications, and rationalisation of TECAB on one-vessel or two-vessel disease. Endoscopic preparation of the graft is introduced to minimise trauma, reduce wound complications, and add

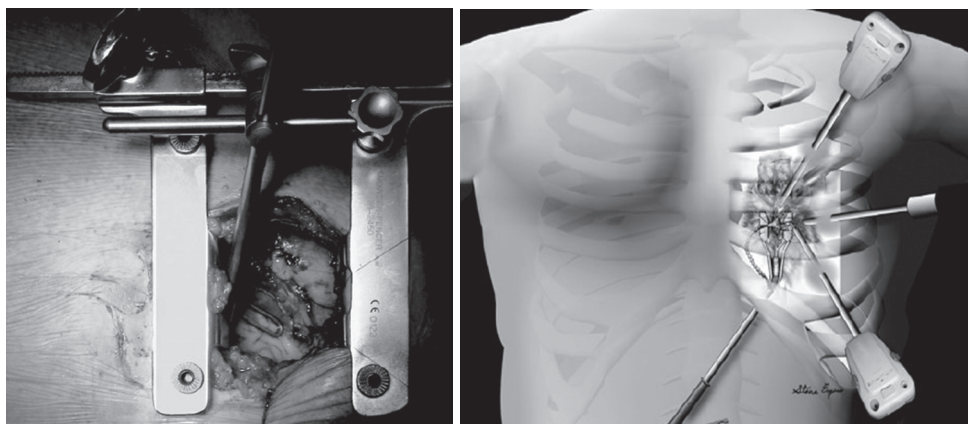


Figure 10. Minimally invasive coronary bypass and totally endoscopic coronary revascularisation

cosmetic benefits. Endoscopic preparation can be used for the radial artery, great saphenous vein, and less frequently-used grafts. The procedure is somewhat longer, and the level of conversion to the open method described is from 0-22%. The risk of early complications is significantly reduced, although the quality of the graft after these procedures has been questioned due to the appearance of some of its less frequent complications (such as air embolisms or thromboembolisms).

Transmyocardial revascularisation laser (TMR)

Despite the success of various therapeutic options in the treatment of coronary artery disease, there are a significant number of patients with refractory angina due to diffuse coronary disease who are not candidates for OMT, PCI or CABG. One technique developed for this group of patients is TMR. Three types of laser are used: carbon dioxide; holmium:Yag; and xenon chloride. The idea is to create vascular channels through the entire thickness of the left ventricular wall at a certain distance from the main blood vessels. Twelve to 20 channels should be created in this way. The mechanism is not completely clear, but it is believed that angiogenesis with redistribution of blood within the wall of the myocardium plays a role in freeing patients from angina and improving left ventricular perfusion. Patients with poor ejection fraction and acute ischaemia are not candidates for this technique. The current mortality rate is about 5%, and the one-year survival rate is 84-95%. Reduction of angina is seen more frequently in patients treated with TMR compared to those receiving OMT. Five-year survival was 65% for patients treated with TMR, and 52% for patients treated with OMT. TMR can be used as an adjunct to those CABG procedures in which one cannot achieve optimal revascularisation due to diffuse coronary disease.

CABG with instillation of angiogenic substances for angiogenesis and stem cells

Experimental in vitro studies have shown that some proteins (VEGF, FGF, FGF1, FGF2) have angiogenic potential, and angiogenesis and new vascular channels have been observed in experiments on animal models. In limited clinical studies, these proteins were applied during CABG surgery. After 16 months, significantly better perfusion was observed in nuclear studies. Another option for bypass is the use of adult or embryonic stem cells. Embryonic angioblasts were found to be more potent in the formation of the primary capillary plexus. Cardiomyocytes are terminally differentiated, and can not regenerate. However, it was shown that a limited number of cardiomyocytes may be regenerated using stem cells. Clinical studies on a limited number of patients treated with stem cells during CABG showed functional improvement.

