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Foreword

Off-Pump Coronary Artery Bypass

Professors Tohru Asai, Masami Ochi, and Hitoshi Yokoyama have created a landmark work devoted to the subject of off-pump coronary artery bypass surgery. In partnership with an outstanding list of experts in coronary surgery, they have focused in a very precise way on the finest technical details for the conduct of state-of-the-art coronary surgery. This book spans the gamut from a careful evaluation of the evidence for and against off-pump coronary bypass surgery to preoperative and intraoperative management of patients undergoing coronary bypass surgery, to an in-depth description of advanced techniques for every aspect of the procedure. There has been no previous text of this depth and breadth devoted to off-pump coronary artery surgery.

The authors guide the interested reader through detailed descriptions of the exposure of all areas of the heart, stabilization of each coronary artery target, construction of precise and reproducible distal anastomoses, and the many alternatives for state-of-the-art proximal anastomotic inflow. The many alternative techniques for arterial and composite grafting are discussed in detail, providing the reader with a road map in this important and controversial area. The value of atraumatic and precise harvesting of coronary conduits is emphasized, as intraoperative graft assessment ensures that the patency and/or ability of off-pump revascularization is optimized. Strategies to reduce stroke and to appropriately manage perioperative anticoagulation are discussed in detail.

Redo coronary bypass grafting without the use of cardiopulmonary bypass is an area of controversy, and the indications and techniques for this approach are discussed in detail. Importantly, the authors and editors of this fine book do not shy away from discussion of difficult cases, indications for conversion to on-pump surgery, and the challenges of teaching off-pump coronary bypass to our next generation of surgical colleagues. The hybrid approach to multivessel coronary artery disease and the evolving techniques of robotic coronary bypass are also discussed, as is the opportunity to combine regenerative medicine technologies, which are in rapid evolution with our off-pump techniques.

Rarely has such a reference work been written which is focused on an in-depth description and analysis of a single operation and in all other iterations. Rarely is a group of true experts assembled as has been accomplished here so that a definitive treatise can be written. Rarely is a text written that is as timely as this one to focus attention on the importance of precision and safety to optimize patient outcomes with a challenging surgical technique. The authors and editors of *Off-Pump Coronary Artery Bypass* are to be congratulated for this outstanding contribution to the surgical literature. I am confident that this text will become a cherished book that is often referenced by coronary surgeons worldwide and that it will make an important contribution to our profession and to our patients.

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Preface

From Gold Standard to Global Standard

The Hippocratic Oath of "First, do no harm" is still alive in this era as one of the medical professional's most important guidelines for medical practice. In the early twentieth century, trials to cut the coronary artery and suture a bypass graft on the beating heart were technically challenging and had a high risk of coronary artery laceration, uncontrollable bleeding, fatal arrhythmia, cardiogenic shock, and death. In the middle of the century, developments in cardiopulmonary bypass made coronary artery bypass grafting (CABG) dramatically safer, followed by a worldwide adoption of on-pump grafting. In the latter part of the century, however, progress in the understanding of the detrimental effects of cardiopulmonary bypass on the human organs rekindled the discussion of CABG's risk. Now, in the early twenty-first century, off-pump coronary artery bypass grafting (OPCAB), an emerging, promising, yet immature procedure, is in the process of growing, to establish a modern "do no harm" principle.

In the growing process of this new procedure, many questions and controversies are emerging (Fig. 1). Numerous randomized controlled trials, large database registry analyses, and other clinical studies have been involved in this debate. Proponents, opponents, and detractors have different views and opinions. So far, diffusion of OPCAB in the United States and Europe remains low, at around 20 % of all CABG. On the other hand, diffusion of OPCAB in Japan is remarkably higher (Fig. 2). What is the reason for this big difference?

All the authors of this book are OPCAB experts and proponents of the new procedure. Many of them have introduced OPCAB to Japanese surgeons, have found that cardiologists have referred more elderly patients who had been considered to have contraindications for

Controversy
Off-pump vs. On-pump

- Aortic clamp
- Technical difficulty
  - Learning curve
  - Training
  - Quality deviation: Surgeon to surgeon
- Graft patency
- Pump Conversion
- Incomplete revascularization
- Hypercoagulation status
- Long-term results

Fig. 1 Controversies in off-pump and on-pump coronary artery bypass surgery

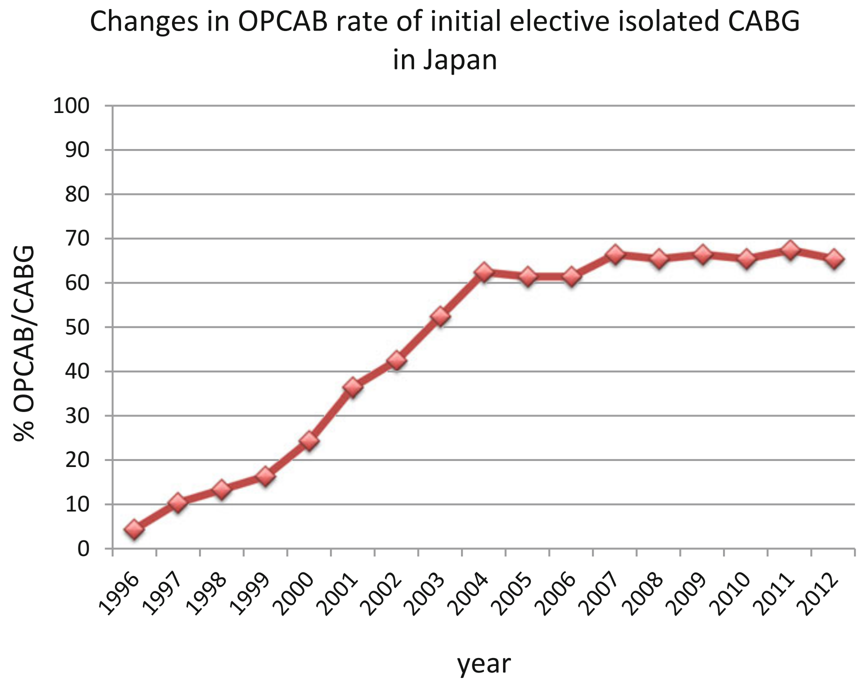

Fig. 2 Trend of off-pump/on-pump coronary artery bypass ratio in Japan (See Chap. 2: Statistics of OPCAB in Japan)

CABG, and have struggled to improve the details of daily OPCAB practice, which has led to many lessons being learned. Thanks to Kaizen Mind (a mindset for continuous, endless improvement known as the Toyota Way), we can eventually enjoy a high level of "OPCAB made in Japan". This procedure is now the gold standard for CABG in Japan. In a 2012 press release, it was announced that the doctors serving the Royal Family decided that the Emperor of Japan, an active gentleman of 78 years of age with a critical left main disease, would undergo double-vessel OPCAB with bilateral internal mammary arteries. The Emperor is now an octogenarian who is doing very well and visiting many countries while having an excellent quality of life following OPCAB surgery.

This story of an octogenarian makes us think about global health trends in the near future. What will happen over the next few decades? We should expect an increasing population of coronary artery disease sufferers with atherosclerosis in multiple organs. We should also expect to see more and more elderly high-risk patients with co-morbidities. In the coming decade, these trends will become serious threats to national health-care budgets in both developed and developing countries. We, as medical professionals, are responsible for developing cost-effective treatments for atherosclerotic diseases and contributing to excellent quality of life for patients while eliminating the need for retreatment, which would entail additional medical costs. Tackling problems arising from an ageing population and coping with the ageing society are global issues.

The editors intend for this new book to include all aspects of the best clinical practices of OPCAB in Japan and have asked the best off-pump surgeons and anesthesiologists with outstanding academic achievements to take part in this challenge. Most of the chapters are listed in the order of daily practice, such as indications, anesthesia, surgical technique, and postoperative care. Special issues on difficult cases and situations are discussed in separate chapters. Additional chapters on the statistics of OPCAB in Japan, criticism of recent clinical studies, teaching and training, and future perspectives are also included for better understanding. The

Our Mission

Although OPCAB is an emerging, immature technique, it is theoretically consistent with the principles of “first, do no harm” and “no extracorporeal circulation or global cardiac ischemia”.

Our mission is
minimize the drawback of OPCAB,
enlighten the excellence of OPCAB,
Show a safe way to introduce OPCAB into daily practice,
and
contribute to the health and happiness
of the people in the world

Fig. 3 Our mission statement

“Zero” Vision of OPCAB

– Urgent pump conversion 0
– Incomplete revascularization 0
– Anastomosis failure 0
– Stroke 0
– Atrial fibrillation 0
– 10-year cardiac death 0

Fig. 4 “Zero” vision of OPCAB

editors requested the authors of each chapter to describe all the tips and secrets of their daily off-pump surgery in detail, along with their personal opinions derived from lessons learned.

The mission of the authors of this book was to minimize the drawbacks of OPCAB, shed light on the excellence of OPCAB, and demonstrate a safe way to introduce OPCAB into daily clinical practice. We hope to contribute to the health and happiness of patients with coronary artery disease by spreading the know-how of the decision making, techniques, and management in OPCAB to surgeons and anesthesiologists worldwide (Fig. 3). Although the skill set and technique for this procedure have not yet been perfected, we will continue to polish this simple and effective modality with Kaizen Mind, hoping to realize “Zero” vision of OPCAB in the near future (Fig. 4). With the aid of this book, we hope the procedure will evolve from being the Japanese gold standard to the global standard for people suffering from coronary artery disease all over the world, now and in the future.

The editors and authors are gratefully acknowledge the superb editorial contribution of Mr. Yukihiko Takayama and Ms. Makie Kambara, Editorial Department, Springer Japan.

Fukushima, Japan Hitoshi Yokoyama

Contents

Part I

Current Overview of OPCAB

1 OPCAB Made in Japan: Evidence on Off-Pump Coronary Artery Bypass Grafting from Japan

Hitoshi Yaku and Kiyoshi Doi

Abstract

Off-pump coronary artery bypass grafting (OPCAB) is a standard procedure for patients who require CABG in Japan, with OPCAB performed in >60 % of patients who undergo CABG. This widespread use of OPCAB in Japan is supported by a number of studies that have been performed in the Japanese population. This chapter introduces those studies that have had a significant impact on OPCAB-related practice and consists of four primary sections that summarize the technical aspects, patient management, intraoperative graft evaluation, and surgical outcomes related to OPCAB. Although the majority of these studies were conducted retrospectively in single institutions, they are well designed, relevant, and innovative. To establish evidence for guidelines to be used in Japanese clinical settings, larger multicenter, randomized prospective, and observational studies using nationwide databases should be conducted.

Keywords

Off-pump coronary artery bypass grafting • Internal thoracic artery • Bypass graft • Coronary artery disease • Drug-eluting stent

1.1 Introduction

Off-pump coronary artery bypass grafting (OPCAB) began in the mid-1980s [1] and has since become increasingly popular worldwide [2, 3]. In Japan, OPCAB was first performed in 1996 [4] and is now the standard strategy for surgical coronary revascularization. The ratio of the number of OPCAB procedures to the total number of coronary artery bypass grafting (CABG) procedures has progressively increased and has exceeded 65 % on an annual basis since 2000 [5]. Many studies worldwide have reported the effects and drawbacks of OPCAB and compared OPCAB with conventional CABG. To evaluate the effects of OPCAB in the Japanese population and to devise a suitable surgical strategy, it would be ideal to refer to clinical studies specific to Japan. In fact, a number of studies have been reported from Japan, although most are retrospective, single-institution studies. In this chapter, we describe relevant clinical studies conducted in Japan and published in the English language. All values are presented as mean ± SD except where otherwise noted.

1.2 Technical Aspects of OPCAB

1.2.1 Harvesting of the Conduits

To obtain high patency rates and good long-term outcomes, the quality of the grafts is crucial in both OPCAB and conventional CABG. Higami et al. [6] reported a unique method of harvesting the internal thoracic artery (ITA) using an ultrasonic scalpel. With their "quick touch method," the ITA can be skeletonized safely and efficiently by removing fat tissues surrounding the artery, and the branches of the ITA

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are divided by employing protein coagulation using the scalpel. A longer ITA could be obtained by skeletonization compared to a pedicle technique. This group also demonstrated excellent early (<30 days) patency of the grafts (99.7 % for the left ITA and 100 % for the right ITA) [7]. Dr. Higami was also involved in experimental research revealing that the improved blood flow achieved with this technique was associated with the release of nitric oxide [8].

Asai et al. [9] described a method for harvesting the right gastroepiploic artery (RGEA) also using an ultrasonic scalpel. The authors reported that the technique was safe, simple, and allowed them not only to harvest the artery faster but also to obtain large spasm-free arterial conduits. With respect to clinical outcomes, Suma et al. [10], who were the first in the world to use the RGEA as a graft in CABG, reported excellent long-term results in both conventional CABG and OPCAB.

1.2.2 Devices Facilitating OPCAB

A few useful devices have been developed to obtain a stable surgical view in OPCAB with no ischemic insult to the myocardium. Arai et al. [11] developed a new heart positioner called TENTACLES™, which comprises three silicone tubes and a suction cup. The suction cup can be applied anywhere on the surface of the heart; subsequently, the heart can be rotated without a significant compromise in blood pressure.

Kamiya et al. [12] developed a synchronized, arterial flow-ensuring system to perform coronary anastomosis safely and without ischemia in OPCAB. Arterial blood from the femoral artery is perfused into the coronary artery in pulsatile mode regulated by a pump controller with synchronization during the diastolic period. Among 524 consecutive patients in whom this pump system was applied, they observed no intraoperative fatal arrhythmias, ventricular arrhythmias, short runs of ventricular tachycardia, or hemodynamic deterioration during anastomoses [13].

1.2.3 Proximal Anastomosis Devices

To avoid complications related to aortic manipulation, several devices have been developed to perform clampless anastomosis. However, only a few studies have reported the late patency of grafts constructed using these devices. Shimokawa et al. [14] investigated the early and 1-year patency rates of saphenous vein grafts (SVGs) constructed using an anastomosis device in patients who underwent OPCAB. They followed 232 patients who had undergone OPCAB using SVGs and received follow-up angiography. For proximal anastomosis, a clampless device was used in 73 patients (HEARTSTRING in 54; Enclose II in 19), and partial clamping was performed in 159 patients. The overall patency rates of SVGs at early and 1-year postoperative angiography were 95.7 % and 83.0 %, respectively. The patency rates were similar between the clampless and partial clamping groups (early 97.3 % vs. 98.1 %, $P=0.729$; 1 year 87.0 % vs. 81.3 %, $P=0.316$). Moreover, the target vessel revascularization rates did not significantly differ during the follow-up examination (6.8 % vs. 10.1 %, $P=0.623$).

Fujii et al. [15] evaluated 39 grafts constructed using the PAS-Port proximal anastomosis system in 28 patients who underwent OPCAB. Early postoperative angiography indicated no bending or stenosis in any graft and a patency rate of 100 %. Kai et al. [16] investigated the mid-term patency rate of SVGs using the PAS-Port. Among 66 patients who had SVGs, 46 patients survived at least 1 year after surgery, and 38 patients consented to late follow-up graft evaluation by means of 3-dimensional computed tomography. Two of the 39 grafts were occluded, and the 1-year patency rate (FitzGibbon grade A) was 94.9 %. No obvious stenosis of SVGs was observed. Twenty-four patients underwent 2-year graft evaluation. The 2-year cumulative patency rate was 91.7 %.

