

Review

Hybrid Coronary Revascularization in Multivessel Disease: The Ideal Strategy for Challenging Scenarios

Antonella Tommasino^{1,*},†, Emiliano Marco Navarra^{2,†}, Federico Dell'Aquila^{1,3}, Camilla Ciani^{2,3}, Vincenzo Fiorentini^{1,3}, Simone Amicizia^{2,3}, Andrea Berni^{1,3}, Emanuele Barbato^{1,3}, Giovanni Melina^{2,3}

¹Division of Cardiology, Sant'Andrea Hospital, 00189 Rome, Italy

²Division of Cardiac Surgery, Sant'Andrea Hospital, 00189 Rome, Italy

³Department of Clinical and Molecular Medicine, Sapienza University of Rome, 00189 Rome, Italy

*Correspondence: antonellatommasino@gmail.com (Antonella Tommasino)

†These authors contributed equally.

Submitted: 26 February 2024 Revised: 10 April 2024 Accepted: 19 April 2024 Published: 23 June 2024

Abstract

The treatment of coronary artery disease (CAD) has considerably evolved over the last three decades thanks to innovations in percutaneous and surgical revascularization techniques. The demographic shift towards an aging population with complex coronary anatomy and multiple comorbidities necessitates a personalized approach. A primary challenge for Heart Teams is to integrate new strategies into their decision-making process. Hybrid coronary revascularization (HCR) combines the long-term benefits of coronary artery bypass grafting (CABG) with percutaneous coronary intervention (PCI) to treat complex coronary artery disease. Selection of the ideal candidate for HCR requires careful evaluation of anatomic challenges and risk profiles. Although recent evidence demonstrates the safety and efficacy of HCR and makes it a viable alternative to conventional methods, further large-scale randomized controlled trials (RCTs) are needed to establish its role in routine practice. In this manuscript, we have provided an overview of the major advances in both percutaneous and surgical techniques. In addition, we have addressed the innovative implications of robotic-assisted minimally invasive direct coronary artery bypass (RA-MIDCAB) and described the surgical procedure and postoperative care in detail. Finally, we have outlined the key principles that guide our clinical practice in selecting the appropriate approach for hybrid coronary revascularization.

Keywords

hybrid coronary revascularization; multivessel coronary artery disease; chronic coronary syndrome; acute coronary syndrome; percutaneous coronary intervention; robotic-assisted minimally invasive direct coronary artery bypass

Introduction

The treatment of coronary artery disease (CAD) has considerably improved over the last thirty years. Advances in both percutaneous coronary intervention (PCI) and surgical revascularization have led to better treatment options and long-term clinical outcomes [1].

However, demographic changes towards an older population and improved access to healthcare have led to more complex clinical cases [2,3], often involving frail patients with multiple comorbidities and complex coronary anatomy [4]. The integrated “Heart Team” approach is critical to providing care tailored to patients’ needs. According to the ESC/EACTS and ACC/AHA/SCAI guidelines for coronary revascularization, the development of local institutional protocols is essential to determine the most appropriate revascularization strategy [5,6].

The introduction of new minimally invasive surgical techniques and improved PCI technologies expands the range of options for myocardial revascularization and challenges Heart Teams to effectively integrate these new strategies into their decision-making process.

Innovations in Percutaneous Coronary Intervention

The development of new-generation drug-eluting stents (DES) has significantly improved clinical outcomes for patients undergoing PCI, resulting in a lower incidence of target vessel revascularization (TVR), target lesion revascularization (TLR), in-stent restenosis (ISR) and stent thrombosis (ST) compared to the first generation [7,8]. The introduction of new platforms with reduced strut thickness [9], the use of -limus analog drugs and the application of polymer coatings for drug delivery have been key in improving patient outcomes [10]. New generation DES have significantly narrowed the gap between PCI and coronary artery bypass grafting (CABG) in the treatment of left main

(LM) disease, multivessel CAD and complex lesions, including chronic total occlusions (CTO) and calcified lesions [11].

The innovative aspect of PCI in CTO lies in the concept that coronary anatomy not only determines the need for revascularization, but also guides the choice between an antegrade (forward-moving including dissection/reentry) and retrograde (backward) approach. The improvement of guidewire and microcatheter technologies such as the Tornus (Asahi Intecc, Aichi, Japan) and the Turnpike Gold (Teleflex Medical Australia), which are equipped with a metallic tip to penetrate and disrupt the proximal, heavily calcified CTO cap, and the expanded use of intravascular ultrasound (IVUS)-guided re-entry have significantly increased the success rates of CTO PCI [12].

In managing severely calcified coronary artery lesions, progress in techniques and tools have significantly increased the procedural success [13]. Devices such as modified balloon catheters, including the AngioSculpt Scoring balloon (Brandin Court, Fremont, CA, USA) and cutting balloons such as Flextome and Wolverine (Boston Scientific, Natick, MA, USA), facilitate lumen dilation in calcified stenoses [14,15]. Super high-pressure balloons such as the OPN NC balloon (SIS Medical AG, Winterthur, Switzerland), which can be inflated up to 35 atm, and ablative atherectomy techniques such as the ROTAPRO rotational system (Boston Scientific, Boston, MA, USA) and orbital atherectomy (Diamondback 360, Cardiovascular Systems, St. Paul, MN, USA) are effective for plaque preparation [16,17]. Intravascular lithotripsy (IVL) is a novel technique that has evolved from a similar technology for the treatment of ureteral and renal calculi [18]. It has been adapted for use in calcified arterial lesions with the Shockwave IVL catheter (Shockwave Medical, Santa Clara, CA, USA), a standard monorail system balloon compatible with 0.014-inch guidewires. It effectively disrupts both superficial and deep calcifications by emitting acoustic pulse waves in the circumferential direction [17]. Its simplicity and technical efficiency make it useful for complex interventions. IVL is particularly effective in the treatment of bifurcation stenosis as the side branch wire can be preserved during inflation [19].

While recent technological advances have facilitated the treatment of complex coronary lesions [20], the results of randomized trials in recent decades have highlighted the effectiveness of fractional flow reserve (FFR)-guided PCI in terms of improved follow-up outcomes, including a reduction in mortality and myocardial infarction [21,22]. This method results in fewer vessels being treated, fewer stents being used and a lower rate of repeat revascularization [23]. In addition, the ability of FFR to distinguish between diffuse and focal disease patterns during pullback is key to determining the most appropriate anatomic target, facilitating decision making regarding the need and optimal strategy for revascularization [21]. New tools such as

the TruePhysio® Rapid Exchange Pressure Microcatheter (Insight. Lifetech, Shenzhen, China) allow for easier FFR assessment due to the possibility to use a workhorse 0.014" guidewire. Moreover, new specialized software is now available, such as the Quantitative Flow Ratio (QFR 2.0 software version, ClinFact Medis, Leiden, Netherlands). It allows estimation of FFR by tridimensional (3D) reconstruction during diagnostic coronary angiography. This makes the analysis of stenoses faster and less invasive, shortening the process and reducing the need for more invasive traditional FFR measurements [24].

Routine use of functional-guided assessment in the context of multivessel coronary artery disease often leads to its reclassification and allows treatment of stenoses that have been shown to be functionally significant. This strategy leads to less invasive and simpler interventions [23].