Hybrid procedures – Integrated coronary revascularisation

In the case of older patients, diffuse atherosclerosis, significant comorbidity, and low ejection fraction are often present, and hybrid operations can have a major

effect in terms of relieving anginal disorders and increasing life expectancy. Hybrid operations are a combination of minimally invasive direct coronary artery bypass (MIDCAB) – incorporating LIMA-LAD via the left thoracotomy – and percutaneous coronary interventions (PCI). The need to perform these procedures has led to the creation of a team of cardiologists and cardiovascular surgeons and a technically-equipped hybrid operating room, in which it is possible to undertake both types of procedure either simultaneously or in quick succession.

Outcome

Operative mortality ranges from 2.6-4% (27), and is gradually falling due to constant improvement of surgical skills, myocardial protection and anesthetic techniques. In a study by Mack et al in 2002, the mortality rate in a group of 51,353 patients was 2.24%. Causes of death were: heart failure, 65%; neurological deficits, 7.3%; bleeding, 7%; respiratory failure, 5.5%; and dysrhythmias, 5.5%. Operative morbidity related to the development of myocardial infarction appears in 1-5% of patients with a poor prognosis for long-term survival. Post-operative myocardial dysfunction, presented as syndrome of low cardiac output (28), has also been a common problem, and requires inotropic support. Its incidence is 9%, and in severe cases treatment requires an IABP. (29) LOS is a marker of increased operative mortality. Independent predictors of LOS in patients are: a poor EF < 20%, reoperation, vital operation, female gender, diabetes (30,31), age greater than 70 years (32,33), left main disease (34), recent AMI, and three-vessel disease.

Discussion

Cardiovascular incidents remain the leading cause of morbidity and mortality in both the developed world and developing countries. In Europe and the USA, there have been around 2.5 million hospital admissions due to acute coronary syndrome. This large number of cases continues to dictate the efforts of the health system to preserve the population's quality of life and increase its life expectancy. Although the introduction of percutaneous cardiac procedures has provided a remarkable reduction in the number of candidates for coronary surgery, the overall situation has not changed greatly. Vast improvements have occurred in the field of diagnosis of coronary artery disease, and in standardisation of indications. On the basis of angiographic characteristics, the SYNTAX study demonstrated that patients with higher scores are candidates for coronary surgery, and that compared with PCI, this surgery has lower rates of mortality and complications. The SYNTAX Score II combines the angiographic and clinical characteristics of a patient, and contributes to a much better preoperative assessment. Techniques for functional assessment of coronary stenosis (FAME study) leads to a further qualitative improvement in the indication for a particular type of treatment (OMT, PCI, or CABG). Intravascular visualisation techniques of atherosclerotic plaque further contribute to the knowledge of coronary artery disease, and have an impact on clinical decision making. Technological development

in surgery occurs continuously, so that the improved capabilities of extracorporeal circulation, haemodynamic monitoring and the development of specific endoscopic systems constantly make surgery easier and more confident. The choice of graft in coronary surgery today is quite clear: the LIMA graft is used in more than 95% of coronary surgeries. This is followed by the RIMA graft, whose usability and quality is likely to be confirmed upon completion of the ARTS 2018 study. A venous graft with meticulous surgical preparation remains an essential factor in long-term patency using antiagregants and statins. Radial artery and gastroepiploic artery application is useful in the case of subocclusion or native vessel occlusion, as the competing flow of native vessels leads quickly to spasm and thrombosis of the graft. Improving the results of treatment outcomes for coronary patients is based on an individual approach, and includes assesment of indications, consideration of diagnostic possibilities and careful selection of treatment methods. Comorbidities and an ageing population can be seen to take treatment results to their limits in term of morbidity and mortality in coronary surgery. In Bosnia and Herzegovina it is necessary to make an extra effort for the early detection of coronary artery disease, as the population of patients with ischaemic heart disease is significantly younger compared to Western European countries and the USA.