1.2.4 Awake OPCAB

Watanabe et al. [17] reported awake subxiphoid CABG in three patients with severe pulmonary dysfunction. A catheter for high thoracic epidural anesthesia was inserted 1 day before surgery, and under the appropriate amount of epidural anesthesia, the right gastroepiploic artery was harvested through a small subxiphoid incision, and the artery was anastomosed to the left anterior descending artery (LAD). They further reported the results of awake OPCAB in 72 patients comparing them with matched patients under general anesthesia [18]. Fifteen percent of the awake patients were able to leave the operating room in a wheelchair. The time until patients were able to drink water and walk and the duration of hospital stay were significantly shorter in the awake OPCAB group than in the general anesthesia group, with no operative or postoperative complications or deaths.

1.2.5 Revascularization Technique for Diffuse Coronary Lesions

Fukui et al. [19] developed a long-onlay patch method using the left ITA for diffusely diseased LAD. Endarterectomy is warranted depending on the severity of coronary atherosclerosis. In their study, preoperative angiography revealed the diffusely diseased LAD. The patent graft could be seen early postoperatively, but the reconstructed LAD was dilated and had an irregular wall. Interestingly, after 1 year, the LAD was reversely remodeled and the border between the graft and the native coronary artery was hardly visible. Event-free survival among patients who underwent this technique was excellent at 3 years [20].

1.3 Patient Management During OPCAB

1.3.1 Intraoperative Management

Occasionally, because of hemodynamic instability or arrhythmia due to displacement of the heart without cardiopulmonary bypass, OPCAB must be converted to on-pump CABG. According to the annual report of the Japanese Association for Coronary Artery Surgery [21], operative mortality and the incidence of stroke were significantly higher in patients converted intraoperatively from OPCAB to on-pump CABG than in patients in whom OPCAB or on-pump CABG treatment was planned and executed accordingly. Shiga et al. [22] studied the financial implications of intraoperative conversion and its effect on quality of life using a decision-analysis model and the Monte Carlo simulation. They found that OPCAB is superior (less costly and more effective) if the conversion rate from OPCAB to on-pump CABG is below 8.5 %, whereas costs increase exponentially if the probability of conversion exceeds 15 %.

Mitral regurgitation (MR) during OPCAB is a very important issue that may cause deterioration of hemodynamics and lead to conversion to on-pump CABG. In an experimental study, Koga et al. [23] demonstrated that cardiac displacement alone did not cause MR if coronary perfusion was maintained and that occlusion of the LAD rarely caused MR. However, occlusion of the left circumflex artery (LCx) caused MR from the posteromedial site. In a clinical study, Akazawa et al. [24] investigated the relationship between left ventricular function and the severity of MR during OPCAB. They found that MR was most severe during anastomosis of the LCx, with 39 % of patients experiencing moderate to severe MR. Significant differences were observed in preoperative serum brain natriuretic peptide (BNP) levels, Tei index values, and mitral inflow propagation velocity between patients who developed moderate to severe MR and patients who had no to mild MR during anastomosis of the LCx.

In an experimental study, Wakamatsu et al. [25] reported the effects of landiolol, an ultra-short-acting selective β-1 blocker, on the motion of the LAD using 3D digital motion capture and reconstruction technology. Landiolol ($0.12\ \mu g \cdot kg^{-1} \cdot min^{-1}$) significantly decreased heart rate, the 3D distance moved, acceleration and deceleration, without inducing a significant change in systolic blood pressure, cardiac output, or pulmonary wedge pressure. This study demonstrated the possible application of landiolol as a chemical stabilizer during OPCAB.

1.3.2 Pathophysiology During OPCAB

Moriyama et al. [26] sought to verify the hypothesis that amino acid infusions stimulate the release of metabolic hormones during surgery and increase energy expenditure, resulting in thermogenesis. Twenty-four patients were randomly assigned to two groups and received amino acid ($4\ kJ \cdot kg^{-1} \cdot hour^{-1}$) or saline treatment, which was infused over 2 h during OPCAB. Amino acid infusion significantly increased core body temperature and oxygen consumption during OPCAB. Given the release of insulin and leptin in response to amino acid infusion, these hormonal signaling pathways may partially contribute to the thermogenic response occurring during OPCAB.

Mitaka et al. [27] investigated nitric oxide (NO) production in OPCAB and on-pump CABG in 116 patients who had undergone elective CABG with ($n = 66$) and without ($n = 50$) cardiopulmonary bypass. Urinary nitrite/nitrate (NOx) excretion was measured as an index of endogenous NO production over 2 days after the operation. The mean urinary NOx/creatinine (Cr) excretion ratio did not significantly differ on the first day, and it significantly decreased ($P < 0.01$) from the first day to the second day in the on-pump CABG group, but not in the OPCAB group. The mean urinary NOx/Cr excretion ratio was significantly higher ($P < 0.01$) in the OPCAB group than in the on-pump CABG group (0.51 ± 0.26 vs. 0.38 ± 0.20, $P < 0.01$). The mean serum C-reactive protein (CRP) concentration was also significantly higher ($P < 0.01$) in the OPCAB group than in the on-pump CABG group on the second day. The two groups demonstrated no significant differences in mean cardiac index or mean systemic vascular resistance index after the operation. The authors concluded that endogenous NO production in patients who underwent CABG is stimulated by a surgical inflammatory response and that cardiopulmonary bypass does not trigger NO production.

Miura et al. [28] tested the hypothesis that intraoperative hemodynamic compromise due to cardiac displacement during OPCAB is related to jugular bulb desaturation, which is related to specific hemodynamic and physiological changes. Jugular bulb desaturation (≤50 %) frequently occurred during surgical displacement of the heart. Multivariate logistic regression analysis demonstrated that mixed venous oxygen saturation (S_VO_2) ≤70 %, arterial partial pressure of carbon dioxide ($PaCO_2$) ≤40 mmHg, and central venous pressure (CVP) ≥8 mmHg were likely predictors of the occurrence of jugular bulb desaturation, leading the authors to suggest that cerebral desaturation during OPCAB could be prevented by achieving normal values of S_VO2, PaCO2, and CVP.

1.4 Intraoperative Graft Evaluations

1.4.1 Imaging of Grafts

Suma et al. [29] demonstrated a thermal coronary artery imaging procedure, using a new-generation infrared camera for intraoperative graft evaluation, in 12 patients undergoing OPCAB. All grafts were clearly visualized, and the anastomosis and flow status could be observed by local epicardial cooling using a CO_2 blower on the normothermic heart. Among 17 grafts, one ITA graft showed anastomotic failure and was successfully revised. The results of postoperative coronary angiography confirmed the patency of all grafts.

Takahashi et al. [30] demonstrated the importance of graft evaluation during the operation using the SPY system, which is an imaging system based on the fluorescence of indocyanine green dye. They obtained high-quality images of all 290 grafts in 72 OPCAB patients and successfully revised four anastomoses that had failed according to the SPY system.

1.4.2 Functional Evaluation of Grafts

Transit-time flow measurement for the intraoperative evaluation of grafts began being performed in the late 1990s and is now a standard method. Takami et al. [31] compared intraoperative parameters determined by a transit-time flowmetry with quantitative parameters determined by postoperative coronary angiograms. Patent and nonpatent grafts significantly differed in all intraoperative flow parameters. The cutoff value to distinguish patent from nonpatent grafts was a fast Fourier transformation ratio of 1.0. The degree of stenosis at the heel of the anastomosis correlated significantly with intraoperative mean flow values.

Tokuda et al. [32] showed that a mean flow of 15 ml/min, a pulsatility index of 5.1, and a backward flow of 4.1 % were the optimal cutoff criteria to predict early graft failure of the left coronary system. For the right coronary system, the cutoff values were 20 ml/min, 4.7, and 4.6 %, respectively. They also compared the intraoperative parameters determined by a transit-time flowmetry with mid-term graft patency from 1 to 4 years after surgery [33]. Of 104 grafts, 21 were found to have a new mid-term occlusion or worsening of stenosis. They concluded that grafts with lower intraoperative mean flow, and especially with a higher percentage of backward flow, should be carefully monitored, even if they were initially anatomically patent.

Harada et al. [34] conducted a prospective comparison of the diagnostic accuracy of both fast Fourier transformation analysis of transit-time flowmetry waveform and an intraoperative fluorescence imaging system to determine graft failure. Neither intraoperative fluorescence imaging nor the mean graft flow/pulsatility index could detect a SVG with 75 % stenosis diagnosed by postoperative angiography; however, harmonic distortion of the transit-time flowmetry from stenosed SVGs significantly differed from that of patent SVGs.

1.5 Surgical Outcomes of OPCAB

1.5.1 Surgical Results of OPCAB Compared to On-Pump CABG

The surgical results of OPCAB were first compared with those of conventional CABG by Ishida et al. [35]. This retrospective study demonstrated that the operating time, ICU stay, and ventilation time were statistically significantly shorter in the OPCAB group than in the conventional CABG group. Postoperative blood loss within 12 h and transfusion volume were statistically significantly lower in the OPCAB group, as were peak serum blood urea nitrogen and Cr concentrations. Notably, no perioperative strokes occurred in the OPCAB group, whereas 6.4 % of patients in the conventional group suffered from a stroke. Graft patency did not significantly differ between the two groups (95.6 % vs. 94.9 %).

Kobayashi et al. [36] reported the surgical results of a prospective randomized controlled trial comparing OPCAB to on-pump CABG. In this study, 167 consecutive patients were randomly assigned to multiple arterial OPCAB and on-pump CABG groups. The number of grafts per patient and the number of arterial grafts per patient were similar. Completeness of revascularization was 98 % in both groups. The incidence of intraoperative and postoperative complications was comparable. The OPCAB group contained a larger number of patients without blood transfusion. Postoperative levels of S-100 protein and neuron-specific enolase were lower in the OPCAB group. The maximum CKMB level was also lower in the OPCAB group. The total patency rate was 98 % in both groups, and the stenosis-free patency rate was 93 % in the OPCAB group and 96 % in the on-pump group, with no significant difference. The authors concluded that OPCAB with multiple arterial grafts was as safe as conventional CABG, with similar completeness of revascularization and early graft patency.

1.5.2 Patients with Diabetes Mellitus (DM)

Tsuruta et al. [37] reported the impact of preoperative HbA1c levels in diabetic patients on long-term outcomes after OPCAB. They divided 893 patients who underwent primary isolated OPCAB into three groups based on preoperative HbA1c levels (HbA1c $<$ 6.5 %, 6.5 % $\leq$ HbA1c $<$ 7.5 %, and HbA1c $\geq$ 7.5 %). No operative or in-hospital mortality occurred. All-cause mortality and cardiac mortality rates were 6.2 % (19 patients) and 1.3 % (four patients), respectively, during a mean follow-up period of 3.6 ± 1.7 years. Kaplan-Meier survival curves indicated no significant differences in all-cause or cardiac mortality (log-rank test, $P = 0.26$, and $P = 0.17$, respectively).

Kai et al. [38] retrospectively examined the effects of OPCAB with skeletonized bilateral ITAs in patients with insulin-dependent DM. Surgical outcomes were compared to those of on-pump CABG with pedicled bilateral ITAs. No 30-day mortality occurred in either group. The incidence of deep sternal infection was significantly lower in the OPCAB group than in the on-pump CABG group (0.6 % vs. 13.0 %; $P = 0.01$). Early angiographic results did not differ between the two groups. During the 3.4-year follow-up period (range 0.1–9.9 years), the two groups demonstrated no differences in survival, freedom from cardiac mortality, and freedom from cardiac-related events. Dialysis, peripheral vascular disease, ejection fraction less than 0.40, and age were independent risk factors of mortality in the long-term period.

Fujii et al. [39] reported the usefulness of perioperative blood glucose control in patients undergoing OPCAB. Patients with DM were aggressively treated with intensive insulin therapy to achieve a preoperative fasting blood glucose level of 140 mg/dl and a postoperative level of 200 mg/dl. In comparing DM patients with non-DM patients, they found that the amount of insulin used during surgery was greater, the duration of intensive care unit (ICU) stay was longer, and the incidence of all complications was higher in patients with DM. When patients with a mean blood glucose level of <200 mg/dl in the ICU were compared to those with a mean blood glucose level of ≥200 mg/dl, the proportion of patients with DM was higher, duration of ICU stay was longer, and the incidence of all complications was higher in those with a mean glucose level of ≥200 mg/dl.

1.5.3 Perioperative Stroke

Nishiyama et al. [40] investigated the temporal pattern of strokes after on-pump CABG and OPCAB. They analyzed 2,516 consecutive patients who underwent primary elective isolated CABG, and the primary end point in this study was stroke. The temporal onset of the deficits was classified as "early stroke" or "delayed stroke". An early stroke was defined as a stroke presenting just after emergence from anesthesia, and a delayed stroke as a stroke presenting after awaking from surgery without a neurological deficit. In the study population, 63 % of strokes were delayed. Patients who underwent OPCAB had a significantly lower incidence of early stroke (0.1 % vs. 1.1 %, $P = 0.0009$), whereas the incidence of delayed strokes was not significantly different between the patients underwent OPCAB and on-pump CABG (0.9 % vs. 1.4 %, $P = 0.3484$). Multivariate analyses revealed that undergoing OPCAB was an independent protective factor for all strokes (relative risk 0.29, 95 % confidence interval 0.14–0.56, $P = 0.0005$) and early strokes (relative risk 0.05, 95 % confidence interval 0.003–0.24, $P < 0.0001$); however, it was not an independent protective factor for delayed strokes (relative risk 0.54, 95 % confidence interval 0.24–1.17, $P = 0.1210$).

Another study revealed the importance of preoperative evaluation of intracranial and neck vessels for estimating patient prognosis in terms of stroke [41]. In that study, patients were divided into two groups, low risk and high risk, based on the findings of MRI and carotid Doppler imaging. No intraoperative stroke occurred in either group. The high-risk group had a higher incidence of delayed stroke and stroke even after 1 month. Univariate analysis revealed designation as high risk was the only predictor of delayed stroke. Moreover, the high-risk group had a significantly lower freedom from stroke in the long term.

Miyazaki et al. [42] investigated risk factors of stroke/transient ischemic attack (TIA) and delirium after OPCAB in a review of the medical records of 685 patients. The incidence of postoperative stroke/TIA and delirium after OPCAB was 2.6 % ($n = 18$) and 16.4 % ($n = 112$), respectively. Carotid artery stenosis >50 % was a significant risk factor of stroke or TIA ($P = 0.02$) as well as delirium ($P = 0.04$) after OPCAB. Histories of atrial fibrillation ($P = 0.037$) or DM ($P = 0.041$) were risk factors of postoperative stroke/TIA. By contrast, age >75 years ($P = 0.006$), serum Cr > 1.3 mg/dl ($P = 0.011$), history of hypertension ($P = 0.001$), history of atrial fibrillation ($P = 0.024$), and smoking ($P = 0.048$) were significant risk factors of postoperative delirium.

Contrary to these studies, Manabe et al. [43] reported that the effect of carotid artery stenosis on the incidence of perioperative stroke may be low in OPCAB. They conducted a retrospective study of 461 patients who underwent elective OPCAB after screening for carotid artery stenosis. The screening detected significant carotid artery stenosis in 49 patients. Neither stroke nor in-hospital mortality occurred in patients with carotid stenosis, although two strokes (0.49 %) and three in-hospital mortalities (0.73 %) were observed in patients without carotid stenosis.

Osawa et al. [44] studied the incidence of stroke in relation to surgical manipulation of the ascending aorta. Two of 451 patients (0.47 %) who underwent OPCAB using the aortic nonclamping technique developed delayed strokes, whereas one in nine patients who underwent OPCAB with aortic partial clamping for proximal anastomosis had an early stroke. The authors concluded that the aortic nonclamping technique might reduce the incidence of stroke. Kobayashi et al. [45] also reported no operative death or stroke by using an aorta no-touch technique with in situ graft and composite and sequential grafting methods.