Progress in Surgical Technique Revascularization

Traditional Coronary Artery Bypass Grafting (CABG)

CABG has become one of the most performed major operations in the world [25]. The procedure had evolved considerably by the mid-20th century, with Vasili Kolesov performing the first 'modern' CABG [26]. René Favaloro further refined the technique and is considered the 'father' of bypass surgery [27]. Traditional CABG involves a sternotomy, cardiopulmonary bypass (CPB) and cardiac arrest by cardioplegia. These elements can lead to complications such as wound infection, systemic inflammation and embolization risks [28]. To mitigate these risks, less invasive methods such as off-pump CABG (OPCAB), minimally invasive direct CABG (MIDCAB) or totally endoscopic techniques (TECAB) have been developed. OPCAB is performed on the beating heart without CPB, which potentially reduces the associated risks of inflammation and embolization [29]. Observational studies have shown that OPCAB is associated with a reduced need for transfusion and a lower risk of renal dysfunction and postoperative atrial fibrillation [30]. However, randomized clinical trials such as the CABG Off or On Pump Revascularization Study (CORONARY) [31] and the Randomized On/Off Bypass (ROOBY) trials [32], have provided mixed results in terms of early mortality or major complications, suggesting that the benefits of OPCAB over standard CABG may be particularly important in high-volume centers.

Robotic-Assisted Minimally Invasive Direct Coronary Artery Bypass (RA-MIDCAB)

Application Progress

Originally limited to revascularization of the left anterior descending artery (LAD) due to technical limitations,

the use of MIDCAB in high-volume centers has now expanded to a broader patient population, including those with two- or three-vessel disease [33]. Robotic-assisted minimally invasive direct coronary artery bypass (RA-MIDCAB) is a major step forward. Indeed, the use of robots in minimally invasive CABG has led to progresses such as improved visualization, better camera control, 3D-vision, magnification and better surgical dexterity. Compared to conventional MIDCAB, robotic harvesting often results in longer grafts as access to both the proximal and distal segments is improved. Robotic telemanipulation allows the removal of pericardial fat, precise localization of the left anterior descending artery (LAD), assessment of anatomical suitability for minimally invasive techniques, and precise determination of the intercostal space [34]. Consequently, this allows for a much more comfortable procedure for the harvesting of single and double collections of the internal mammary artery (IMA), as demonstrated by two studies which found similar collection times for right internal mammary artery (RIMA) and left internal mammary artery (LIMA) [35,36]. In expert hands, RA-MIDCAB has proven to be safe and effective, offering benefits such as a reduced need for blood transfusions and faster patient recovery [37]. Several studies have compared conventional MIDCAB with RA-MIDCAB, finding a similar incidence of angina and major adverse events at mid-term. They also highlight the benefits of the robotic technique, including shorter intensive care unit (ICU) and hospital length of stay, faster extubation, and a lower rate of major adverse events in the mid-term, despite the slightly longer operative time [38,39].

Thanks to advances in robotic surgical technologies, MIDCAB is increasingly being performed as a totally endoscopic strategy (TECAB). This operation can be performed both on the beating heart and on the arrested heart. Both single and multiple grafts can be placed, and both TECAB and MIDCAB can be combined with percutaneous coronary intervention in hybrid procedures [40], which show excellent short- and long-term results [41,42].

Surgical Technique

The patient is positioned in the anterolateral decubitus position with the left chest and left buttock elevated by about 20–30 degrees. In an emergency, the left groin is kept in a sterile state and is accessible. For better recognition, one-lung ventilation is performed, which is facilitated by the insertion of a double-lumen endotracheal tube (Fig. 1).

The left internal mammary artery (LIMA) is carefully removed from the left chest using RATS instruments (Robot-Assisted Thoracic Surgery). These instruments are inserted through ports in the second, third and fourth intercostal spaces located about 2 cm above and below the anterior axillary line, with the trajectory directed towards the mediastinum (Fig. 1a).

In order to improve visibility during the procedure, a controlled pneumothorax is induced by carbon dioxide insufflation.

The LIMA is removed, whereby it can either be skeletonized or pedicled (Fig. 2). Heparin is then administered to the patient and the distal ends of the chest wall arteries are transected. After LIMA removal, the robotic device is detached.

The anastomosis between the LIMA and the LAD is performed via a mini-thoracotomy approach (Fig. 2d). This is usually a 5–6 cm left anterolateral muscle-sparing incision in the fourth or fifth intercostal space, located 2–3 cm inferior to the nipple. The pericardium is longitudinally incised, typically 1–2 finger widths lateral to the LIMA pedicle, and held open with traction sutures. The LAD is then identified. The lateral traction sutures are moved upward toward the top of the wound to facilitate rotation of the heart, exposing the LAD for easier anastomosis. One of the ports is used for insertion of tissue stabilizing devices. The distal end of the LIMA is divided and prepared for the anastomosis. Visualization of the LAD is further enhanced by manipulation of the pericardial margins and selective inflation of the lung. A suction stabilizer is used to secure the LAD during the anastomosis.

A shunt is inserted into the LAD to create a bloodless field. After anastomosis, restoration of blood flow through the LAD is confirmed. Hemostasis is carefully achieved, and the effect of heparin is reversed.

Finally, a chest drain is placed in the left pleural space and the thoracotomy site is closed according to standard procedures.

Post-Operative Care

The patient is then transferred to the intensive care unit (ICU) for intensive monitoring. This early postoperative phase, which lasts approximately six hours, is crucial to detect immediate complications such as excessive bleeding through the thoracic drain [43]. During this critical phase, the patient undergoes close hemodynamic monitoring, including analysis of hematological and biochemical parameters and chest radiographs to immediately detect signs of bleeding or other abnormalities. If the monitored parameters are within the limits specified in the guidelines and the amount of bleeding meets the predefined safety criteria, the patient is gradually awakened from anesthesia and then extubated. The stay in the intensive care unit lasts a total of 24 hours. Thereafter, a repeat blood test and chest X-ray are performed to confirm the absence of complications before the patient is approved for transfer to the cardiothoracic surgery ward. Post-operative management on the ward aims to promote healing and avoid complications. On the second postoperative day, the chest drain is removed and the surgical wound is dressed. This procedure is repeated every other day until complete healing is achieved. Between the fourth and fifth day after surgery,

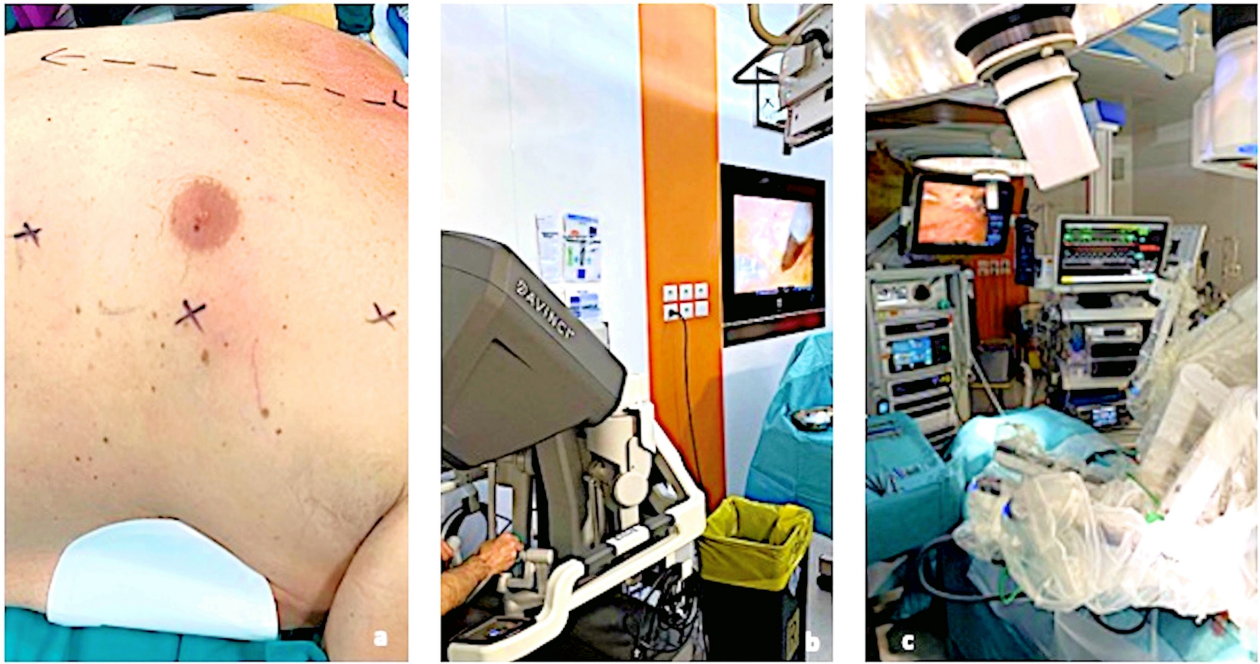


Fig. 1. Patient preparation phases for a robotically assisted minimally invasive direct coronary artery bypass (RA-MIDCAB). (a) shows the precise preoperative markings on the patient's chest. (b) shows the robotic system positioned for surgery, while (c) shows the robot actively involved in the RA-MIDCAB procedure, surrounded by the surgical team and advanced technology in the operating room.