References

1. Wijns W, Kolho P, Danchin N, Di Mario C, et al. ESC/EACTS guidelines; Guidelines on Myocardial Revascularisation. *Eur Heart J.* 2010;(31):2501-55.
2. Levine GN, Bates ER, Blankenship JC, Bailey SR, Bittl JA, Čerček B, et al. 2011 ACCF/AHA/SCAI Guideline for Percutaneous coronary intervention: A Report of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines and the Society for Cardiovascular Angiography and Interventions. *Circulation.* 2011;(124):e574-e651.
3. Hillis LD, Smith PK, Anderson JL, Bittl JA, Bridges CR, Byrne JG, et al. 2011 ACCF/AHA Guideline for Coronary Artery Bypass Graft Surgery: A Report of the American College of Cardiology Foundation / American Heart Association Task Force on Practice Guidelines. *Circulation* 2011. <http://circ.ahajournals.org/by guest on March 22, 2012>.
4. Mohr FW, Morice MC, Kappetein AP, Feldman TE, Stahle E, Colombo A, et al. Coronary artery bypass surgery versus percutaneous coronary intervention in patients with three-vessel disease and left main coronary disease: 5-year follow-up of a randomized, clinical trial SYNTAX. *Lancet.* 2013;(381):629-38.
5. De Bruyne B, Pijls NHJ, Kalesan B, Barbato E, Tonino PAL, Piróth Z, et al. Fractional Flow Reserve-Guided PCI versus Medical Therapy in Stable Coronary Disease. *N Engl J Med.* 2012;(367):991-1001. (FAME 2 Trial Investigators)
6. Garcia-Garcia HM, Costa MA, Serruys PW. Imaging of coronary atherosclerosis: Intravascular Ultrasound. *N Engl J Med.* 2010;(3):2456-69.
7. Terashima M, Kaneda H, Suzuki T. The role of optical coherence tomography in coronary interventions. *Korean J Intern Med.* 2012;27(1):1-12.
8. Sarno G, Decraemer I, Vanhoenacker PK, de Bruyne B, et al. On the inappropriateness of non invasive multidetector computed tomography coronary angiography to trigger

- coronary revascularisation: a comparison with invasive angiography. *JACC Cardiovasc Interv.* 2009;(2):550-7.
9. Boden WE, O'Rourke RA, Teo KK, et al. COURAGE Trial Investigators. Impact of optimal medical therapy with or without percutaneous coronary intervention on long-term cardiovascular end points in patients with stable coronary artery disease (from the COURAGE Trial). *J Am Coll Cardiol.* 2009;104(1):1-4. [PMID: 19576311]
 10. Simard T, Hibbert B, Ramirez FD, Froeschl M, Chen YX, O'Brien ER. The Evolution of Coronary Stents: a Brief Review. *Can J Cardiol* of 2014;30(1):35-45.
 11. Farooq H, van Klaveren D, Steyerberg EW et al. Anatomical and clinical characteristics to guide decision making between coronary artery bypass surgery and percutaneous coronary intervention for individual patients: development and validation of SYNTAX score II. *Lancet.* 2013;(381):639-50.
 12. Montalescot G, Sechtem U, Achenbach S, Andreotti F, Arden C, Budai A, et al. 2013 ESC Guidelines on the management of stable coronary artery disease: The Task Force on the management of stable coronary artery disease of the European Society of Cardiology. *N Engl J Med.* 2013;(34):2949-3003.
 13. Greason KL, Sundt III TM, Myocardial Revascularisation with Cardiopulmonary Bypass. In: Cohn LH, editor. *Cardiac Surgery in the Adult.* Elsevier Saunders. 4th-Ed; 2012. p. 479-503.
 14. Halkos ME, Puskas JD. Myocardial Revascularisation without Cardiopulmonary Bypass. In: Cohn LH, editor. *Cardiac Surgery in the Adult.* Elsevier Saunders. 4th-Ed; 2012. p. 505-20.
 15. Holzhey DM, Rastan AJ, Falk V, Mohr FW. Minimally Invasive Myocardial Revascularisation. In: Cohn LH, editor. *Cardiac Surgery in the Adult.* Elsevier Saunders. 4th-Ed; 2012. p. 553-66.
 16. Horvath KA, Zhou Y. Transmyocardial Laser Revascularization and Extravascular Angiogenetic Techniques to Increase Myocardial Blood Flow. In: Cohn LH, editor. *Cardiac Surgery in the Adult.* Elsevier Saunders. 4th-Ed; 2012. p. 585-601.
 17. Popma JJ, Nathan S, Hagberg RC, Khabbaz KR. Hybrid myocardial revascularisation: An integrated approach to coronary revascularization. *Cath and Cardiovasc Int.* 2010;75(1):28-34.
 18. Adams C, Burns DJP, Chu MWA, Jones AM, Shridar J, et al. Single-stage hybrid coronary revascularisation with long-term follow-up. *Eur J Cardiovasc Surg.* 2013;234-41.
 19. Conradi L, Treed H, Reichensperner H. Hybrid coronary revascularisation: a task for the true heart team. *Eur J Cardiovasc Surg.* 2014;45(3):443-4.
 20. Taggart DP. Current status of arterial grafts for coronary artery bypass grafting. *Ann Cardiovasc Surg.* 2013;2(4):427-30.
 21. Cheng A, Slaughter MS. How I choose conduits and configure grafts for my patients – rationales and practices. *Ann Cardiovasc Surg.* 2013;2(4):527-32.
 22. Barner HB. Conduits for Coronary Bypass Strategies. *Korean J Thorac Cardiovasc Surg.* 2013;(46):319-27.
 23. Li J, Liu Y, Zheng J, et al. The patency of sequential and individual vein coronary bypass grafts: a systematic review. *Surg.* 2011;(92):1292-8.
 24. Bello SOZ, Peng EWK, Sarkar PK. Conduits for coronary artery bypass surgery: the quest for second best. *J Cardiovasc Med.* 2011;(12):411-21.