1.5.4 Perioperative Neuropsychological Dysfunction

Baba et al. [46] conducted a prospective study in 218 patients who had undergone elective OPCAB ($n=89$) or on-pump CABG ($n=129$). Four cognitive tests were performed preoperatively and at 1 week postoperatively. Neuropsychological dysfunction was defined as a decrease in an individual's performance of at least 20 % from baseline in more than two tests. The incidence of neuropsychological dysfunction was 11.2 % in the OPCAB group and 22.5 % in the on-pump group ($P=0.02$). Multivariate analysis revealed that neuropsychological dysfunction was associated with cardiopulmonary bypass and multiple cerebral infarctions.

1.5.5 Impact of Preoperative Renal Dysfunction

To study the association between renal dysfunction and OPCAB, Ogawa et al. divided patients into three groups depending on preoperative serum Cr levels: normal, moderately depressed, and severely depressed [47]. The severely depressed group included more patients with postoperative Cr levels >1.6 times the preoperative levels. The predictors of postoperative renal impairment were preoperative Cr > 2.5 mg/dl, ejection fraction <40 %, amount of blood transfusion, and >4 grafts.

Kinoshita et al. [48] divided patients undergoing OPCAB into three groups based on preoperative glomerular filtration rate (GFR), < 30 ml/min/1.73 m^2, 30–60 ml/min/1.73 m^2, and > 60 ml/min/1.73 m^2, and reported that long-term survival and freedom from cardiac death depended on preoperative renal function as indicated by GFR, but noncardiac death did not depend on preoperative renal function. Hayashida et al. [49] compared the postoperative renal function of 52 OPCAB patients to that of 53 matched patients undergoing conventional CABG. The increase in Cr levels was significantly smaller in the OPCAB group than in the conventional CABG group (0.16 ± 0.05 vs. 0.45 ± 0.06 mg/dl).

1.5.6 Patients on Hemodialysis

Oyamada et al. [50] investigated the preoperative risk factors of performing OPCAB in patients on chronic dialysis. Forty-one patients on chronic dialysis who underwent OPCAB were retrospectively reviewed, of whom 29 had diabetic nephropathy (DN group) and the remaining 12 did not (NDN group). The two groups significantly differed in the duration of dialysis before surgery (4.2 ± 5.5 years in DN vs. 9.1 ± 7.5 years in NDN, $P=0.028$). Low cardiac output (LV ejection fraction <30 %) was observed only in the DN group (7/29, $P=0.048$). Early mortality was 6.9 % (2/29) in the DN group and 16.7 % (2/12) in the NDN group ($P=0.349$). The actuarial survival rates in the DN group were 85 % at 1 year, 45 % at 3 years, and 30 % at 5 years, whereas in the NDN group, they were 71 %, 49 %, and 49 %, respectively ($P=0.789$). For patients on chronic dialysis, arteriosclerosis and age (>65 years) were predicted risk factors for OPCAB; however, diabetic nephropathy was not.

Sunagawa et al. [51] compared the mid-term clinical results of CABG and PCI with drug-eluting stents (DES) in patients with chronic renal failure on hemodialysis. Thirty-day mortality was 3.3 % for CABG including OPCAB (83 % of the total cases) and 4.0 % for PCI. The 2-year survival rate was 84.0 % for CABG and 67.6 % for PCI ($P=0.0271$). The cardiac death-free curve at 2 years was 100 % for CABG and 84.1 % for PCI ($P=0.0122$). The major adverse cardiac event-free rate at 2 years was 75.8 % for CABG and 31.5 % for PCI ($P<0.0001$). During the follow-up period, six late deaths occurred in the CABG group and 27 late deaths, including six sudden deaths, occurred in the PCI group.

1.5.7 Patients with Left Main Disease (LMD)

Stenosis in the left main trunk has historically been recognized as a risk factor for patients undergoing CABG. To analyze the effects of OPCAB in patients with significant stenosis in the left main trunk, Suzuki et al. [52] reviewed 268 patients with significant LMD among 665 patients who underwent OPCAB and compared them with 237 propensity score-matched patients without LMD. The operative mortality rate was 0.8 % in the LMD group and 1.7 % in the non-LMD group. The rate of 6-year freedom from all-cause death was 87.3 % in the LMD group and 60.7 % in the non-LMD group ($P=0.17$), and the rate of 6-year freedom from cardiac events was 80.4 % in the LMD group and 70.4 % in the non-LMD group ($P=0.98$). The authors concluded that LMD did not significantly affect OPCAB outcomes in either the short or long term.

Fukui et al. [53] retrospectively reviewed 768 patients who underwent OPCAB with bilateral ITAs. Among them, 268 patients had LMD and 500 patients did not. Operative mortality and the incidence of complications were not significantly different between the two groups. In the patients without LMD, the left and right ITAs were used for the LAD in 87.4 % and 12.2 % of the patients, respectively, whereas in patients with LMD, the left and right ITAs were used for the LAD in 70.5 % and 29.1 %, respectively. In the patients without LMD, the 1-year patency rate of left and right ITAs was 97.6 % and 91.6 %, respectively, whereas in the patients with LMD, it was 97.0 % and 93.2 %, respectively. The patency rates of the left and right ITAs did not significantly differ in patients with or without LMD ($P=0.9803$ and $P=0.7205$ for left and right ITAs, respectively).

1.5.8 Patients with Previous Percutaneous Coronary Intervention (PCI)

Previous PCI was reported to have an adverse impact on the surgical outcomes of CABG [54], and several Japanese studies have investigated this impact. Fukui et al. [55] retrospectively reviewed 545 patients who underwent first-time isolated OPCAB. Among them, 154 had previous PCIs, including 99 patients with stents. The number of anastomoses per patient was lower in the PCI patients than in the non-PCI patients (3.8 vs. 4.2; $P=0.0066$). Neither operative mortality (0 % vs. 1.8 %; $P=0.1995$) nor major morbidity rates differed between these groups. Similar results were obtained for the comparison between patients with stents and those without stents. No significant difference was observed in graft patency rates between the PCI patients and non-PCI patients (97.1 % vs. 97.9 %; $P=0.4976$).

Kinoshita et al. [56] compared patients with previous PCI to those without PCI after OPCAB. The patients with previous PCI had a significantly higher prevalence of history of myocardial infarction, renal dysfunction, and hemodialysis. The rate of surgical mortality was higher in the patients with previous PCI (7.6 % vs. 1.0 %, $P=0.008$). A multivariate logistic regression analysis revealed that previous PCI remained a strong predictor of surgical mortality (odd ratio, 6.9; 95 % confidence interval, 1.2–4.2; $P=0.035$). After matching and regression adjustment by propensity score, the impact of previous PCI on surgical mortality was found to remain significant (matching odd ratio, 6.5; 95 % confidence interval, 0.8–55.0; $P=0.088$; regression adjustment odd ratio, 6.3; 95 % confidence interval, 1.2–33.6; $P=0.031$).

1.5.9 Postoperative Atrial Fibrillation (AF)

AF is the most common complication after CABG and is associated with an increased risk of stroke and longer hospital stay. As described below, several studies have examined the predictors of AF after OPCAB.

Hosokawa, et al. [57] retrospectively reviewed 296 consecutive patients who underwent OPCAB, in whom the incidence of AF was 32 %. AF prolonged the hospital stay by 3 days ($P<0.01$). Stepwise multivariate analysis identified increasing age (odd ratio 1.44 per 10-year increase; confidence interval 1.06–1.95), intraoperative core body temperature (odd ratio 1.64; 95 % confidence interval 1.05–2.56), average cardiac index in the ICU (odd ratio 0.37; 95 % confidence interval 0.19–0.71), and intraoperative fluid balance (odd ratio 0.96 per 100-ml increase; 95 % confidence interval 0.93–0.99) as independent predictors for the development of AF.

Ishida et al. [58] examined the relationship between proinflammatory cytokines, which play an important role in the upstream regulation of inflammatory cascades, and the development of AF after OPCAB in a case series of 39 patients, 11 of whom (28 %) developed AF postoperatively. Patients with postoperative AF had higher levels of interleukin-6 at 3 and 6 h after anastomoses, which was a significant predictor of postoperative AF along with age, whereas tumor necrosis factor-α levels did not change during the study period. Interleukin-8 and CRP levels significantly increased after surgery; however, no significant difference was detected between the two groups.

Akazawa et al. [59] investigated the relationship between preoperative BNP levels and postoperative AF after OPCAB. They analyzed the data of 150 patients without a history of AF who underwent elective OPCAB, 26 of whom (17.3 %) developed postoperative AF. Univariate analysis demonstrated that age (odd ratio 1.060; 95 % confidence interval 1.008–1.114; $P=0.023$), previous myocardial infarction (odd ratio 2.628; 95 % confidence interval 1.031–6.697; $P=0.043$), and BNP level (odd ratio 7.336; 95 % confidence interval 2.401–22.409/log BNP level; $P<0.001$) were accurate predictors of postoperative AF. Stepwise multivariate regression analysis indicated that age (odd ratio 1.059; 95 % confidence interval 1.002–1.120; $P=0.043$) and BNP level (odd ratio 6.272; 95 % confidence interval 1.980–19.861/log BNP level; $P=0.002$) were the only independent predictors of postoperative AF.

Several studies have focused on the prevention of AF after CABG. Fujii et al. [60] conducted a randomized prospective trial to determine the efficacy of intravenous landiolol administration in the early period after OPCAB followed by treatment with carvedilol for prevention of AF. Seventy consecutive patients were enrolled in the study. Patients in the treatment group received landiolol intravenously ($5\ \mu g \cdot kg^{-1} \cdot min^{-1}$) in the ICU immediately after surgery until carvedilol was administered orally. All patients received oral carvedilol (2.5–5 mg/day) after extubation and this treatment was continued even after discharge. Postoperative AF occurred in four (11.1 %) of the 36 patients in the landiolol group and in 11 (32.3 %) of the 34 patients in the control group, indicating that the development of AF was significantly inhibited by landiolol treatment ($P=0.042$).

Kinoshita et al. [61] assessed the preventive effect of preoperative statin treatment on the development of AF after elective isolated OPCAB. Among 584 patients, 364 patients received statin at least 5 days before surgery and 220 patients received no statin. The authors identified 195 propensity score-matched pairs. AF occurred in 14.4 % of the patients in the statin group and in 24.6 % of the patients in the no statin group ($P=0.01$). Multivariate logistic regression, including potential univariate predictors, identified statin treatment (odd ratio 0.49; 95 % confidence interval 0.22–0.81; $P=0.01$), age (odd ratio 1.33 per 10-year increase; 95 % confidence interval 1.04–1.69; $P=0.02$), and transfusion (odd ratio 2.21; 95 % confidence interval 1.38–3.55; $P=0.01$) as independent predictors of postoperative AF.

Ito et al. [62] assessed the efficacy of treatment with the antiarrhythmic drug propafenone hydrochloride, which was administered in the early postoperative period to prevent development of AF. Seventy-eight patients undergoing isolated OPCAB were divided into two groups: propafenone hydrochloride (P group) and control (C group). Patients in the P group were given propafenone hydrochloride (150–450 mg/day orally) for 10 days from the day of surgery. The incidence of AF was 35 % in the C group and 12 % in the P group ($P=0.0337$). Multiple logistic regression analysis indicated that propafenone hydrochloride was the sole factor that prevented the development of AF after OPCAB (odd ratio 0.207; 95 % confidence interval 0.053–0.804; $P=0.0229$).

Kinoshita et al. [63] investigated the association between preoperative heart rate variability and the incidence of AF after OPCAB. The following time-domain factors of heart rate variability were calculated: standard deviation of all normal-to-normal QRS (SDNN) and square root of mean of sum of squares of differences between adjacent normal-to-normal QRS (RMSSD). AF occurred in 98 (25 %) of 390 patients undergoing elective OPCAB. Patients without AF had significantly lower heart rate variability than patients with AF, with a median SDNN of 91 ms vs. 121 ms and median RMSSD of 19 ms vs. 25 ms. Reduced heart rate variability was significantly associated with a lower risk of postoperative AF (SDNN ≤ 99 ms, odd ratio 0.29, confidence interval 0.17–0.49, $P<0.01$; RMSSD ≤ 20 ms, odd ratio 0.47, 95 % confidence interval 0.30–0.74; $P<0.01$).

1.5.10 Quality of Grafting

Nakjima et al. [64] examined the detailed characteristics of the arterial composite and sequential grafts and delineated the risk factors of graft occlusion. Intermediate patency of a graft with competitive or reverse flow was much lower when it was grafted to a coronary artery with mild disease or the main trunk of the LAD. Side-to-side anastomosis had higher graft patency than end-to-side anastomosis, and the fashion of composite graft (Y, I, or K graft) did not affect graft patency. Multivariate and univariate analyses showed that mild stenosis of the coronary artery and competitive or reverse flow of the graft were important risk factors for intermediate graft occlusion in OPCAB.

Manabe et al. [65] evaluated the angiographic outcomes of composite grafting in patients undergoing OPCAB. They retrospectively reviewed 830 distal anastomoses in 256 patients who underwent OPCAB and 1-year follow-up coronary angiograms, comparing 410 anastomoses that used a composite grafting technique with 420 anastomoses that used individual grafting. In target vessels with mild stenosis, the incidence of graft occlusion or string sign was significantly higher in composite ITAs than in individual ITAs (composite 20.3 % vs. individual 7.3 %, $P=0.018$), and a higher tendency was shown in composite radial artery than in individual radial artery grafts (59.3 % vs. 36.4 %, $P=0.09$). By contrast, in target vessels with severe stenosis, the incidence of graft occlusion was similar between composite and individual ITAs (5.7 % vs. 3.3 %, $P=0.278$) and composite and individual radial artery grafts (11.5 % vs. 9.6 %, $P=0.297$).

Sugimura et al. [66] assessed graft patency and long-term clinical outcomes in 53 patients who underwent primary isolated elective OPCAB with composite arterial Y grafts. During the follow-up period of 18–97 months, no deaths occurred, the incidence of graft failure was 22.6 %, and the incidence of angina recurrence was 13.2 %. A significantly higher rate of graft failure was evident when one end of the composite graft was anastomosed to a coronary artery with 75 % stenosis and the other end to a coronary artery with more than 90 % stenosis.

Matsuura et al. [67] evaluated graft patency and quality of anastomoses to small coronary arteries in OPCAB by early postoperative angiography. The coronary artery branches were categorized as large (>1.5 mm, group L) or small (<1.5 mm, group S) by intraoperative measurement. The overall patency and stenosis-free (FitzGibbon type A) rates were 97.2 % and 96.2 %. Graft patency (96.7 %) and stenosis-free rates (93.3 %) in group S were comparable to those in group L (97.5 % and 97.1 %, respectively).