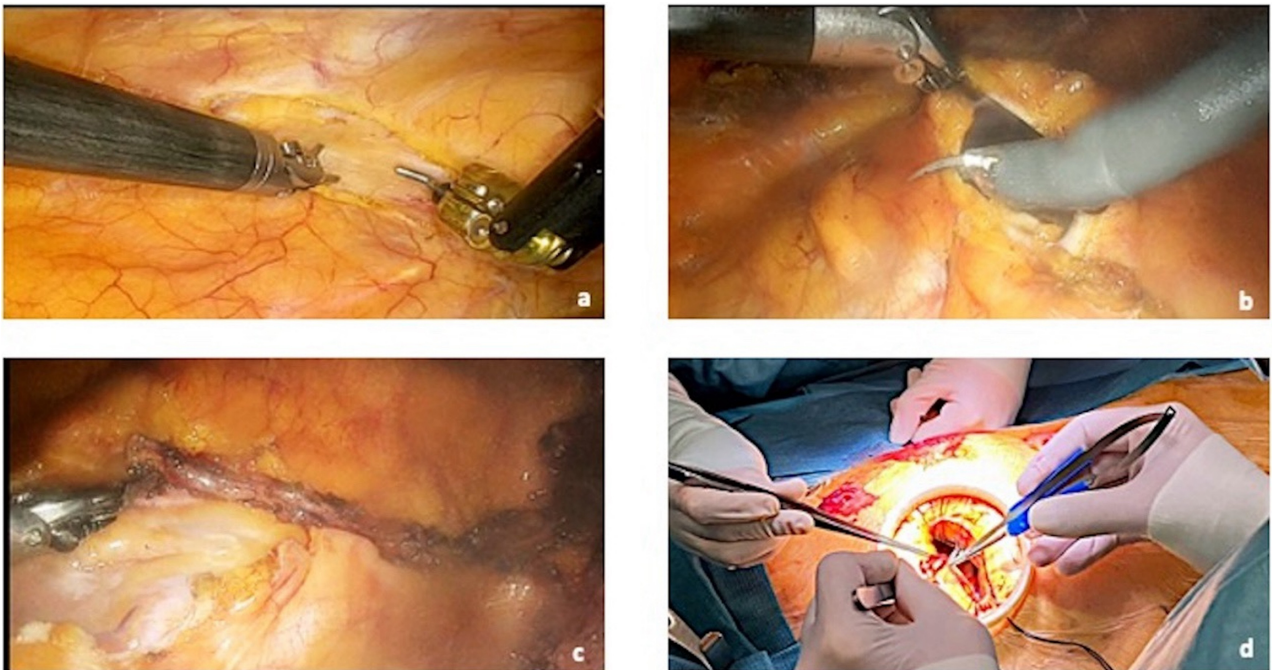


Fig. 2. Visual overview of the operative phases of RA-MIDCAB. (a,b) show the careful incisions through the pleura and pericardium, respectively. (c) focuses on the meticulous isolation of the left internal mammary artery (LIMA). (d) The last panel shows the anastomosis between the LIMA and the left anterior descending artery (LAD), which was performed via a mini-thoracotomy approach.

an echocardiographic check is performed to assess cardiac function and detect possible complications, such as a pericardial effusion. If there are no significant abnormalities, the patient can be discharged, which usually happens be-

tween the fourth and fifth postoperative day. Postoperative care continues at home, with sutures removed in the previously drained region between the tenth and fifteenth day. Approximately one month after discharge, the patient

is called back for an outpatient follow-up visit, which officially concludes the surgical procedure. This multilevel approach to postoperative care aims to optimize the patient's recovery, minimize the risk of complications and accelerate the healing process [44].

Percutaneous versus Surgical Revascularization

The cornerstone of the decision between percutaneous and surgical revascularization was the SYNTAX trial [45]. This multicenter, randomized trial, initiated in 2005, involved 85 medical centers in 17 countries. It included 1800 patients with complex coronary artery disease, including patients with three-vessel disease and left main coronary artery disease. Patients were assigned in a 1:1 ratio to either PCI with the first-generation paclitaxel-eluting Taxus stent or CABG.

The SYNTAX trial introduced the SYNTAX score, a tool for grading the complexity of coronary artery disease to help physicians decide on the most appropriate treatment. The primary results published in 2009 showed that PCI was associated with similar rates of death and myocardial infarction compared to CABG but had higher rates of repeat revascularization [45]. CABG showed better efficacy in patients with higher SYNTAX scores indicating more complex coronary disease. Long-term follow-up data showed that CABG was superior to PCI in terms of major adverse cardiac and cerebrovascular events, especially in patients with higher SYNTAX scores [46,47]. The SYNTAX trial has significantly influenced guidelines [5,6] and the treatment of complex coronary artery disease by emphasizing a personalized approach based on anatomic complexity. However, it is important to note that the SYNTAX trial used a first-generation drug-eluting stent.

Recent randomized controlled trials (RCTs) have compared surgical and percutaneous revascularization in complex coronary anatomies using new generation DES [48]. These studies have significantly narrowed the gap between PCI and CABG in the treatment of LM coronary artery disease and multivessel CAD.

While the indication for CABG in patients with a high SYNTAX score is now well established, the optimal approach for LM disease with low to moderate SYNTAX scores remains controversial. The NOBLE trial [49], which focused on patients with LM disease, failed to demonstrate the non-inferiority of PCI over CABG. In contrast, the EXCEL trial found that PCI with everolimus-eluting stents was comparable to CABG in terms of the composite endpoint of death, stroke or myocardial infarction at three years [50].

The interpretation and methodology of these RCTs is controversial, particularly regarding the criteria for patient selection, the endpoints considered and the duration of follow-up.

In a comprehensive meta-analysis including data from EXCEL and NOBLE, a cohort of 4595 patients with coronary artery disease LM was studied. Despite some methodological limitations such as the lack of stratification according to the anatomical complexity of CAD and patients' comorbidities, the analysis showed that the risks for all-cause mortality, cardiovascular mortality, myocardial infarction and stroke were comparable between PCI and CABG after a median follow-up of 60 months [51]. In addition, a meta-analysis of 11 randomized trials showed a mortality benefit of coronary CABG over PCI, especially in patients with diabetes and in patients with high SYNTAX scores. However, in LM coronary artery disease, survival rates were similar between PCI and CABG, regardless of diabetes status or SYNTAX score [52].

Specific indications for PCI or CABG can be identified, such as high coronary complexity reflected in a high SYNTAX score or increased operative risk for CABG due to comorbidities. Both anatomic complexity such as multivessel or LM involvement, the presence of CTOs or severe calcified stenosis, and individual patient factors, including diabetes status, play a role in deciding on the optimal revascularization strategy.