25. Dreifaldt M, Mannion JD, Bodin L, Olsson H, Zagozdzon L, Souza D. The no-touch saphenous vein as the preferred second conduit for coronary artery bypass grafting. *Surg.* 2013;(96):105-11.
26. 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.
27. Ferguson TB Jr. Mortality in Coronary Artery Bypass Grafting: What's next? *Circulation.* 2012;(125):2409-11.
28. Nagendran J, Norris CM, Graham MM, Ross DB, MacArthur RG, Keiser TM, et al. Coronary revascularisation for patients with severe left ventricular dysfunction. *Surg.* 2013;(96):2038-44.
29. Hamad MAS, van Straten AHM, Shonberger JPAM, ter Woorst JFJ, de Wolf AM, Martens EJ, van Zundert AAJ. Preoperative ejection fraction as predictor of survival after coronary artery bypass grafting: comparison with a matched general population. *Journal of Cardiothoracic Surgery.* 2010;(5):29.
30. Aggarwal B, Goel S, Sabik JF, Shishehbor MH. The FREEDOM trial: in appropriate patients with diabetes and multivessel coronary artery disease, CABG Beats PCI. *Cliv Clin J Med.* 2013;(80):515-23.
31. Farkouh ME, Domanski M, Sleeper LA, et al. FREEDOM Trial Investigators. Strategies for multivessel revascularisation in patients with diabetes. *N Engl J Med.* 2012;(367):2375-84.
32. Yanagawa B, Algarni KD, Yau TM, Brister SJ. Improving results for coronary artery bypass graft surgery in the elderly. *Eur J Cardiovasc Surg.* 2012;42(3):507-12.
33. Saito A, Motomura S, Miyata H, Takamoto S, Kyo S, Ono M, Database Organisation JC. Age-specific risk stratification in 13488 isolated coronary artery bypass grafting procedures. *Interact Cardiovasc Thorac Surg.* 2011;(12):575-81.
34. Ngaage DL, Sogliano F, Tang A. Early and late survival after surgical revascularisation for left main coronary artery stenosis in the stent era. *Am J Cardiol.* 2012;(119):134-8.