1.5.11 The Impact of the Use of Bilateral ITA vs. Single ITA

The bilateral use of ITAs has been reported to be associated with higher survival benefit than the use of a single ITA. However, whether bilateral ITAs remain beneficial in the elderly population is less clear. Kinoshita et al. [68] compared outcomes in propensity score-matched patients, 70 years of age or older, undergoing isolated OPCAB using bilateral ITAs or a single ITA. A total of 217 pairs were matched using propensity scores calculated from nine preoperative factors. The rate of postoperative complications was similar between the two groups. The rate of 5-year freedom from overall death was 86.4 ± 3.2 % in the bilateral group and 73.5 ± 3.9 % in the single group ($P=0.01$), and the rate of 5-year freedom from cardiac events was 93.2 ± 2.7 % in the bilateral group and 87.5 ± 3.0 % in the single group ($P=0.01$). In multivariate Cox models, the bilateral use of ITAs was significantly associated with a lower risk of overall death (odd ratio 0.56; 95 % confidence interval 0.31–0.99; $P=0.04$) and cardiac events (odd ratio 0.36; 95 % confidence interval 0.15–0.88; $P=0.03$) even in elderly patients.

Saito et al. [69] evaluated early outcomes of bilateral ITA compared with single ITA in patients who had undergone isolated CABG from the Japan Adult Cardiovascular Surgery Database. Among 8,136 single ITA and 4,093 bilateral ITA patients, they performed a one-to-one matched analysis on the basis of estimated propensity scores for patients in each group balanced for baseline characteristics. The rate of off-pump CABG was similar (75 %) in both groups, and the mean number of anastomoses was 3.1 in the single ITA and 3.4 in the bilateral ITA group ($P<0.0001$). Thirty-day operative mortality was 1.2 % in both groups, and the overall incidence of postoperative complications was also similar, although deep sternal infection was more frequent with bilateral ITA (1.3 % of single ITA and 2.3 % of bilateral ITA patients; $P=0.0001$).

1.5.12 Outcomes of OPCAB vs. PCI

A number of studies compared the efficacy of PCI and CABG. However, the impact of OPCAB has not been well elucidated. Marui et al. [70] analyzed the largest registry of CABG and PCI involving bare metal stents in Japan, called the KREDO-Kyoto registry. From this registry, 6,327 patients with multivessel disease and/or LMD were enrolled in the study. Among them, 3,877 patients were treated with PCI, 1,388 received with on-pump CABG, and 1,069 received with OPCAB. The median follow-up period was 3.5 years. The propensity score-adjusted all-cause mortality after PCI was higher than that after on-pump CABG or OPCAB (odd ratio 1.37; 95 % confidence interval 1.15–1.63; $P<0.01$). The incidence of stroke was lower after PCI than that after on-pump CABG or OPCAB (odd ratio 0.75; 95 % confidence interval 0.59–0.96; $P=0.02$). Propensity score-adjusted all-cause mortality after PCI was higher than that after OPCAB (odd ratio 1.50; 95 % confidence interval 1.20–1.86; $P<0.01$). The adjusted mortality rate was similar between the OPCAB and on-pump CABG groups (odd ratio 1.18; 95 % confidence interval 0.93–1.51; $P=0.33$). The incidence of stroke after OPCAB was similar to that after PCI (odd ratio 0.98; 95 % confidence interval 0.71–1.34; $P>0.99$); however, the incidence of stroke after on-pump CABG was higher than that after OPCAB (odd ratio 1.59; 95 % confidence interval 1.16–2.18; $P<0.01$). In contrast to many randomized studies showing comparable survival between PCI and CABG, in this real-world registry in Japan, the survival advantage of CABG including OPCAB was clearly superior to that of PCI with bare metal stents in patients with multivessel disease and/or LMD.

A few studies have compared PCI with drug-eluting stents and OPCAB. Yamagata et al. [71] examined 208 patients with multivessel disease and DM, including 92 patients treated with sirolimus-eluting stents (SES) and 116 patients with OPCAB. During the mean follow-up period of 42 ± 8 months, the rate of repeat revascularization was significantly higher in the SES group than that in the OPCAB group (21 % vs. 6.9 %, $P=0.003$). By contrast, the incidence of cerebrovascular events was higher in the OPCAB group than that in the SES group. The cumulative risk of major adverse cardiac and cerebrovascular events (defined as all-cause death, nonfatal myocardial infarction, cerebrovascular events, and repeat revascularization) was similar between the two groups (27 % vs. 23 %, $P=0.492$).

Dohi et al. [72] compared the long-term outcomes after OPCAB or PCI with SES in DM patients with multivessel disease and/or LMD. They enrolled 350 patients who underwent OPCAB and 143 patients who were treated with SES implantation. During the mean follow-up period of 2.6 ± 1.6 years, no difference was observed between OPCAB and SES implantation in all-cause mortality or cardiac death. However, acute coronary syndrome, target vessel revascularization, and major adverse cardiac and cerebrovascular events were markedly lower in patients undergoing OPCAB than in those receiving SES.

Shimizu et al. [73] compared intermediate outcomes between CABG including OPCAB (92 % in the total number of CABG) and PCI with DES in patients with unprotected LMD. The overall survival rate did not differ (CABG 93.4 %, DES 91.9 % at 2 years; ns). Major cardiac and cerebrovascular event-free survival was superior in the CABG group (CABG 82.2 %, DES 62.6 % at 2 years; $P=0.033$), and the total hospitalization costs were lower in the CABG group (CABG, median 3.225 million yen; DES, median 4.192 million yen; $P=0.013$).

1.5.13 Redo OPCAB

Dohi et al. [74] performed a propensity analysis based on the Japan Cardiovascular Surgical Database (JCVSD) comparing the early surgical results between off- and on-pump CABG in patients who had undergone previous CABG. Operative mortality tended to be lower, and the composite endpoint of mortality or major complications was statistically significantly less frequent for off-pump redo CABG compared to on-pump redo CABG.

1.6 Summary

A number of excellent and interesting studies have been performed in Japan on factors associated with OPCAB. The high rate of OPCAB among CABG procedures (more than 60 %) has been supported by these clinical results. However, most were observational studies performed in single institutions. To establish evidence applicable to instituting guidelines for Japanese clinical settings, larger multicenter, randomized prospective, and observational studies using nationwide databases should be conducted.

References

1. Benetti FJ (1985) Direct coronary surgery with saphenous vein bypass without cardiopulmonary bypass or cardiac arrest. J Cardiovasc Surg 26:217–222
2. Calafiore AM, Di Giammarco GD, Teodori G, Bosco G, D'Annunzio E, Barsotti A, Maddestra N, Paloscia L, Vitolla G, Sciarra A, Fino C, Contini M (1996) Left anterior descending coronary artery grafting via left anterior small thoracotomy without cardiopulmonary bypass. Ann Thorac Surg 61:1658–1663
3. Buffalo E, Summo H, Aguiar LF, Teles CA, Branco JNR (1997) Myocardial revascularization in patients 70 years of age and older without the use of extracorporeal circulation. Am J Geriatr Cardiol 6:6–9
4. Sezai Y, Tsukamoto S (1998) Coronary artery surgery results 1996. Ann Thorac Cardiovasc Surg 4:103–106
5. Sakata R, Fujii Y, Kuwano H, Committee for Scientific Affairs (2011) Thoracic and cardiovascular surgery in Japan during 2009. Annual report by the Japanese Association for Thoracic Surgery. Gen Thorac Cardiovasc Surg 59:636–667
6. Higami T, Kozawa S, Asada T, Shida T, Ogawa K (2000) Skeletonization and harvest of the internal thoracic artery with an ultrasonic scalpel. Ann Thorac Surg 70:307–308
7. Higami T, Yamashita T, Nohara H, Iwahashi K, Shida T, Ogawa K (2001) Early results of coronary grafting using ultrasonically skeletonized internal thoracic arteries. Ann Thorac Surg 71:1224–1228
8. Maruo A, Hamner CE, Rodrigues AJ, Higami T, Greenleaf JF, Schaff HV (2004) Nitric oxide and prostacyclin in ultrasonic vasodilatation of the canine internal mammary artery. Ann Thorac Surg 77:126–132
9. Asai T, Tabata S (2002) Skeletonization of the right gastroepiploic artery using an ultrasonic scalpel. Ann Thorac Surg 74:1715–1717
10. Suma H, Tanabe H, Takahashi A, Horii T, Isomura T, Hirose H, Amano A (2007) Twenty years experience with the gastroepiploic artery graft for CABG. Circulation 116(11 Suppl):I188–I191
11. Arai H, Mizuno T, Yoshizaki T, Itoh F, Oi K, Someya T, Tanaka H, Sunamori M (2006) A new multisuction cardiac positioner for multivessel off-pump coronary artery bypass grafting. Innovations 1:126–130
12. Kamiya H, Watanabe G, Doi T, Saito T, Takahashi M, Tomita S, Tsukioka T, Kanamori T (2002) Coronary active perfusion system can maintain myocardial blood flow and tissue oxygenation. Eur J Cardiothorac Surg 22:410–414
13. Watanabe G, Kamiya H, Nagamine H, Tomita S, Koshida Y, Nishida S, Ohtake H, Arai S, Yasuda T (2005) Off-pump CABG with synchronized arterial flow ensuring system. Ann Thorac Surg 80:1893–1897
14. Shimokawa T, Manabe S, Sawada T, Matsuyama S, Fukui T, Takanashi S (2009) Intermediate-term patency of saphenous vein graft with a clampless hand-sewn proximal anastomosis device after off-pump coronary bypass grafting. Ann Thorac Surg 87:1416–1420
15. Fujii T, Watanabe Y, Shiono N, Ozawa T, Hamada S, Masuhara H, Teramoto C, Hara M, Koyama N (2009) Study of coronary artery bypass using the PAS-Port device: assessment by multidetector computed tomography. Gen Thorac Cardiovasc Surg 57:79–86
16. Kai M, Hanyu M, Soga Y, Nomoto T, Nakano J, Matsuo T, Kawato M, Okabayashi H (2009) Mid-term patency rate after saphenous vein grafting with a PAS-Port device. J Thorac Cardiovasc Surg 137:503–504
17. Watanabe G, Yamaguchi S, Tomiya S, Ohtake H (2008) Awake subxiphoid minimally invasive direct coronary artery bypass grafting yielded minimum invasive cardiac surgery for high risk patients. Interact Cardiovasc Thorac Surg 7:910–912
18. Watanabe G, Tomita S, Yamaguchi S, Yashiki N (2011) Awake coronary artery bypass grafting under thoracic epidural anesthesia: great impact on off-pump coronary revascularization and fast-track recovery. Eur J Cardiothorac Surg 40:788–793
19. Fukui T, Tabata M, Taguri M, Manabe S, Morita S, Takanashi S (2011) Extensive reconstruction of the left anterior descending coronary artery with an internal thoracic artery graft. Ann Thorac Surg 91:445–451
20. Shimokawa T, Manabe S, Fukui T, Takanashi S (2009) Remodeling of reconstructed left anterior descending coronary arteries with internal thoracic artery graft. Ann Thorac Surg 88:54–57
21. Sezai Y, Orime Y, Tsukamoto S (2007) Coronary artery surgery results in Japan 2005. Ann Thorac Cardiovasc Surg 13:220–223
22. Shiga T, Apfel CC, Wajima Z, Ohe Y (2007) Influence of intraoperative conversion from off-pump to on-pump coronary artery bypass grafting on costs and quality of life: a cost-effectiveness analysis. J Cardiothorac Vasc Anesth 21:793–799
23. Koga S, Okazaki Y, Kataoka H, Ikeda K, Furukawa K, Ohtsubo S, Itoh T (2007) Configurations of the mitral valve during off-pump coronary artery bypass grafting: endoscopic and three-dimensional analysis. J Heart Valve Dis 16:602–607
24. Akazawa T, Iizuka H, Aizawa M, Warabi K, Ohshima M, Amano A, Inada E (2008) The degree of newly emerging mitral regurgitation during off-pump coronary artery bypass is predicted by preoperative left ventricular function. J Anesth 22:13–20
25. Wakamatsu H, Watanabe T, Sato Y, Takase S, Omata S, Yokoyama H (2012) Landiolol reduces coronary artery motion in an open-chest porcine model: implications for off-pump coronary artery bypass surgery. Surg Today 42:205–208
26. Moriyama T, Tsuneyoshi I, Omae T, Takeyama M, Kanmura Y (2008) The effect of amino-acid infusion during off-pump coronary arterial bypass surgery on thermogenic and hormonal regulation. J Anesth 22:354–360
27. Mitaka C, Yokoyama K, Imai T (2007) Nitric oxide production is more prominent in off-pump than in on-pump coronary artery bypass surgery. Anaesth Intensive Care 35:505–509
28. Miura N, Yoshitani K, Kawaguchi M, Shinzawa M, Irie T, Uchida O, Ohnishi Y, Mackensen GB (2009) Jugular bulb desaturation during off-pump coronary artery bypass surgery. J Anesth 23:477–482
29. Suma H, Isomura T, Horii T, Sato T (2000) Intraoperative coronary artery imaging with infrared camera in off-pump CABG. Ann Thorac Surg 70:1741–1742
30. Takahashi M, Ishikawa T, Higashidani K, Katoh H (2004) SPY™: an innovative intra-operative imaging system to evaluate graft patency during off-pump coronary artery bypass grafting. Interact Cardiovasc Thorac Surg 3:479–483
31. Takami Y, Ina H (2001) Relation of intraoperative flow measurement with postoperative quantitative angiographic assessment of coronary artery bypass grafting. Ann Thorac Surg 72:1270–1274
32. Tokuda Y, Song M-H, Ueda Y, Usui A, Akita T (2007) Predicting early coronary artery bypass graft failure by intraoperative transit time flow measurement. Ann Thorac Surg 84:1928–1934
33. Tokuda Y, Song M-H, Oshima H, Usui A, Ueda Y (2008) Predicting mid-term coronary artery bypass graft failure by intraoperative transit time flow measurement. Ann Thorac Surg 86:532
34. Hatada A, Okamura Y, Kaneko M, Hisaoka T, Yamamoto S, Hiramatsu T, Nishimura Y (2011) Comparison of the waveforms of transit-time flowmetry and intraoperative fluorescence imaging for assessing coronary artery bypass patency. Gen Thorac Cardiovasc Surg 59:14–18
35. Ishida M, Kobayashi J, Tagusari O, Bando K, Niwaya K, Nakajima H, Kitamura S (2002) Perioperative advantages of off-pump coronary artery bypass grafting. Circ J 66:795–799
36. Kobayashi J, Tashiro T, Ochi M, Yaku H, Watanabe G, Satoh T, Tagusari O, Nakajima H, Kitamura S, Japanese Off-Pump Coronary Revascularization Investigation (JOCRI) Study Group (2005) Early outcome of a randomized comparison of off-pump and on-pump multiple arterial coronary revascularization. Circulation 112(9 Suppl):I338–I343