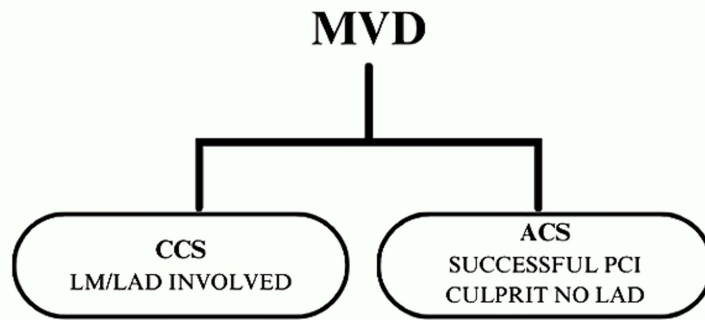
In this context, the SYNTAX II score becomes an important tool [53]. In contrast to the original SYNTAX score, which focused primarily on anatomic complexity, this score incorporates clinical variables and comorbidities, providing a more comprehensive assessment to inform the treatment decision between PCI and CABG in complex cases.

Hybrid Coronary Revascularization

Current Status

With the increasing complexity of clinical cases and the improvement of revascularization techniques, Hybrid Coronary Revascularization (HCR) has become an increasingly important approach in recent decades [54]. It combines the benefit of CABG surgery with PCI. The main advantage of HCR is that it is less invasive compared to traditional CABG, resulting in shorter hospital stays and faster recovery times [55]. In addition, HCR allows for precise treatment of complex lesions using PCI while offering the durability of surgical bypass revascularization. Conventional HCR typically combines procedures such as MIDCAB using the LIMA to the LAD artery and is complemented by PCI on at least one non-LAD coronary artery. In more advanced HCR variants, both internal thoracic arteries (ITAs) are used, extending access not only to the LAD but also to the left circumflex artery or diagonal branches [56].

In a prospective, non-randomized study, Bachinsky *et al.* [57] reported a significant reduction in blood transfusions (12% vs. 67%, $p < 0.001$) and hospital stays (5.1 ±



Patient related features	Coronary anatomy related features	Surgical related features
Diabetes	Long stenosis	STS score > 5
Morbidly obesity	Severe calcified stenosis	Severe aortic calcification
Severely compromised cardiac function	CTO with high JCTO score	Prior sternotomy
COPD	Previous unsuccessful PCI	High risk of deep sternal wound infection
Renal Failure		Absence of suitable venous conduits
HBR		
Significant carotid stenosis		
Significant neurologic disease		

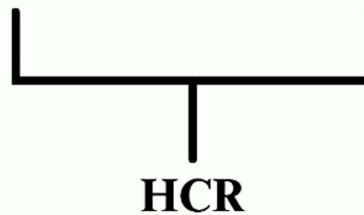


Fig. 3. Clinical, anatomical and surgical characteristics of a patient who could ideally be referred for an HCR procedure in our center. List of abbreviations: MVD, multivessel disease; ACS, acute coronary syndrome; CCS, stable coronary artery disease; LM, left main; LAD, left anterior descending; PCI, percutaneous coronary intervention; COPD, chronic obstructive pulmonary disease; HBR, high bleeding risk; CTO, chronic total occlusion; HCR, hybrid coronary revascularization.

0.8 vs. 8.2 ± 5.4 days, $p < 0.01$) with HCR compared to CABG Length of hospital stay was examined as a secondary endpoint in the HREVS (Residual Myocardial Ischemia and Clinical Outcomes at One Year—Hybrid coronary REvascularization Versus Stenting or Surgery) trial [58]. Both CABG and HCR surgery were associated with a longer hospital stay compared to PCI, with no significant differences between CABG and HCR (13.8 days and 13.5 days, respectively). In addition, the rate of MACCE in the HCR group (secondary endpoint) was the same as in the CABG group.

These results are consistent with those from the POLMIDES study [59]. In particular, it was found that the mortality rate at 5 years was similar between the HCR group (6.4%) and the CABG group (9.2%). In addition, no significant differences were found between the two groups in terms of myocardial infarction, repeat revascularization and

major adverse cardiovascular and cerebrovascular events (MACCE). On the other hand, a small, randomized pilot study by Esteves *et al.* [60] found a possible tendency towards increased revascularization and myocardial infarction in patients with high SYNTAX scores.

This trial suggests that HCR is a safe and viable option for patients with multivessel disease. This trend towards increased revascularization after HCR was also observed in a meta-analysis of 9 studies by Nolan *et al.* [61]. Despite these results, HCR was associated with a shorter ICU stay (25.4 hours for HCR vs. 45.7 hours for CABG) and hospitalization (6.0 days for HCR vs. 7.8 days for CABG) and fewer infections (OR, 0.19; 95% CI, 0.04–0.98) compared to CABG. A recent meta-analysis by Lui Yu *et al.* [62] evaluated a total of 18 studies, including three randomized trials and 15 observational studies, which included 2041 cases of

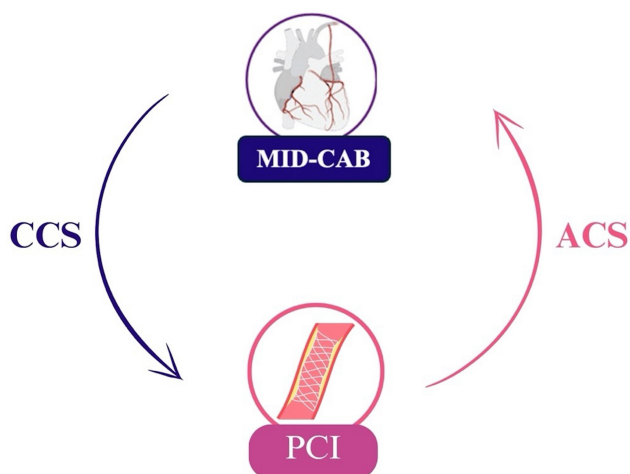


Fig. 4. Timing of HCR intervention based on the patient's clinical presentation. In stable patients in particular, a CABG-first approach is usually preferred, whereas in patients with ACS, especially those with a culprit lesion that is not part of the left anterior descending branch, a PCI-first strategy is usually used. List of abbreviations: ACS, acute coronary syndrome; CCS, stable coronary artery disease; PCI, percutaneous coronary intervention; MID-CAB, minimally invasive direct – coronary artery bypass.

hybrid coronary revascularization (HCR) and 2993 cases of coronary artery bypass grafting (CABG).

The study found that there was no statistically significant difference in the incidence of major adverse cardiac and cerebrovascular events (MACCE) between the two procedures in the short-term follow-up periods (<30 days OR = 0.90, 95% CI 0.54–1.48, $p = 0.67$), medium-term (1 to 5 years OR = 1.25, 95% CI 0.53–2.97, $p = 0.61$), and long-term (>5 years OR = 0.93, 95% CI 0.61–1.41, $p = 0.72$). In addition, patients who underwent HCR had a lower risk of death than patients who underwent CABG in the long-term follow-up (OR = 0.35, 95% CI 0.18–0.69, $p = 0.002$). HCR patients had a significantly lower rate of blood transfusion (OR = 0.38, 95% CI 0.28–0.51, $p < 0.001$) and experienced shorter times in the ICU (WMD = –13.34, 95% CI –20.27 to –6.41), $p < 0.001$ and hospital (WMD = –1.62, 95% CI –2.38 to –0.85), $p < 0.001$) compared to those who underwent CABG. In addition, less atrial fibrillation and infection occurred in the HCR group compared to the CABG group (R = 0.58, 95% CI 0.36–0.93, $p = 0.02$ and OR = 0.24, 95% CI 0.09–0.64, $p = 0.004$, respectively). The current evidence suggests that HCR is not inferior to CABG in patients with multivessel disease. However, it should be noted that these data are based on small randomized clinical trials, which may limit the generalizability of the results. In addition, the selection of patients and the timing of the intervention are crucial aspects that need to be considered. It should also be recognized that performing two high-risk interventions (PCI and MIDCAB) in a short period of time can be a significant logistical and financial challenge.

Patient Selection

Careful selection of patients for HCR requires a comprehensive assessment of their clinical and anatomical characteristics to determine the most appropriate therapeutic approach. In such scenarios, strategies such as MIDCAB at the LAD, possibly followed by PCI at other vessels, are a safer alternative to conventional open surgery [63].

Ideal candidates are patients with anatomical challenges that make them unsuitable for PCI, especially in the area between the LM and LAD. This group includes patients with long or heavily calcified stenoses, where under-expansion of the stent is highly likely or where extensive vessel stenting is required, as well as patients with CTOs in anatomies unfavorable for PCI or with a previous unsuccessful PCI attempt.

In addition, the patient's risk profile is critical to their suitability for HCR.

It is important to carefully assess the risk of bleeding from dual antiplatelet therapy (DAPT) and other comorbidities that may affect the outcome of the procedure. Patients with diabetes, morbid obesity, severely impaired cardiac function, COPD, renal failure, significant carotid stenosis or neurological disease are prime candidates for a less invasive HCR procedure. The decision-making process also includes an assessment of surgical-related risk. Severe aortic calcification, prior sternotomy, risk of deep sternal wound infection, and lack of adequate venous conduits are conditions that should lead to considering HCR as the optimal treatment (Fig. 3).

Timing

The appropriate timing of intervention for HCR depends on a combination of clinical factors, such as whether the patient has stable coronary artery disease (CCS) or acute coronary syndrome (ACS) (Fig. 4), as well as anatomic considerations. For example, patients with a sub-occlusive stenosis in the LM coronary artery cannot be safely discharged and treated later, unlike patients with a CTO of the LAD, in whom later intervention may be more feasible.

There are two approaches to HCR: a simultaneous procedure or a 'second stage' procedure [64].

The simultaneous approach, which is performed during the same hospitalization, usually involves CABG before PCI (Fig. 4). This sequence allows assessment of the LIMA-LAD graft prior to PCI. Typically, the MIDCAB procedure is performed with acetylsalicylic acid 100 mg therapy, while a single loading dose of clopidogrel (600 mg) is administered immediately prior to PCI. This approach may increase cost-effectiveness, reduce hospital length of stay and improve patient satisfaction, although it is challenging to balance antiplatelet therapy with surgical bleeding risks.

In contrast, the 'second stage' procedure typically depends on the clinical presentation and coronary anatomy.

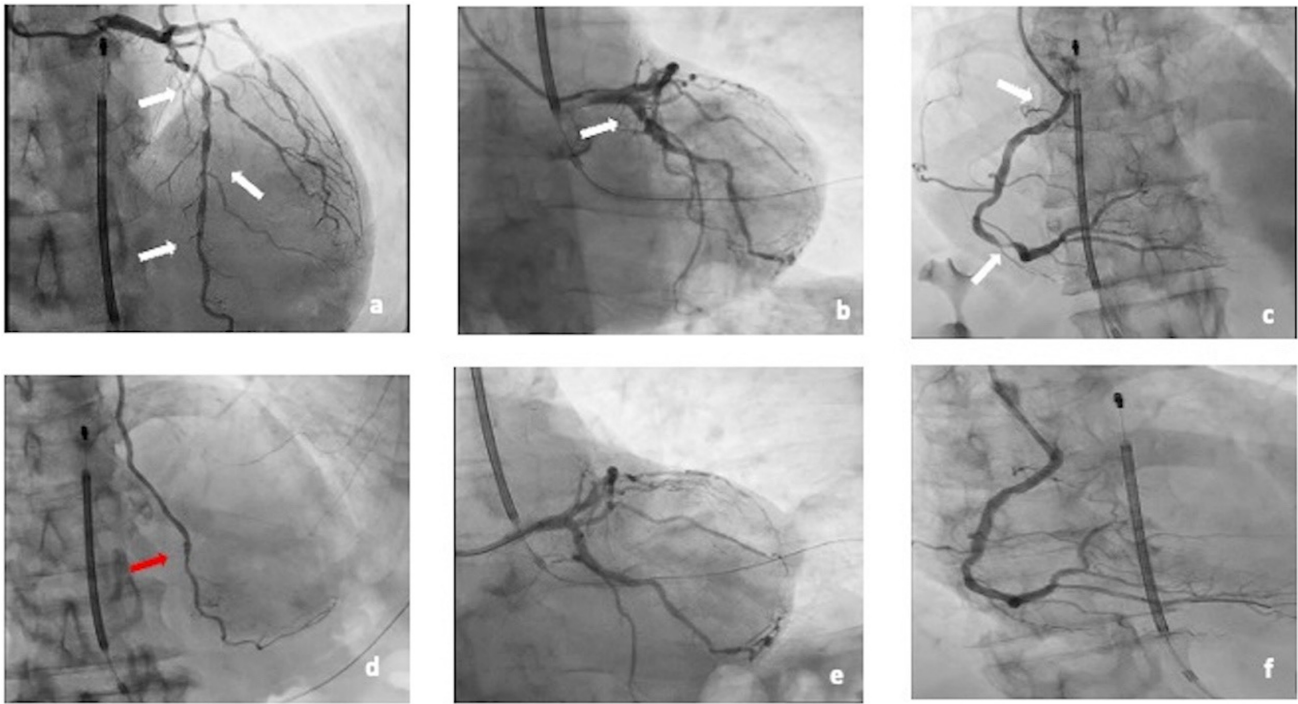


Fig. 5. Hybrid coronary revascularization case. Coronary angiography revealed a long, heavily calcified stenosis in the proximal to mid left anterior descending (LAD) artery (a), a focal stenosis in the proximal left circumflex artery (b), and a severe stenosis in the proximal and mid-distal right coronary artery (c). After a discussion in the Heart Team, a hybrid coronary revascularization (HCR) strategy was chosen. A robotic-assisted minimally invasive direct coronary artery bypass (RA-MIDCAB) was performed to bypass the LAD with the left internal mammary artery. Subsequent angiography confirmed the patency of the graft (d). The left circumflex and right coronary arteries were then successfully stented (e,f). The white arrows show the coronary stenosis, while the red arrow represents the anastomosis between LIMA and LAD.

A CABG-first approach is usually preferred, especially in stable patients who prefer revascularization of a larger myocardial area. This approach allows revascularization of lesions previously considered unsuitable for PCI and expands treatment options (Fig. 5). For example, a complex lesion involving the distal left main bifurcation can be easily treated with a provisional single stent strategy from LM to left circumflex (LCx) artery after confirming patency of the LIMA-LAD graft during PCI. It is our practice to give the patient aspirin before CABG, while the second antiplatelet agent is used after the bypass procedure.

Alternatively, a PCI-first strategy is usually applicable in patients with ACS, especially in patients undergoing PCI for a non-LAD culprit lesion and significant comorbidities. However, this strategy increases the risk of bleeding during subsequent surgery, as DAPT usually starts before PCI. However, previous studies have shown promising results for staged HCR in ACS scenarios, with an average of 10–14 days between PCI and surgery [65] (Fig. 4).

Future Directions

Available data suggest that hybrid coronary revascularization provides equivalent long-term outcomes in

terms of major adverse cardiac and cerebrovascular events (MACCE) and mortality, while reducing in-hospital morbidity and shortening hospital length of stay by reducing the need for blood transfusion and the incidence of infection [56–61]. However, the available evidence comes from small randomized controlled trials and further studies with larger cohorts are needed to confirm the efficacy of this technique. Regrettably, the Hybrid Coronary Revascularization trial (NCT03089398), which was designed to compare HCR with multivessel PCI, was terminated early due to slow patient recruitment and limited surgeon experience in MIDCAB. The rationale of hybrid revascularization is to perform the bypass in a minimally invasive manner, thereby reducing surgical trauma and improving recovery. It is worth noting that robotic CABG currently accounts for only 1% of all CABGs performed in North America. This is due to several factors, including a lack of data in the medical literature and a steep learning curve. Experts estimate that perfecting this technique requires approximately 250–500 interventions with at least 2 years of training [66].