37. Tsuruta R, Miyauchi K, Yamamoto T, Dohi S, Tambara K, Dohi T, Inaba H, Kuwaki K, Daida H, Amano A (2011) Effect of preoperative hemoglobin A1c levels on long-term outcomes for diabetic patients after off-pump coronary artery bypass grafting. J Cardiol 57:181–186
38. Kai M, Hanyu M, Soga Y, Nomoto T, Nakano J, Matsuo T, Umehara E, Kawato M, Okabayashi H (2007) Off-pump coronary artery bypass grafting with skeletonized bilateral internal thoracic arteries in insulin-dependent diabetes. Ann Thorac Surg 84:32–36
39. Fujii T, Watanabe Y, Shiono N, Kawasaki M, Yokomuro H, Ozawa T, Hamada S, Masuhara H, Koyama N (2007) Usefulness of perioperative blood glucose control in patients undergoing off-pump coronary artery bypass grafting. Gen Thorac Cardiovasc Surg 55:409–415
40. Nishiyama K, Horiguchi M, Shizuta S, Doi T, Ehara N, Tanuguchi R, Haruna Y, Nakagawa Y, Furukawa Y, Fukushima M, Kita T, Kimura T (2009) Temporal pattern of strokes after on-pump and off-pump coronary artery bypass graft surgery. Ann Thorac Surg 87:1839–1844
41. Doi K, Yaku H (2010) Importance of cerebral artery risk evaluation before off-pump coronary artery bypass grafting to avoid perioperative stroke. Eur J Cardiothorac Surg 38:568–572
42. Miyazaki S, Yoshitani K, Miura N, Irie T, Inatomi Y, Ohnishi Y, Kobayashi J (2011) Risk factors of stroke and delirium after off-pump coronary artery bypass surgery. Interact Cardiovasc Thorac Surg 12:379–383
43. Manabe S, Shimokawa T, Fukui T, Fumimoto KU, Ozawa N, Seki H, Ikenaga S, Takanashi S (2008) Influence of carotid artery stenosis on stroke in patients undergoing off-pump coronary artery bypass grafting. Eur J Cardiothorac Surg 34:1005–1008
44. Osawa H, Inaba H, Kinoshita O, Akashi O, Minegishi S (2011) Off-pump coronary artery bypass grafting with an aortic nonclamping technique may reduce the incidence of cerebral complications. Gen Thorac Cardiovasc Surg 59:681–685
45. Kobayashi J, Sasako Y, Bando K, Niwaya K, Tagusari O, Nakajima H, Nakamura Y, Ishida M, Kitamura S (2002) Multiple off-pump coronary revascularization with “aorta no-touch” technique using composite and sequential methods. Heart Surg Forum 5:114–118
46. Baba T, Goto T, Maekawa K, Ito A, Yoshitake A, Koshiji T (2007) Early neuropsychological dysfunction in elderly high-risk patients after on-pump and off-pump coronary bypass surgery. J Anesth 21:452–458
47. Ogawa M, Doi K, Yamada Y, Okawa K, Kan’bara T, Koushi K, Yaku H (2007) Renal outcome in off-pump coronary artery bypass grafting: predictors for renal impairment with multivariate analysis. Innovations 2:192–197
48. Kinoshita T, Asai T, Murakami Y, Suzuki T, Kambara A, Matsubayashi K (2010) Preoperative renal dysfunction and mortality after off-pump coronary bypass grafting in Japanese. Circ J 74:1866–1872
49. Hayashida N, Teshima H, Chihara S, Tomoeda H, Takaseya T, Hiratsuka R, Shoujima T, Takagi K, Kawara T, Aoyagi S (2002) Does off-pump coronary artery bypass grafting really preserve renal function? Circ J 66:921–925
50. Oyamada S, Kobayashi J, Tagusari O, Nakajima H, Nakamura S, Yagihara T, Kitamura S (2009) Is diabetic nephropathy a predicted risk factor? – Kaplan-Meier and multivariate analysis of confounding risk factors in off-pump coronary artery bypass grafting for chronic dialysis patients. Circ J 73:2056–2060
51. Sunagawa G, Komiya T, Tamura N, Sakaguchi G, Kobayashi T, Murashita T (2010) Coronary artery bypass surgery is superior to percutaneous coronary intervention with drug-eluting stents for patients with chronic renal failure on hemodialysis. Ann Thorac Surg 89:1896–1900
52. Suzuki T, Asai T, Matsubayashi K, Kambara A, Hiramatsu N, Kinoshita T, Nishimura O (2010) Left main coronary artery disease does not affect the outcome of off-pump coronary artery bypass grafting. Ann Thorac Surg 90:1501–1506
53. Fukui T, Tabata M, Manabe S, Shimokawa T, Shimizu J, Morita S, Takanashi S (2010) Off-pump bilateral internal thoracic artery grafting in patients with left main disease. J Thorac Cardiovasc Surg 140:1040–1045
54. Thielmann M, Leyh R, Massoudy P, Neuhäuser M, Aleksic I, Kamler M, Herold U, Piotrowski J, Jakob H (2006) Prognostic significance of multiple previous percutaneous coronary interventions in patients undergoing elective coronary artery bypass surgery. Circulation 114(1 Suppl):1441–1447
55. Fukui T, Manabe S, Shimokawa T, Takanashi S (2010) The influence of previous percutaneous coronary intervention in patients undergoing off-pump coronary artery bypass grafting. Ann Thorac Cardiovasc Surg 16:99–104
56. Kinoshita T, Asai T, Murakami Y, Takashima N, Hosoba S, Nishimura O, Ikegami H, Hiramatsu N, Suzuki T, Kambara A, Matsubayashi K (2009) Impact of previous PCI on hospital mortality after off-pump coronary artery bypass grafting in diabetic patients with multivessel disease. Innovations 4:334–339
57. Hosokawa K, Nakajima Y, Umenai T, Ueno H, Taniguchi S, Matsukawa T, Mizobe T (2007) Predictors of atrial fibrillation after off-pump coronary artery bypass graft surgery. Br J Anaesth 98:575–580
58. Ishida K, Kimura F, Imamaki M, Ishida A, Shimura H, Kohno H, Sakurai M, Miyazaki M (2006) Relation of inflammatory cytokines to atrial fibrillation after off-pump coronary artery bypass grafting. Eur J Cardiothorac Surg 29:501–505
59. Akazawa T, Nishihara H, Iwata H, Warabi K, Ohshima M, Inada E (2008) Preoperative plasma brain natriuretic peptide level is an independent predictor of postoperative atrial fibrillation following off-pump coronary artery bypass surgery. J Anesth 22:347–353
60. Fujii M, Bessho R, Ochi M, Shimizu K, Terajima K, Takeda S (2012) Effect of postoperative landiolol administration for atrial fibrillation after off pump coronary artery bypass surgery. J Cardiovasc Surg (Trino) 53:369–374
61. Kinoshita T, Asai T, Nishimura O, Hiramatsu N, Suzuki T, Kambara A, Matsubayashi K (2010) Statin for prevention of atrial fibrillation after off-pump coronary artery bypass grafting in Japanese patients. Circ J 74:1846–1851
62. Ito N, Tashiro T, Morishige N, Nishimi M, Hayashida Y, Takeuchi K, Minematsu N, Kuwahara G, Sukehiro Y (2010) Efficacy of propafenone hydrochloride in preventing postoperative atrial fibrillation after coronary artery bypass grafting. Heart Surg Forum 13:E223–E227
63. Kinoshita T, Asai T, Ishigaki T, Suzuki T, Kambara A, Matsubayashi K (2011) Preoperative heart rate variability predicts atrial fibrillation after coronary artery bypass grafting. Ann Thorac Surg 91:1176–1181
64. Nakajima H, Kobayashi J, Funatsu T, Shimahara Y, Kawamura M, Kawamura A, Yagihara T, Kitamura S (2007) Predictive factors for the intermediate-term patency of arterial grafts in aorta no-touch off-pump coronary revascularization. Eur J Cardiothorac Surg 32:711–717
65. Manabe S, Fukui T, Shimokawa T, Tabata M, Katayama Y, Morita S, Takanashi S (2010) Increased graft occlusion or string sign in composite arterial grafting for mildly stenosed target vessels. Ann Thorac Surg 89:683–687
66. Sugimura Y, Toyama M, Katoh M, Kotani M, Kato Y, Hisamoto K (2011) Outcome of composite arterial Y-grafts in off-pump coronary artery bypass. Asian Cardiovasc Thorac Ann 19:119–122
67. Matsuura K, Kobayashi J, Tagusari O, Bando K, Niwaya K, Nakajima H, Yagihara T, Kitamura S (2004) Rationale for off-pump coronary revascularization to small branches: angiographic study of 1,283 anastomoses in 408 patients. Ann Thorac Surg 77: 1530–1534

68. Kinoshita T, Asai T, Nishimura O, Suzuki T, Kambara A, Matsubayashi K (2010) Off-pump bilateral versus single skeletonized internal thoracic artery grafting in patients with diabetes. Ann Thorac Surg 90:1173–1179
69. Saito A, Miyata H, Motomura N, Ono M, Takamoto S, Japan Cardiovascular Surgery Database Organization (2013) Propensity-matched analysis of bilateral internal mammary artery vs single internal mammary artery in 7702 cases of isolated coronary artery bypass grafting. Eur J Cardiothorac Surg 44:711–717
70. Marui A, Kimura T, Tanaka S, Furukawa Y, Kita T, Sakata R, CREDO-Kyoto Investigators (2012) Significance of off-pump coronary artery bypass grafting compared with percutaneous intervention: a propensity score analysis. Eur J Cardiothorac Surg 41:94–101
71. Yamagata K, Kataoka Y, Kokubu N, Kasahara Y, Abe M, Nakajima H, Kobayashi J, Otsuka Y (2010) A 3-year clinical outcome after percutaneous coronary intervention using sirolimus-eluting stent and off-pump coronary artery bypass grafting for the treatment of diabetic patients with multivessel disease. Circ J 74:671–678
72. Dohi S, Kajimoto K, Miyauchi K, Yamamoto T, Tambara K, Inaba H, Kuwaki K, Tamura H, Kojima T, Yokoyama K, Kurata T, Daida H, Amano A (2012) Comparing outcomes after off-pump coronary artery bypass versus drug-eluting stent in diabetic patients. J Cardiol 59:195–201
73. Shimizu T, Ohno T, Ando J, Fujita H, Nagai R, Motomura N, Ono M, Kyo S, Takamoto S (2010) Mid-term results and costs of coronary artery bypass vs drug-eluting stents for unprotected left main coronary artery disease. Circ J 74:449–455
74. Dohi M, Miyata H, Doi K, Okawa K, Motomura N, Takamoto S, Yaku H (2015) The off-pump technique in redo coronary artery bypass grafting reduces mortality and major morbidities: propensity score analysis of data from the Japan Cardiovascular Surgery Database. Eur J Cardiothorac Surg 47(2):299–307

Statistics of OPCAB in Japan

2

Yukihiko Orime

Abstract

This chapter focuses on the status and outcome of coronary artery surgery performed in Japan between January 1 and December 31, 2012. A total of 14,999 patients underwent coronary artery bypass grafting (CABG), 10,658 (71 %) of which received isolated CABG. During this period, the operative mortality rate for patients who underwent isolated CABG was 1.49 %, while the mortality for initial elective CABG was 0.72 %. These are the best results obtained since this survey was initially established in 1996. The number of off-pump CABG (OPCAB) cases has since remarkably increased on an annual basis. This less invasive procedure was performed on 5,865 patients in 2012, which is 65.0 % of the total number of initial elective CABG cases (8,983). The mortality rate of complete OPCAB patients was 0.45 %, which is approximately one-fifth of that in the previous year (2011), indicating quality improvement. More than half (58.9 %) of patients with 4 or more grafting underwent OPCAB, which was a higher rate than 56.9 % in 2011. Vein grafts were utilized in 42 %, which had gradually increased over the previous 8 years. The complicated rate of cerebral-vascular stroke in complete OPCAB was significantly lower than those in on-pump beating CABG and conversion cases from off- to on-pump CABG. This less invasive procedure demonstrated a reduction in adverse cerebral-vascular events.

Keywords

Coronary artery bypass grafting (CABG) • Off-pump CABG (OPCAB) • Survey • Japan • 2012

2.1 Introduction

The Japanese Association for Coronary Artery Surgery (JACAS) has been conducting surveys of the status of coronary artery surgery since 1970 [1–11]. The most recent survey was conducted from January 1 to December 31, 2012. Questionnaires were completed and returned by 326 (71.1 %) out of a total of 459 institutions with departments of cardiac surgery. This report summarizes the advances in coronary artery surgery with special focus on the current status of off-pump coronary artery bypass (OPCAB) in Japan. Results of the status of coronary artery surgery from the previous year as well as from previous surveys were reviewed and considered in the present report.

Operative mortality is defined as any death within 30 days after the day of surgery. Patient characteristics were examined by X^2 statistics with regard to operative mortality.

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2.2 Total Number of Coronary Artery Surgeries and Off-Pump CABG Rate

A total of 14,999 patients underwent coronary artery bypass surgery in 2012, with 10,658 (71 %) of which receiving coronary artery bypass grafting (CABG) only. The remaining 4,341 patients underwent additional procedures for myocardial infarction or other complications at the same time. Of those who received CABG alone, initial elective surgery was performed in 8,983 patients, and 5,865 (65 %) of those underwent off-pump CABG (OPCAB). Other than those who received initial elective surgery (emergency and/or redo cases: 1,675), OPCAB was performed in 880 patients (53 %) (Table 2.1).

Table 2.1 Total number of coronary artery surgery and off-pump CABG rate

Total number	14,999
Isolated CABG	10,658 (71 %)
Concomitant CABG	4,341 (29 %)
Isolated CABG	
Initial elective: 8,983	Other than initial elective: 1,675
Off pump: 5,865	Off pump: 880
On pump: 3,118	On pump: 795
(Off-pump rate: 65 %)	(Off-pump rate: 53 %)

CABG coronary artery bypass grafting

2.3 Changes in OPCAB Rate of Initial Elective Isolated CABG

Figure 2.1 shows the changes in OPCAB rates over the previous 17 years from 1996 to 2012. Since 1996, the number of OPCAB cases had remarkably increased annually until 2004, reaching 62 %. Although there was a slight decrease in 2005, 65 % of patients who underwent initial elective isolated CABG received OPCAB in 2012, indicating a persistently high rate.

2.4 Surgical Procedures of Initial Elective Isolated CABG

Regarding initial elective isolated CABG, a total of 2,038 patients (22.7 %) underwent on-pump CABG with cardiac arrest, 1,080 patients underwent on pump with cardiac beating (12.0 %), and OPCAB was performed in 5,865 cases (65.3 %). In those OPCAB cases, 5,718 patients (97.5 %) underwent off pump until the end of operation, and the remaining 147 cases required conversion from off-pump to on-pump CABG. This conversion rate was 2.5 %, which was lower than 3.8 % in 2011 as shown in Table 2.2.

2.5 Outcome According to Procedures

The mortality rate in patients who underwent isolated CABG was 1.49 %, which was much lower than that in 2011, and that for isolated initial elective CABG cases was 0.72 %,

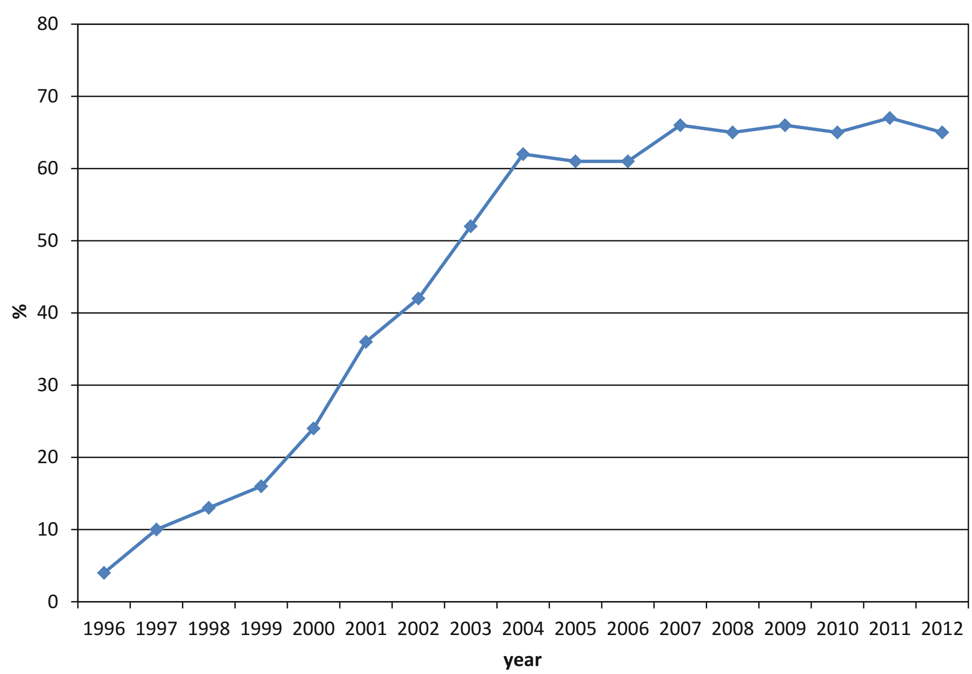


Fig. 2.1 Changes in OPCAB rate of initial elective isolated CABG

achieving the best result since the survey was first conducted. The mortality rate for complete OPCAB was 0.45 %, which is the lowest since this less invasive procedure was introduced. In addition, the mortality rate for conversion from off- to on-pump cases was 2.72 %, which is lower than those of previous years (Table 2.3).