Recently, a study by Dokollari *et al.* [42] analyzed the data of 2280 patients who underwent robotic CABG between 2005 and 2021. The patients were divided into three groups based on the years in which they underwent the

procedure. The study found that the third group, who underwent the procedure from 2017–2021, had a significantly lower mortality rate (3.8% compared to 4.9% in Group I, $p < 0.01$) and fewer major adverse cardiac and cerebrovascular events (16% compared to 26% in Group I) over a median follow-up period of 4.2 years. In addition, the third group had a shorter hospital stay ($p < 0.001$), a lower need for intraoperative blood transfusion ($p < 0.001$) and a lower rate of postoperative renal failure ($p < 0.001$). Furthermore, these results suggest that with further research and refinement of the technique, the use of robotic-assisted CABG could increase in the future, which in turn would allow for an increase in the rate of hybrid revascularization.

Conclusions

The role of HCR outside specific patient groups remains uncertain as there are no comprehensive randomized trials. HCR is a valid treatment option for patients at high risk for standard coronary artery bypass graft surgery. Patient selection should be individualized and based on a Heart Team approach. Large-scale RCTs are essential to establish a solid evidence base for these methods and to conclusively demonstrate their impact on patient outcomes. Ongoing studies, such as the forthcoming prospective MIST trial (NCT03447938), are likely to provide much-needed clarity in this area.

Abbreviations

CAD, Coronary Artery Disease; HRC, Hybrid Coronary Revascularization; PCI, Percutaneous Coronary Intervention; CABG, Coronary Artery Bypass Grafting; DES, Drug-Eluting Stents; TVR, Target Vessel Revascularization; TLR, Target Lesion Revascularization; ISR, In-Stent Restenosis; ST, Stent Thrombosis; LM, Left Main; CTO, Chronic Total Occlusions; IVL, Intravascular lithotripsy; FFR, Fractional Flow Reserve; QFR, Quantitative Flow Ratio; CPB, Cardiopulmonary Bypass; OPCAB, Off-Pump Coronary Artery By-pass; MIDCAB, Minimally Invasive Direct Coronary Artery By-pass; RA-MIDCAB, Robotic-assisted minimally invasive direct coronary artery by-pass; TECAB, Totally Endoscopic Coronary Artery By-pass; LIMA, Left Internal Mammary Artery; ITAs, internal thoracic arteries; LAD, Left Anterior Descending artery; LCX, Left Circumflex artery; RCA, Right Coronary Artery; DAPT, Dual Antiplatelet Therapy; CCS, Stable Coronary Artery Disease; ACS, Acute Coronary Syndrome; MACCE, Major Adverse Cardiovascular Events; RCTs, Randomized Controlled Trials.

Author Contributions

AT and EMN designed the research study. FDA, CC and VF conducted the bibliographic research. AT, EMN, FDA, CC and VF wrote the manuscript. VF created the figures. SA wrote the manuscript and created the figures. AB contributed to study conception. EB and GM designed the research study and critically reviewed the manuscript, contributing to its increased valued. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity are addressed.

Ethics Approval and Consent to Participate

Not applicable.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

Prof E. Barbato reports speaker fees from Boston Scientific, Abbott, and Insight Lifetech. The remaining authors have no conflict of interest “including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work”.

References

- [1] Head SJ, Börgermann J, Osnabrugge RLJ, Kieser TM, Falk V, Taggart DP, *et al.* Coronary artery bypass grafting: Part 2—optimizing outcomes and future prospects. *European Heart Journal.* 2013; 34: 2873–2886.
- [2] Kirtane AJ, Doshi D, Leon MB, Lasala JM, Ohman EM, O’Neill WW, *et al.* Treatment of Higher-Risk Patients with an Indication for Revascularization: Evolution Within the Field of Contemporary Percutaneous Coronary Intervention. *Circulation.* 2016; 134: 422–431.
- [3] Khan MA, Hashim MJ, Mustafa H, Baniyas MY, Al Suwaidi SKBM, AlKatheeri R, *et al.* Global Epidemiology of Ischemic Heart Disease: Results from the Global Burden of Disease Study. *Cureus.* 2020; 12: e9349.