Table 2.2 Surgical procedures of initial elective isolated CABG

Total number of initial elective	8,983 (100 %)
On pump (cardiac arrest)	2,038 (22.7 %)
On pump (cardiac beating)	1,080 (12.0 %)
Off pump (total number)	5,865 (65.3 %)
Off pump (complete)	5,718
On pump (conversion)	147
Off pump (complete rate)	97.5 %
Off to on pump (conversion rate)	2.5 % (previous year: 3.8 %)

Table 2.3 Outcome according to procedures

Mortality for isolated CABG	1.49 % (previous year: 2.72 %)
Mortality for initial elective CABG	0.72 % (previous year: 2.12 %)
On pump (cardiac arrest)	0.83 %
On pump (cardiac beating)	1.67 %
Off pump (total)	0.51 %
Off pump (complete)	0.45 % (previous year: 2.11 %)
On pump(conversion)	2.72 % (previous year: 3.16 %)

CABG coronary artery bypass grafting

2.6 Changes in Mortality of CABG

The changes in mortality since 1996 are shown in Fig. 2.2. The clinical results improved remarkably annually; the operative mortality rate of isolated CABG cases decreased to 1.49 % and that of initial elective patients decreased to 0.72 % in 2012. These are the best results obtained since the surveys were introduced 30 years previously.

2.7 Changes in Mortality According to Procedures: Isolated Initial Elective CABG

Figure 2.3 shows the changes in mortality according to procedures since 2004. Generally, the mortality rate of off- to on-pump conversion cases was high. In contrast, the mortalities of on pump (arrest) and off pump (complete) were lower, with the lowest rate of 0.45 % in complete OPCAB in 2012.

2.8 Number of Grafts According to Surgical Procedures

Figure 2.4 shows the number of grafts according to surgical procedures. The mean number of grafts of total initial elective CABG cases was 2.97/patient, which is approximately the same as that in 2011 (2.96). The mean number of grafts of on pump (cardiac arrest) was 3.22/patient, that of on pump

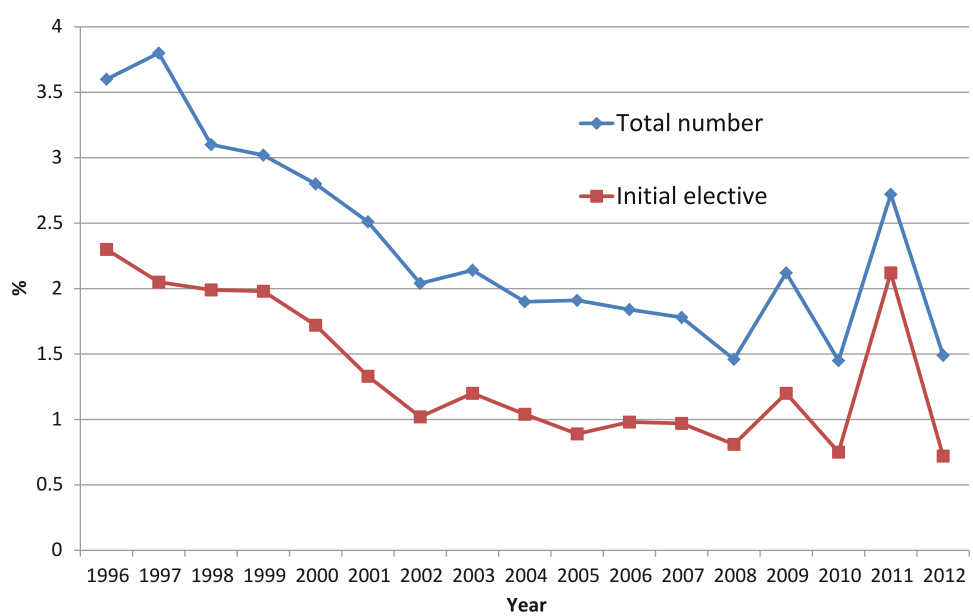


Fig. 2.2 Changes in mortality of CABG

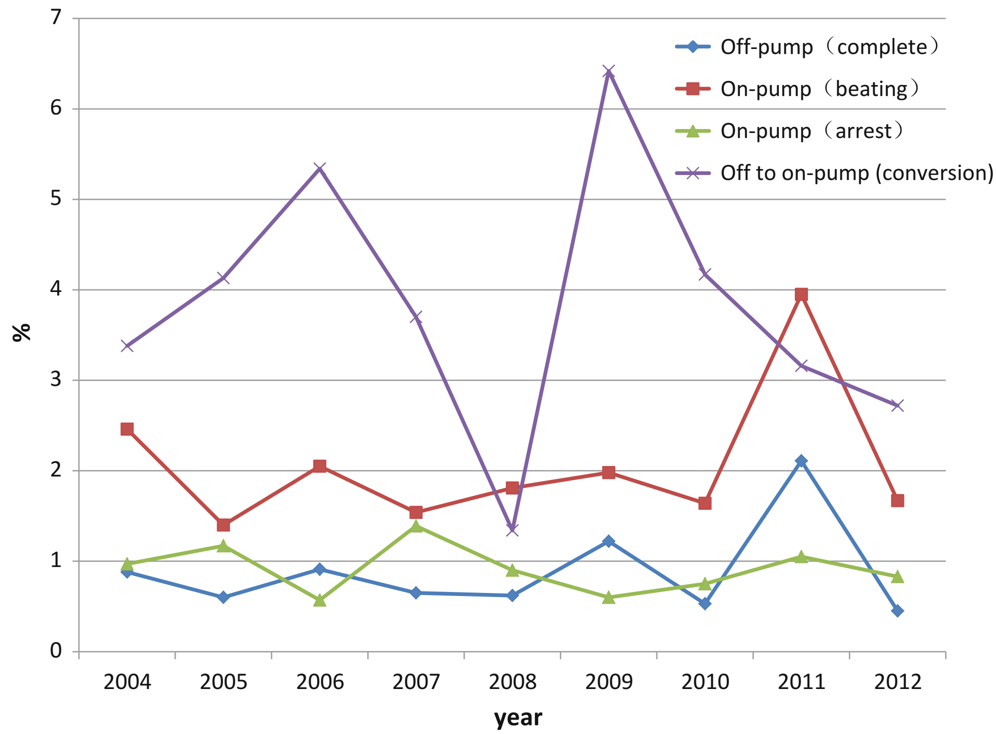
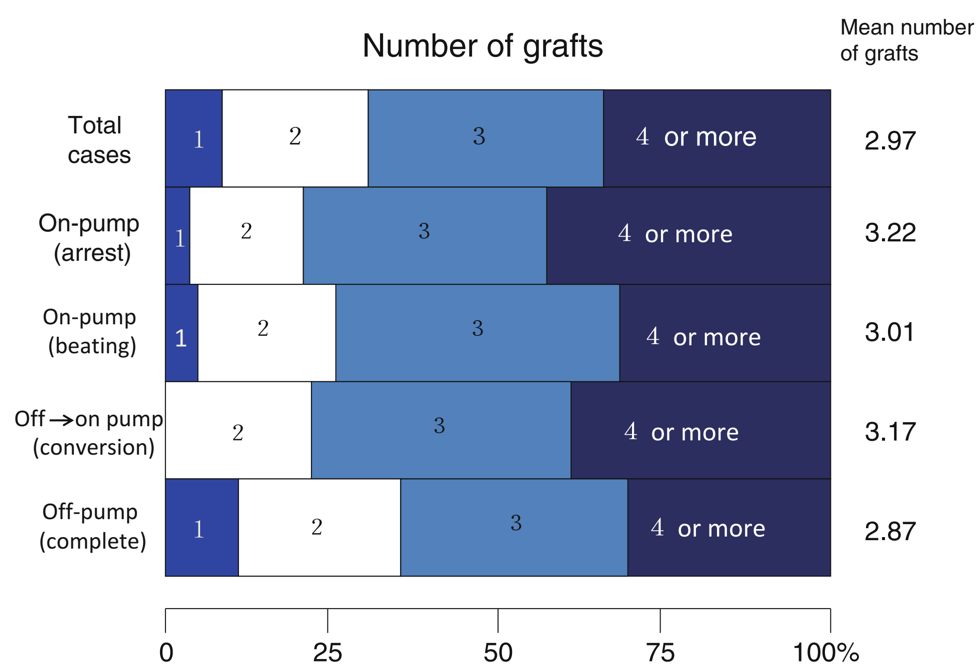


Fig. 2.3 Changes in mortality according to procedures: isolated initial elective CABG

Fig. 2.4 Number of grafts according to surgical procedures



(cardiac beating) was 3.01/patient, that of off- to on-pump conversion cases was 3.17/patient, and that of complete off pump was 2.87/patient.

2.9 Surgical Procedures According to Number of Grafts

Figure 2.5 shows surgical procedures according to the number of grafts. Eighty-seven percent of single-vessel grafting patients underwent OPCAB. The rate of on-pump cardiac arrest CABG increased with increasing numbers of grafts. More than half (58.9 %) of 4 or more grafts underwent OPCAB, which was higher than 56.9 % in 2011.

2.10 Comparison of On-Pump Arrest and Off-Pump According to Anastomosis Site of Coronary Artery: Initial Elective Surgery

There are almost no differences in the anastomosis rate of the right coronary artery and left ascending artery between on-pump arrest and off-pump procedures. However, in the left circumflex coronary artery, the anastomosis rate of on-pump arrest is higher than that of the off pump (Fig. 2.6).

2.11 Graft Selection: Isolated CABG Cases

The total number of grafts was 28,489 in the isolated CABG cases. Of those, the left internal thoracic artery was most commonly used, accounting for 35.9 %, followed by the saphenous vein. The utilization rate of arterial grafts was 58 % of isolated CABG (Fig. 2.7).

2.12 Complication Rate of Cerebral-Vascular Stroke According to Surgical Procedures: Isolated CABG Cases

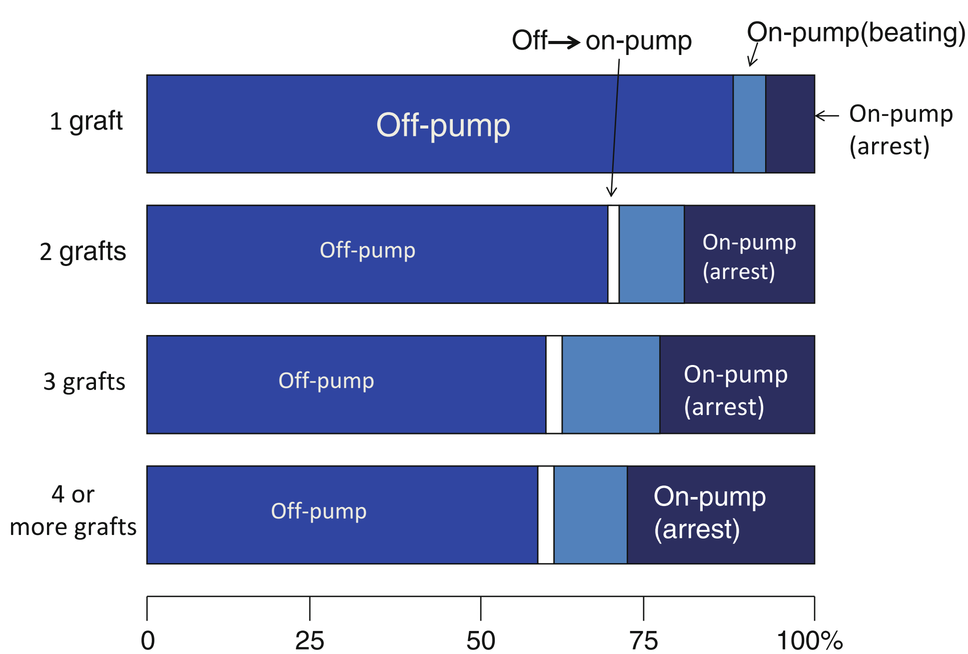
Cerebral-vascular stroke is defined as central neurological deficiency persisting for more than 72 h with physical disability. Of all isolated CABG cases (10,658), 112 patients were defined as having a cerebral-vascular stroke, indicating a complication rate of 1.05 %. The complication rate of complete off-pump procedure was 0.81 %, which was significantly lower than that of the on-pump (cardiac beating) cases and off- to on-pump conversion surgery (Fig. 2.8). This result demonstrated that the less invasive complete off-pump procedure is effective against adverse cerebral-vascular events.

2.13 Special Survey for OPCAB in 2012

In 2012, the Japanese Association for Coronary Artery Surgery (JACAS) made an additional special survey concerning OPCAB. The questions were regarding the following ten items:

1. First choice of CABG procedure
2. Countermeasures against hypotension during OPCAB
3. How to overturn a heart
4. How to stabilize a heart
5. Choice of composite graft type
6. Frequency of use of harmonic scalpel to skeletonize a graft

Fig. 2.5 Surgical procedures according to number of grafts



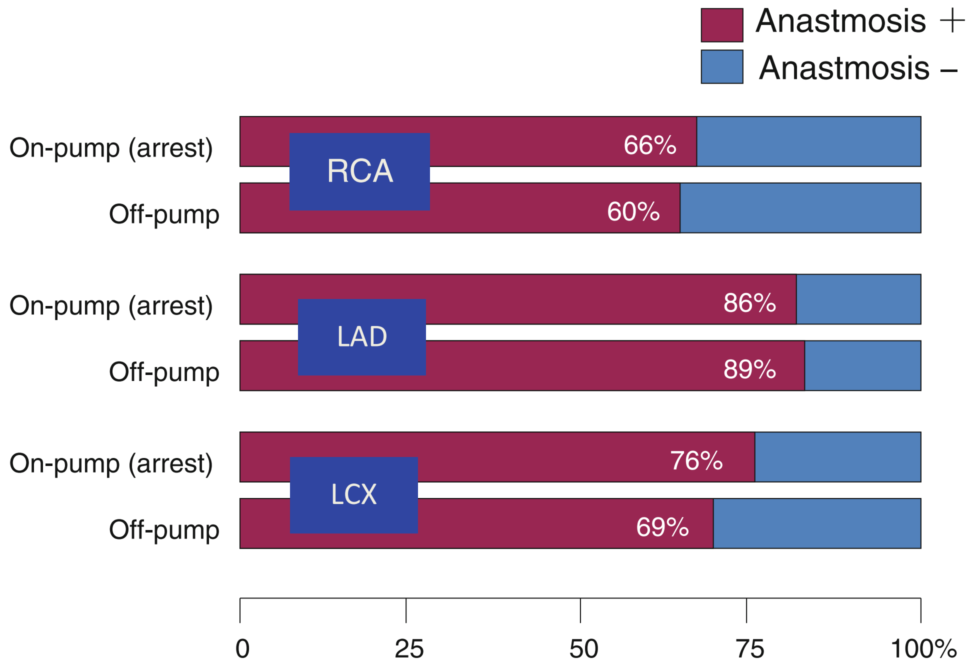


Fig. 2.6 Comparison of on-pump arrest and off pump according to anastomosis site of coronary artery: initial elective surgery

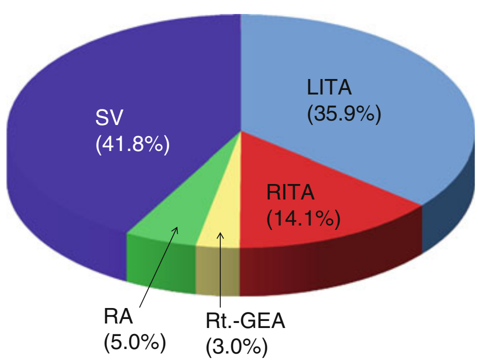


Fig. 2.7 Graft selection: isolated CABG cases

7. Use of endoscopy for graft harvesting
8. Implementation of coronary artery endarterectomy
9. Procedure of proximal anastomosis for OPCAB
10. How to evaluate intraoperative graft flow

Figure 2.9 shows the occupancy rate of the first choice for CABG procedure, where 63.5 % of patients underwent OPCAB, indicating the highest rate. On-pump arrest was performed in 28.5 %, followed by on-pump beating CABG. As a countermeasure against hypotension during OPCAB, inotropic drugs were administered in 54.2 %, and volume loading was performed in 43.1 % (Fig. 2.10).

How to overturn a heart is shown in Figs. 2.11 and 2.12. A heart positioner was utilized in 87 %, demonstrating a high rate. The remaining 13 % of the total cases adopted other procedures, of which LIMA suture was utilized in 80 %.

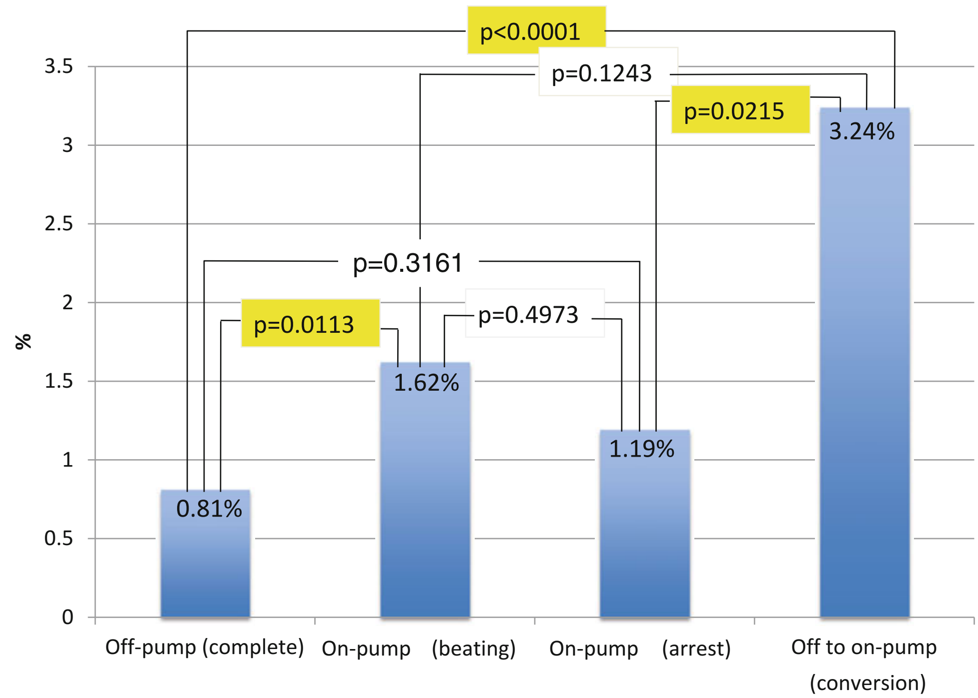
Tissue stabilizer was used to stabilize a heart in all cases (Fig. 2.13). Figure 2.14 shows the frequency of the use of composite graft type. Although almost half of all institutes did not use any type of composite graft, I-composite graft was used in 25.5 % and Y-composite graft in 22.3 %.

The frequency of harmonic scalpel usage for skeletonizing a graft is shown in Fig. 2.15. The frequency was high in most cases (82.3 %), followed by occasional use in 8.4 % and no usage in 9.3 %. Figure 2.16 shows the use of endoscopy for graft harvesting. 87.4 % of the institutes did not use an endoscope to harvest grafts.

During OPCAB, coronary artery endarterectomy was performed in only 26 % of all cases (Fig. 2.17). Procedures of proximal anastomosis for OPCAB are shown in Fig. 2.18. Seventy percent of OPCAB were carried out with the application of the aorta non-touch technique, using assistive devices.

Figure 2.19 shows how to evaluate intraoperative graft flow. A transit time flow meter was used in 73.8 % of all patients, followed by SPY in 6.2 % and ultrasonic echogram in 4.9 %. On the other hand, 12.3 % of all cases did not evaluate graft flow during surgery.

Fig. 2.8 Complication rate of cerebral-vascular stroke according to surgical procedures: isolated CABG



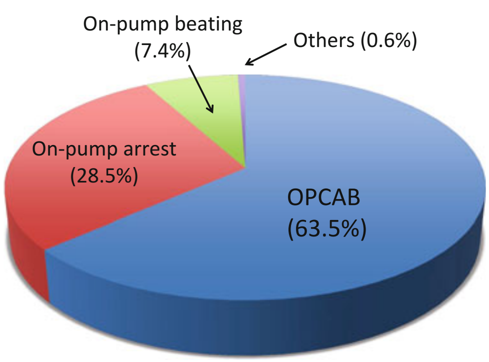


Fig. 2.9 First choice of procedure for CABG

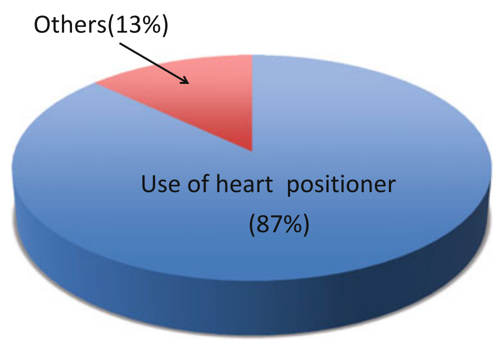


Fig. 2.11 How to overturn a heart (1)

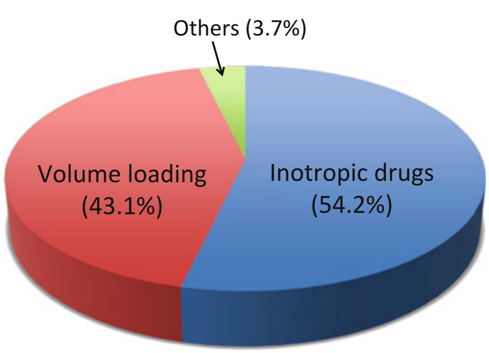


Fig. 2.10 Countermeasures against hypotension during OPCAB

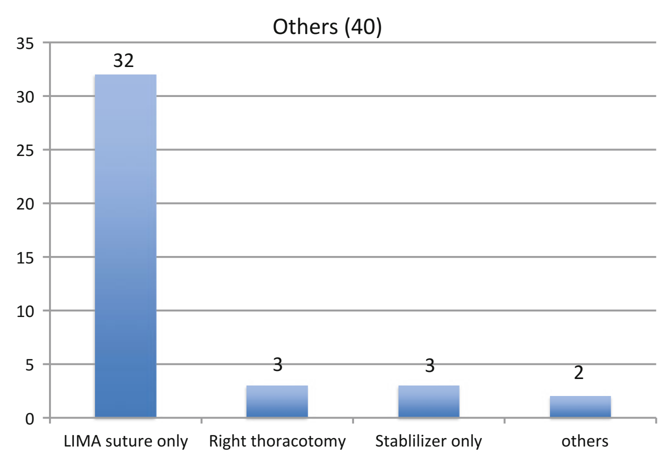


Fig. 2.12 How to overturn a heart (2)

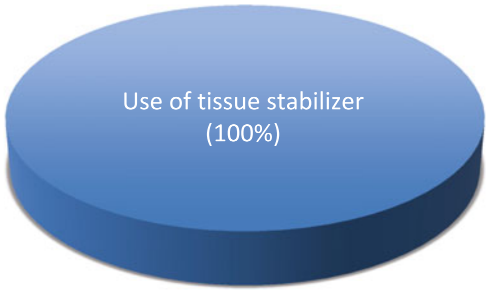


Fig. 2.13 How to stabilize a heart

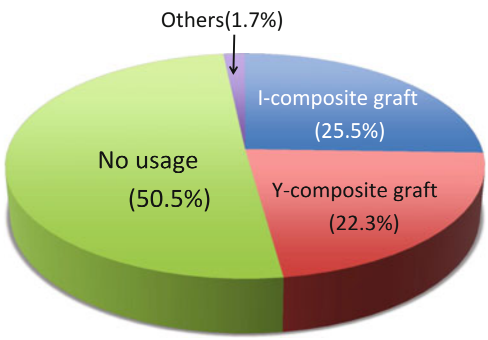


Fig. 2.14 Frequency of use of composite graft type

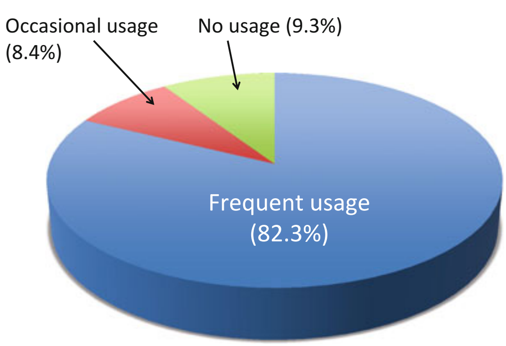


Fig. 2.15 Frequency of use of harmonic scalpel to skeletonize graft

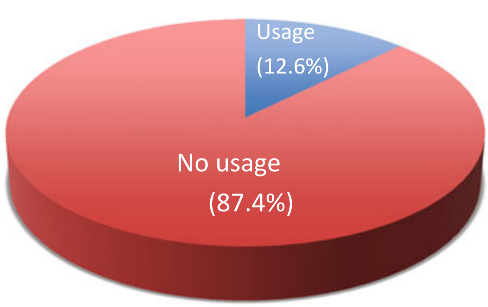


Fig. 2.16 Usage of endoscope for graft harvesting

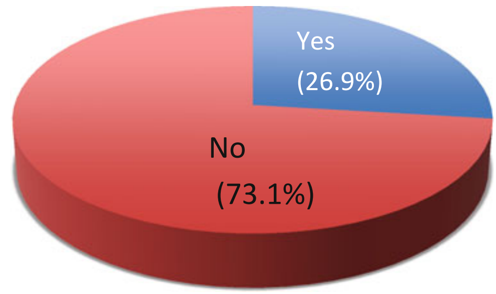


Fig. 2.17 Operation of coronary artery endarterectomy

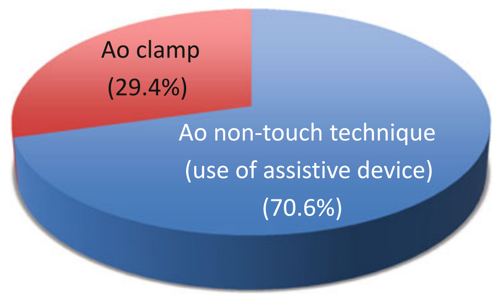


Fig. 2.18 Procedure of proximal anastomosis for OPCAB

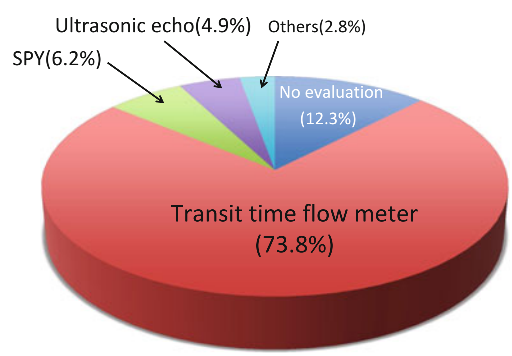


Fig. 2.19 How to evaluate intraoperative graft flow

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References

1. Sezai Y, Kitamura S, Harada Y et al (1989) Results of coronary artery surgery in Japan. Jpn Ann Thorac Surg 9:53–62
2. Sezai Y, Hasegawa T, Kitamura S et al (1991) Surgical management of acute myocardial infarction in the 24 hours-the Japanese experience. In: D'Alessandro LC (ed) Heart surgery 1991. Casa Editrice Scientifical Inermazionale, Rome, pp 417–424

3. Sezai Y (1997) Coronary artery surgery status in Japan. In: Sazai Y (ed) Advances in coronary artery surgery. Axcel Springer Japan, Tokyo, pp 3–12
4. Sezai Y, Tsukamoto S (1998) Coronary artery surgery results 1996. Ann Thorac Cardiovasc Surg 4:103–106
5. Sezai Y, Orime Y, Tsukamoto S (2002) Coronary artery surgery results 2000. Ann Thorac Cardiovasc Surg 8:241–247
6. Sezai Y, Orime Y, Tsukamoto S (2004) Coronary artery surgery results 2002. J Jpn Coron Assoc 10:1–4
7. Sezai Y, Orime Y, Tsukamoto S (2004) Coronary artery surgery results 2002 in Japan. Ann Thorac Cardiovasc Surg 10:266–271
8. Sezai Y, Orime Y, Tsukamoto S (2004) Coronary artery surgery results 2003. J Jpn Coron Assoc 10:141–145
9. Sezai Y, Orime Y, Tsukamoto S (2006) Coronary artery surgery results 2004. J Jpn Coron Assoc 12:9–16
10. Sezai Y, Orime Y, Tsukamoto S (2007) Coronary artery surgery results 2005 in Japan. Ann Thorac Cardiovasc Surg 13:220–223
11. Official home page of Japanese Association for Coronary Artery Surgery. http://www.jacas.org/

3 Evidence in OPCAB: Critical Appraisal of Recent RCT Based on CABG in Japan

Junjiro Kobayashi

Abstract

The operative mortality, graft patency, and long-term outcomes in OPCAB compared with conventional CABG are still controversial. The 30-day mortality after primary elective CABG with CPB was less than 1.0 % in Japan in 2011. Therefore, it is not surprising that the recent RCTs in western countries showed no difference in operative mortality between OPCAB and on-pump CABG. Prospective, randomized trials have been criticized because they lack adequate power to assess clinical outcomes because they had been performed in single centers and the surgeons were not accustomed to both OPCAB and standard CABG. Considering the high occlusion late of saphenous vein graft (SVG) in OPCAB because of hypercoagulability status after surgery, OPCAB may sacrifice graft patency and cause late unfavorable cardiac events.