- [4] Van den Eynde J, Bennett J, McCutcheon K, Adriaenssens T, Desmet W, Dubois C, *et al.* Heart team 2.0: A decision tree for minimally invasive and hybrid myocardial revascularization. *Trends in Cardiovascular Medicine*. 2021; 31: 382–391.
- [5] Neumann FJ, Sousa-Uva M, Ahlsson A, Alfonso F, Banning AP, Benedetto U, *et al.* 2018 ESC/EACTS Guidelines on myocardial revascularization. *European Heart Journal*. 2019; 40: 87–165.
- [6] Lawton JS, Tamis-Holland JE, Bangalore S, Bates ER, Beckie TM, Bischoff JM, *et al.* 2021 ACC/AHA/SCAI Guideline for Coronary Artery Revascularization: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. *Circulation*. 2022; 145: e18–e114.
- [7] Bennett J, Dubois C. A novel platinum chromium everolimus-eluting stent for the treatment of coronary artery disease. *Biologics: Targets & Therapy*. 2013; 7: 149–159.
- [8] Bangalore S, Kumar S, Fusaro M, Amoroso N, Attubato MJ, Feit F, *et al.* Short- and long-term outcomes with drug-eluting and bare-metal coronary stents: a mixed-treatment comparison analysis of 117 762 patient-years of follow-up from randomized trials. *Circulation*. 2012; 125: 2873–2891.
- [9] Tommasino A, Burzotta F, Sciahbasi A, Trani C, De Vita M, Romagnoli E, *et al.* Procedural and clinical evaluation of the novel zotarolimus-eluting resolute stent in patients with unselected bifurcated coronary stenosis treated by provisional approach: a multicenter registry. *The Journal of Invasive Cardiology*. 2011; 23: 50–54.
- [10] Navarese EP, Tandjung K, Claessen B, Andreotti F, Kowalewski M, Kandzari DE, *et al.* Safety and efficacy outcomes of first and second generation durable polymer drug eluting stents and biodegradable polymer biolimus eluting stents in clinical practice: comprehensive network meta-analysis. *BMJ (Clinical Research Ed.)*. 2013; 347: f6530.
- [11] Moreno PR, Stone GW, Gonzalez-Lengua CA, Puskas JD. The Hybrid Coronary Approach for Optimal Revascularization: JACC Review Topic of the Week. *Journal of the American College of Cardiology*. 2020; 76: 321–333.
- [12] Wang C, Liu S, Kamronbek R, Ni S, Cheng Y, Yan H, *et al.* Percutaneous Coronary Intervention versus Coronary Artery Bypass Grafting for Chronic Total Occlusion of Coronary Arteries: A Systematic Review and Meta-Analysis. *Journal of Interventional Cardiology*. 2023; 2023: 9928347.
- [13] Angsubhakorn N, Kang N, Fearon C, Techorueangwiwat C, Swamy P, Brilakis ES, *et al.* Contemporary Management of Severely Calcified Coronary Lesions. *Journal of Personalized Medicine*. 2022; 12: 1638.
- [14] Otsuka Y, Koyama T, Imoto Y, Katsuki Y, Kawahara M, Nakamura K, *et al.* Prolonged Inflation Technique Using a Scoring Balloon for Severe Calcified Lesion. *International Heart Journal*. 2017; 58: 982–987.
- [15] Okura H, Hayase M, Shimodozono S, Kobayashi T, Sano K, Matsushita T, *et al.* Mechanisms of acute lumen gain following cutting balloon angioplasty in calcified and noncalcified lesions: an intravascular ultrasound study. *Catheterization and Cardiovascular Interventions: Official Journal of the Society for Cardiac Angiography & Interventions*. 2002; 57: 429–436.
- [16] Rheude T, Rai H, Richardt G, Allali A, Abdel-Wahab M, Sulimov DS, *et al.* Super high-pressure balloon versus scoring balloon to prepare severely calcified coronary lesions: the ISAR-CALC randomised trial. *EuroIntervention: Journal of EuroPCR in Collaboration with the Working Group on Interventional Cardiology of the European Society of Cardiology*. 2021; 17: 481–488.
- [17] Barbato E, Gallinoro E, Abdel-Wahab M, Andreini D, Carrié D, Di Mario C, *et al.* Management strategies for heavily calcified coronary stenoses: an EAPCI clinical consensus statement in collaboration with the EURO4C-PCR group. *European Heart Journal*. 2023; 44: 4340–4356.
- [18] Kereiakes DJ, Ali ZA, Riley RF, Smith TD, Shlofmitz RA. Intravascular Lithotripsy for Treatment of Calcified Coronary Artery Disease. *Interventional Cardiology Clinics*. 2022; 11: 393–404.
- [19] Azzalini L, Ancona MB, Bellini B, Chieffo A, Carlino M, Montorfano M. Intravascular Lithotripsy and Microaxial Percutaneous Left Ventricular Assist Device for Complex and High-Risk Percutaneous Coronary Intervention. *The Canadian Journal of Cardiology*. 2019; 35: 940.e5–940.e7.
- [20] Lee JM, Hwang D, Choi KH, Rhee TM, Park J, Kim HY, *et al.* Prognostic Implications of Relative Increase and Final Fractional Flow Reserve in Patients with Stent Implantation. *JACC: Cardiovascular Interventions*. 2018; 11: 2099–2109.
- [21] Fournier S, Ciccarelli G, Toth GG, Milkas A, Xaplanteris P, Tonino PAL, *et al.* Association of Improvement in Fractional Flow Reserve with Outcomes, Including Symptomatic Relief, After Percutaneous Coronary Intervention. *JAMA Cardiology*. 2019; 4: 370–374.
- [22] Lee JM, Lee SH, Shin D, Choi KH, van de Hoef TP, Kim HK, *et al.* Physiology-Based Revascularization: A New Approach to Plan and Optimize Percutaneous Coronary Intervention. *JACC: Asia*. 2021; 1: 14–36.
- [23] De Bruyne B, Pijls NHJ, Kalesan B, Barbato E, Tonino PAL, Piroth Z, *et al.* Fractional flow reserve-guided PCI versus medical therapy in stable coronary disease. *The New England Journal of Medicine*. 2012; 367: 991–1001.
- [24] Cerrato E, Mejía-Rentería H, Franzè A, Quadri G, Belligiano D, Biscaglia S, *et al.* Quantitative flow ratio as a new tool for angiography-based physiological evaluation of coronary artery disease: a review. *Future Cardiology*. 2021; 17: 1435–1452.
- [25] Gaudino M, Bakaen F, Davierwala P, Di Franco A, Fremes SE, Patel N, *et al.* New Strategies for Surgical Myocardial Revascularization. *Circulation*. 2018; 138: 2160–2168.
- [26] Kolessov VI. Mammmary artery-coronary artery anastomosis as method of treatment for angina pectoris. *The Journal of Thoracic and Cardiovascular Surgery*. 1967; 54: 535–544.
- [27] Bakaen FG, Blackstone EH, Pettersson GB, Gillinov AM, Svensson LG. The father of coronary artery bypass grafting: René Favaloro and the 50th anniversary of coronary artery bypass grafting. *The Journal of Thoracic and Cardiovascular Surgery*. 2018; 155: 2324–2328.
- [28] Head SJ, Kieser TM, Falk V, Huysmans HA, Kappetein AP. Coronary artery bypass grafting: Part 1—the evolution over the first 50 years. *European Heart Journal*. 2013; 34: 2862–2872.
- [29] Farina P, Gaudino M, Angelini GD. Off-pump coronary artery bypass surgery: The long and winding road. *International Journal of Cardiology*. 2019; 279: 51–55.
- [30] Shaefi S, Mittel A, Loberman D, Ramakrishna H. Off-Pump Versus On-Pump Coronary Artery Bypass Grafting—A Systematic Review and Analysis of Clinical Outcomes. *Journal of Cardiothoracic and Vascular Anesthesia*. 2019; 33: 232–244.
- [31] Lamy A, Devereaux PJ, Prabhakaran D, Taggart DP, Hu S, Straka Z, *et al.* Five-Year Outcomes after Off-Pump or On-Pump Coronary-Artery Bypass Grafting. *The New England Journal of Medicine*. 2016; 375: 2359–2368.
- [32] Shroyer AL, Hattler B, Wagner TH, Collins JF, Baltz JH, Quin JA, *et al.* Five-Year Outcomes after On-Pump and Off-Pump Coronary-Artery Bypass. *The New England Journal of Medicine*. 2017; 377: 623–632.
- [33] Hammal F, Nagase F, Menon D, Ali I, Nagendran J, Stafinski T. Robot-assisted coronary artery bypass surgery: a systematic review and meta-analysis of comparative studies. *Canadian Journal of Surgery. Journal Canadien De Chirurgie*. 2020; 63: E491–E508.
- [34] Gofus J, Cerny S, Shahin Y, Sorm Z, Vobornik M, Smolak P,

- et al.* Robot-assisted vs. conventional MIDCAB: A propensity-matched analysis. *Frontiers in Cardiovascular Medicine*. 2022; 9: 943076.
- [35] Derose JJ, Jr, Balam SK, Ro C, Swistel DG, Singh V, Wilentz JR, *et al.* Mid-term results and patient perceptions of robotically-assisted coronary artery bypass grafting. *Interactive Cardiovascular and Thoracic Surgery*. 2005; 4: 406–411.
- [36] Halkos ME, Liberman HA, Devireddy C, Walker P, Finn AV, Jaber W, *et al.* Early clinical and angiographic outcomes after robotic-assisted coronary artery bypass surgery. *The Journal of Thoracic and Cardiovascular Surgery*. 2014; 147: 179–185.
- [37] Torregrossa G, Kanei Y, Puskas J. Hybrid robotic coronary artery bypass grafting: how do we do it. *Annals of Cardiothoracic Surgery*. 2016; 5: 582–585.
- [38] Gong W, Cai J, Wang Z, Chen A, Ye X, Li H, *et al.* Robot-assisted coronary artery bypass grafting improves short-term outcomes compared with minimally invasive direct coronary artery bypass grafting. *Journal of Thoracic Disease*. 2016; 8: 459–468.
- [39] Sabashnikov A, Patil NP, Weymann A, Mohite PN, Zych B, Garcia Sáez D, *et al.* Outcomes after different non-sternotomy approaches to left single-vessel revascularization: a comparative study with up to 10-year follow-up. *European Journal of Cardiothoracic Surgery: Official Journal of the European Association for Cardio-thoracic Surgery*. 2014; 46: e48–55.
- [40] Balkhy HH, Nisivaco S, Kitahara H, AbuTaleb A, Nathan S, Hamzat I. Robotic advanced hybrid coronary revascularization: Outcomes with two internal thoracic artery grafts and stents. *JTCVS Techniques*. 2022; 16: 76–88.
- [41] Repossini A, Di Bacco L, Nicoli F, Passaretti B, Stara A, Jonida B, *et al.* Minimally invasive coronary artery bypass: Twenty-year experience. *The Journal of Thoracic and Cardiovascular Surgery*. 2019; 158: 127–138.e1.
- [42] Dokollari A, Sicouri S, Erten O, Gray WA, Shapiro TA, McGeehin F, *et al.* Long-term clinical outcomes of robotic-assisted surgical coronary artery revascularisation. *EuroIntervention: Journal of EuroPCR in Collaboration with the Working Group on Interventional Cardiology of the European Society of Cardiology*. 2024; 20: 45–55.
- [43] Ul Islam M, Ahmad I, Khan B, Jan A, Ali N, Hassan Khan W, *et al.* Early Chest Re-Exploration for Excessive Bleeding in Post Cardiac Surgery Patients: Does It Matter? *Cureus*. 2021; 13: e15091.
- [44] Spanjersberg A, Hoek L, Ottervanger JP, Nguyen TY, Kaplan E, Laurens R, *et al.* Early home discharge after robot-assisted coronary artery bypass grafting. *Interactive Cardiovascular and Thoracic Surgery*. 2022; 35: ivac134.
- [45] Mohr FW, Morice MC, Kappetein AP, Feldman TE, Ståhle E, Colombo A, *et al.* Coronary artery bypass graft surgery versus percutaneous coronary intervention in patients with three-vessel disease and left main coronary disease: 5-year follow-up of the randomised, clinical SYNTAX trial. *Lancet (London, England)*. 2013; 381: 629–638.
- [46] Serruys PW, Morice MC, Kappetein AP, Colombo A, Holmes DR, Mack MJ, *et al.* Percutaneous coronary intervention versus coronary-artery bypass grafting for severe coronary artery disease. *The New England Journal of Medicine*. 2009; 360: 961–972.
- [47] Thuijs DJFM, Kappetein AP, Serruys PW, Mohr FW, Morice MC, Mack MJ, *et al.* Percutaneous coronary intervention versus coronary artery bypass grafting in patients with three-vessel or left main coronary artery disease: 10-year follow-up of the multicentre randomised controlled SYNTAX trial. *Lancet (London, England)*. 2019; 394: 1325–1334.
- [48] Sabatine MS, Bergmark BA, Murphy SA, O’Gara PT, Smith PK, Serruys PW, *et al.* Percutaneous coronary intervention with drug-eluting stents versus coronary artery bypass grafting in left main coronary artery disease: an individual patient data meta-analysis. *Lancet (London, England)*. 2021; 398: 2247–2257.
- [49] Holm NR, Mäkikallio T, Lindsay MM, Spence MS, Erglis A, Menown IBA, *et al.* Percutaneous coronary angioplasty versus coronary artery bypass grafting in the treatment of unprotected left main stenosis: updated 5-year outcomes from the randomised, non-inferiority NOBLE trial. *Lancet (London, England)*. 2020; 395: 191–199.
- [50] Azzalini L, Stone GW. Percutaneous Coronary Intervention or Surgery for Unprotected Left Main Disease: EXCEL Trial at 5 Years. *Interventional Cardiology Clinics*. 2020; 9: 419–432.
- [51] Garg A, Rao SV, Agrawal S, Theodoropoulos K, Mennuni M, Sharma A, *et al.* Meta-Analysis of Randomized Controlled Trials of Percutaneous Coronary Intervention with Drug-Eluting Stents Versus Coronary Artery Bypass Grafting in Left Main Coronary Artery Disease. *The American Journal of Cardiology*. 2017; 119: 1942–1948.
- [52] Head SJ, Milojevic M, Daemen J, Ahn JM, Boersma E, Christiansen EH, *et al.* Mortality after coronary artery bypass grafting versus percutaneous coronary intervention with stenting for coronary artery disease: a pooled analysis of individual patient data. *Lancet (London, England)*. 2018; 391: 939–948.
- [53] Farooq V, van Klaveren D, Steyerberg EW, Meliga E, Vergouwe Y, Chieffo A, *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 (London, England)*. 2013; 381: 639–650.
- [54] Toeg H, Al-Atassi T, Labinaz M, Le May M, Ruel M. Hybrid approach for coronary artery revascularization: where do we stand? *Current Opinion in Cardiology*. 2014; 29: 534–541.
- [55] Patel NC, Hemli JM, Kim MC, Seetharam K, Pirelli L, Brinster DR, *et al.* Short- and intermediate-term outcomes of hybrid coronary revascularization for double-vessel disease. *The Journal of Thoracic and Cardiovascular Surgery*. 2018; 156: 1799–1807.e3.
- [56] Rodriguez M, Ruel M. Minimally Invasive Multivessel Coronary Surgery and Hybrid Coronary Revascularization: Can We Routinely Achieve Less Invasive Coronary Surgery? *Methodist DeBakey Cardiovascular Journal*. 2016; 12: 14–19.
- [57] Bachinsky WB, Abdelsalam M, Boga G, Kiljanek L, Mumtaz M, McCarty C. Comparative study of same sitting hybrid coronary artery revascularization versus off-pump coronary artery bypass in multivessel coronary artery disease. *Journal of Interventional Cardiology*. 2012; 25: 460–468.
- [58] Ganyukov V, Kochergin N, Shilov A, Tarasov R, Skupien J, Szot W, *et al.* Randomized Clinical Trial of Surgical vs. Percutaneous vs. Hybrid Revascularization in Multivessel Coronary Artery Disease: Residual Myocardial Ischemia and Clinical Outcomes at One Year-Hybrid coronary REvascularization Versus Stenting or Surgery (HREVS). *Journal of Interventional Cardiology*. 2020; 2020: 5458064.
- [59] Tajstra M, Hrapkiewicz T, Hawranek M, Filipiak K, Gierlotka M, Zembala M, *et al.* Hybrid Coronary Revascularization in Selected Patients with Multivessel Disease: 5-Year Clinical Outcomes of the Prospective Randomized Pilot Study. *JACC. Cardiovascular Interventions*. 2018; 11: 847–852.
- [60] Esteves V, Oliveira MAP, Feitosa FS, Mariani J, Jr, Campos CM, Hajjar LA, *et al.* Late clinical outcomes of myocardial hybrid revascularization versus coronary artery bypass grafting for complex triple-vessel disease: Long-term follow-up of the randomized MERGING clinical trial. *Catheterization and Cardiovascular Interventions: Official Journal of the Society for Cardiac Angiography & Interventions*. 2021; 97: 259–264.
- [61] Nolan S, Filion KB, Atallah R, Moss E, Reynier P, Eisenberg MJ. Hybrid Coronary Revascularization vs Complete Coronary

- ArteryBypass Grafting for Multivessel Coronary Artery Disease: A Systematic Review and Meta-Analysis. *The Journal of Invasive Cardiology*. 2018; 30: E131–E149
- [62] Yu L, Zhu K, Du N, Si Y, Liang J, Shen R, *et al*. Comparison of hybrid coronary revascularization versus coronary artery bypass grafting in patients with multivessel coronary artery disease: a meta-analysis. *Journal of cardiothoracic surgery*. 2022; 17: 147.
- [63] Bonatti J, Lehr E, Vesely MR, Friedrich G, Bonaros N, Zimrin D. Hybrid coronary revascularization: which patients? When? How? *Current Opinion in Cardiology*. 2010; 25: 568–574.
- [64] Dimeling G, Bakaeen L, Khatri J, Bakaeen FG. CABG: When, why, and how? *Cleveland Clinic Journal of Medicine*. 2021; 88: 295–303.
- [65] Rossi M, Calabrese V, Tripepi G, Mallia G, Benedetto F, Fratto P. Staged Hybrid Coronary Revascularization in Acute Coronary Syndrome. *Annals of Thoracic Surgery Short Reports*. 2023;1: 293–297.
- [66] Whellan DJ, McCarey MM, Taylor BS, Rosengart TK, Wallace AS, Shroyer ALW, *et al*. Trends in Robotic-Assisted Coronary Artery Bypass Grafts: A Study of The Society of Thoracic Surgeons Adult Cardiac Surgery Database, 2006 to 2012. *The Annals of Thoracic Surgery*. 2016; 102: 140–146.