Routine early postoperative angiography was performed in 3,532 patients between January 2002 and December 2005 in 12 centers within 3 weeks after CABG in Japan. OPCAB was performed in 85 % of all cases. The occlusion rate of SVG (7.3 %) was significantly higher than left internal thoracic artery (LITA) (1.7 %), right internal thoracic artery (RITA) (1.7 %), radial artery (RA) (3.4 %), and right gastroepiploic artery (GEA) (3.8 %) in OPCAB. There was no difference in the bypass occlusion and stenosis rate between OPCAB and standard CABG cases. The occlusion rate of SVG (7.3 %) in OPCAB was significantly ($p = 0.032$) higher than that (2.8 %) in standard CABG. Bypass occlusion and stenosis rate of RITA to left anterior descending artery (LAD) (6.1 %) was significantly ($p = 0.013$) higher than that of LITA to LAD (3.8 %). In the circumflex area bypass occlusion rate of SVG (7.1 %) was significantly higher than that of all arterial grafts of LITA (4.2 %, $p = 0.030$), RITA (1.7 %, $p < 0.001$), RA (2.2 %, $p < 0.001$), and GEA (3.7 %, $p = 0.029$). Bypass occlusion rate in the right coronary territory was not related to graft material. The LITA was the best graft for LAD, and the RA was as good as the RITA and better than SVG in the circumflex area. SVG should be avoided in OPCAB, and multiple arterial OPCAB in Japan is the optimal strategy.

Keywords

Cardiopulmonary bypass • Heart disease • Surgery • Coronary artery

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3.1 Different Situation of OPCAB in Japan

The number of coronary artery bypass grafting (CABG) reached more than 22,000 in 2003 in Japan [1]. However, the number declined up to 30 % in 2011 [2] owing to unrestricted percutaneous coronary intervention with drug-eluting stents regardless of coronary artery revascularization guidelines. During the last decade, the development of CABG without cardiopulmonary bypass (CPB) has significantly changed CABG in Japan. In 1967, Kolessov first grafted the left internal thoracic artery (LITA) to the anterior descending artery through a left thoracotomy without CPB [3]. Coronary artery revascularization with cardioplegic arrest became the standard CABG procedure with development of CPB technique and myocardial preservation methods for cardiac arrest during the early 1980s. After the pioneering efforts by Benetti [4] and Buffolo [5] in South America for OPCAB through a median sternotomy during the 1990s, suction-type mechanical stabilizer and apical suction device in addition to Trendelenburg positioning by the operating table allowed exposure of all coronary branches. According to the Japanese Association for Thoracic Surgery, the percentage of off-pump CABG (OPCAB) among the total CABG cases was 35 % in 2001, 46 % in 2002, 55 % in 2003, and 60 % in 2004. The frequency of OPCAB reached a plateau after 2005 according to the database of the Japanese Association for Coronary Artery Surgery. Therefore, OPCAB has become the standard method of CABG in Japan, whereas the percentage of OPCAB cases among all CABGs in North America was less than 20 % and in Germany 5 %. As some surgeons in the United States are performing 90 % or more of the CABGs without CPB, the frequency of OPCAB in standard hospitals might be less than 10 %.

3.2 Positive Impact of OPCAB

The indications of OPCAB are the high risk factors of CPB such as cerebrovascular disease, chronic renal failure, chronic obstructive pulmonary disease, atheromatous or calcified ascending aorta, older age, liver cirrhosis, and cancer. Many retrospective and cohort studies have been published comparing clinical outcomes after OPCAB with conventional CABG [6–11]. In moderate and high-risk patients, the operating time, intubation time, length of ICU stay, length of hospital stay, perioperative myocardial infarction, amount of bleeding and transfusion, inflammatory reaction, stroke, neurocognitive dysfunction, atrial fibrillation, and inotrope requirements were in favor of OPCAB [12].

A meta-analysis of 42 non-randomized trials of high-risk patients by Puskas and associates [13] demonstrated a significant reduction in mortality after OPCAB versus conventional CABG in various high-risk patient subsets (odds ratio (OR): 0.58). Mortality was reduced in patient subgroups with high risk factors of EuroSCORE >5 (OR: 0.39), LV dysfunction (OR: 0.55), atheromatous aorta (OR: 0.54), and multiple risk factors (OR: 0.60). Increased age, left main trunk lesion, diabetes mellitus, renal dysfunction, and chronic obstructive pulmonary disease were not related to the operative mortality irrespective of CPB.

A systematic review and meta-analysis of propensity score analysis by Kuss and associates in 123,137 patients of 35 papers found that OPCAB was superior to conventional CABG [14]. The benefit was operative mortality (OR: 0.69), renal failure, transfusion, wound infection and prolonged ventilation, inotropic support, and intra-aortic balloon pump (IABP) support. However, myocardial infarction, atrial fibrillation, and reoperation for bleeding were similar.

In the early RCTs [15–20], postoperative various complications, ICU stay, hospital stay, bleeding, and transfusion were in favor of OPCAB. The early meta-analysis of previous RCTs by Cheng and associates [21] showed no significant differences in the 30-day mortality, IABP support, myocardial infarction, stroke, renal dysfunction, wound infection, re-exploration for bleeding, or re-intervention for mixed-risk patient population. However, OPCAB significantly decreased atrial fibrillation (OR: 0.58), transfusion (OR: 0.43), inotrope requirements (OR: 0.48), respiratory infection (OR: 0.41), ventilation time (−2.4 h), ICU stay (−0.3 day), and hospital stay (−1.0 day). Results of graft patency and neurocognitive function were inconclusive. In-hospital and 1-year medical costs were generally higher for standard CABG.

Møller also meta-analyzed 66 randomized trials [22]. There were no statistically significant differences regarding mortality (OR: 0.98), myocardial infarction (OR: 0.95), or renewed coronary revascularization (OR: 1.34). There was a significant reduced risk of atrial fibrillation (OR: 0.69) and stroke (OR: 0.53) in off-pump patients. However, when continuity correction for zero-event trials was included, the reduction in stroke became insignificant.

Puskas and associates reported the long-term outcomes of earlier Surgical Management of Arterial Revascularization Therapy (SMART) trial [19] involving 297 patients after isolated elective CABG. After 7.5 years of follow-up, there was no difference in mortality or late graft patency between OPCAB and on-pump CABG. Recurrent angina was more common in the OPCAB group though this did not reach statistical significance [23].

3.3 Negative Impact of OPCAB in RCT

Prospective, randomized trials have been criticized because they lack adequate power to assess clinical outcomes because they had been performed in single centers and the surgeons were not accustomed to both OPCAB and standard CABG. To overcome these problems, Randomized On/Off Bypass (ROOBY) study was performed in 2203 patients in 18 Veterans Affairs medical centers with 53 attending surgeons [24]. There was no difference in 30-day mortality or short-term major adverse cardiovascular events. OPCAB patients received significantly fewer grafts per patient. After 1 year, cardiac-related death (8.8 % versus 5.9 %, $p=0.01$) and major adverse events (9.9 % versus 7.4 %, $p=0.04$) were significantly higher in the OPCAB group. Furthermore, graft patency was significantly lower in the OPCAB group (82.6 % versus 87.8 %, $p<0.001$). There was no difference in neuropsychological testing between the groups.

Recently, the results of the Coronary Artery Bypass Surgery Off or On Pump Revascularization Study (CORONARY) were reported [25, 26]. In the largest trial of OPCAB versus standard CABG, with 4752 patients from 79 centers in 19 countries, no significant difference was observed in the primary outcome of death, myocardial infarction, stroke, or new hemodialysis at 30 days (9.8 % vs. 10.3 %, $p=0.59$). There was a lower rate of transfusion (50.7 % vs. 63.3 %, $p<0.001$) and a higher rate of repeat revascularization (0.7 % vs. 0.2 %, $p=0.01$) in OPCAB group. The 1-year clinical results were consistent with the 30-day findings. There was no significant difference in the composite outcome of death, myocardial infarction, stroke, or new hemodialysis (12.1 % vs. 13.3 %, $p=0.24$). Repeat revascularization remained more common in the OPCAB group (1.4 % vs. 0.8 %, $p=0.07$), and QOL and neurocognitive outcomes were similar in both groups.

Similar negative results of OPCAB were found in the most recent meta-analysis of 8961 patients with a mean age of 63.4 and 16 % females in 59 trials by Afilalo [27]. There was a significant 30 % reduction in the occurrence of postoperative stroke with OPCAB (OR: 0.70). However, there was no significant difference in mortality (OR: 0.90) or myocardial infarction (OR: 0.89).

RCTs were performed in high-risk patients in several studies. In a study involving high-risk patients with three-vessel disease and a EuroSCORE ≥5, Møller and associates could find no difference in morbidity or mortality between OPCAB and standard CABG [28]. The mean number of grafts per patient did not differ significantly between groups (3.22 in OPCAB group and 3.34 in standard CABG group, $p=0.11$). Fewer grafts were performed to the lateral part of the left ventricle territory during OPCAB (0.97 in OPCAB and 1.14 in standard CABG, $p=0.01$).

The German Off-Pump Coronary Artery Bypass Grafting in Elderly Patients (GOPCABE) trial randomly assigned 2539 patients 75 years of age or older from 12 German centers to OPCAB or standard CABG [29]. No significant difference between groups was observed in the primary outcome of death, myocardial infarction, stroke, repeat revascularization, or new renal-replacement therapy at 30 days (7.8 % vs. 8.2 %, $p=0.74$) or at 1 year (13.1 % vs. 14.0 %, $p=0.48$). There were fewer transfusions and more repeat revascularizations (1.3 % vs. 0.4 %, $p=0.04$) with off-pump surgery.

3.4 Multicenter Angiographic Analysis of Early Graft Patency in Relation to Graft Material and OPCAB in Japan

This study was a multicenter retrospective analysis of early elective postoperative coronary angiography performed within 3 weeks after CABG between January 2002 and December 2005 in 12 centers. Postoperative angiography was performed in 3,532 patients who underwent elective and emergent CABG. Mean age at operation was 65.6 ± 10.1 years. OPCAB was performed in 85 % of all cases. Average number of distal anastomoses was 3.4 ± 1.2 (OPCAB, 3.4 ± 1.2; standard CABG, 3.2 ± 1.2, $p<0.001$) (Fig. 3.1). Average number of grafts was 2.4 ± 0.6 (OPCAB, 2.4 ± 0.6; standard CABG, 2.3 ± 0.7, $p=0.35$). Average number of arterial graft anastomosis was 2.9 ± 2.1. Distribution of graft material was 36 % left internal thoracic artery (LITA), 18 % right internal thoracic artery (RITA), 10 % gastroepiploic artery (GEA), 19 % radial artery (RA), and 17 % saphenous vein graft (SVG) with regard to distal anastomosis. Exclusive use of LITA and SVG was applied in 30 % of patients. Both LITA and RITA were used in 45 % of patients. More than two arterial grafts were used in 84 % of patients. Total arterial revascularization was performed in 67 % of patients. Graft configuration was composed of 49 % in situ graft, 39 % composite graft, and 12 % of aortocoronary bypass.

Overall bypass occlusion rate was 3.1 % (366/11,968). Graft stenosis rate was 1.9 %. Overall bypass occlusion rate was 2.1 % in LITA, 1.9 % in RITA, 3.3 % in RA, 6.3 % in SVG, and 4.2 % in GEA. There were 297 patients with at least one occluded bypass. Univariate analysis showed that the risk factors of patients with occluded bypass grafting were female gender, weight, height, diabetes, blood creatinine level, liver dysfunction, non-left main trunk lesion, three-vessel disease, family history of ischemic heart disease, more than four distal anastomoses, and no use of preoperative β blocker and aspirin (Table 3.1). OPCAB or prior percutaneous coronary intervention was not a risk factor. In multivariate analysis, only female gender (HR, 1.53: 95 % CI, 1.13–2.07), liver dysfunction (HR, 2.09: 95 % CI, 1.18

Fig. 3.1 Bypass site and graft arrangement

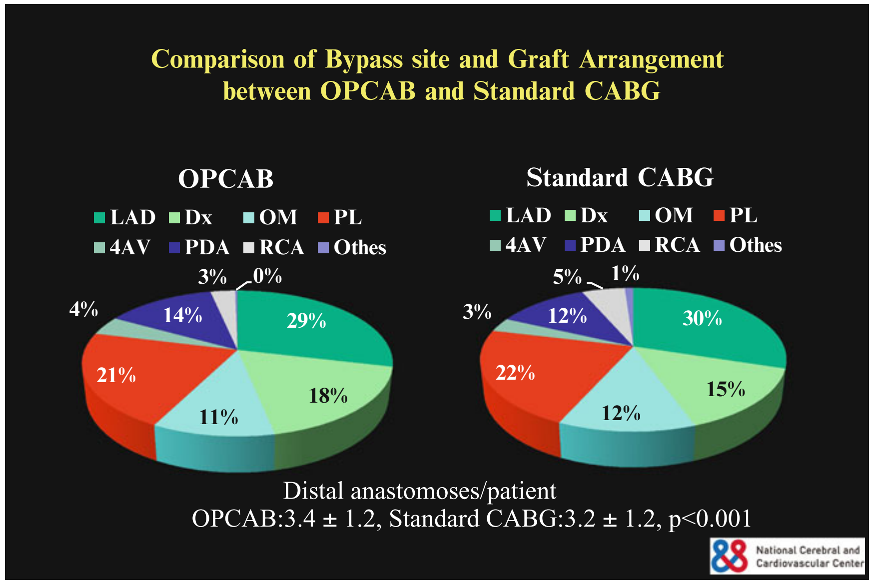

Table 3.1 Patient characteristics in relation to graft occlusion

Univariate analysis			
Variable	With all patent grafts ($n = 3235$)	With occluded graft ($n = 297$)	p value
Age (year)	65.5 ± 1.1	66.5 ± 9.6	0.13
Female	694 (21 %)	84 (28 %)	0.01
Weight (kg)	61.2 ± 10.6	59.6 ± 11.3	0.015
Height (cm)	160.2 ± 8.9	158.0 ± 11.0	0.0002
BMI (kg/m^2)	23.9 ± 5.3	24.1 ± 8.3	0.58
Hypertension	2149 (66 %)	187 (63 %)	0.29
Hypercholesterolemia	1741 (54 %)	157 (53 %)	0.97
Diabetes	1659 (51 %)	131 (44 %)	0.02
Oral medication	445 (14 %)	50 (17 %)	0.006
Insulin	452 (14 %)	35 (12 %)	0.83
Creatinine (mg/dl)	1.67 ± 2.22	2.45 ± 1.00	0.04
Dialysis	208 (6 %)	17 (6 %)	0.97
Liver dysfunction	97 (3 %)	18 (6 %)	0.009
CTR by chest X-ray	50.6 ± 5.6	50.8 ± 5.2	0.64
NYHA class III, IV	578 (18 %)	56 (19 %)	0.22
CCS class III, IV	710 (22 %)	69 (23 %)	0.14
Prior PCI	1354 (42 %)	102 (34 %)	0.06
Prior MI	1107 (34 %)	98 (33 %)	0.59
LVEF	55.6 ± 14.8	57.3 ± 14.4	0.12
EF <0.35	195 (6 %)	16 (5 %)	0.21
Non-LMT lesion	1981 (61 %)	205 (69 %)	0.01
Three-vessel disease	2190 (68 %)	225 (76 %)	0.005
Family history of IHD	397 (12 %)	46 (15 %)	0.03
Emergent surgery	215 (7 %)	16 (5 %)	0.40
OPCAB	2754 (85 %)	261 (88 %)	0.20
≥4 distal anastomoses	1474 (46 %)	157 (53 %)	0.02
β blocker	744 (23 %)	67 (23 %)	0.047
Aspirin	1789 (55 %)	123 (41 %)	0.14

CTR cardiothoracic ratio, *PCI* percutaneous coronary intervention, *MI* myocardial infarction, *LVEF* left ventricular ejection fraction, *LMT* left main coronary artery trunk, *IHD* ischemic heart disease, *OPCAB* off-pump coronary artery bypass grafting

Table 3.2 Patient characteristics in relation to graft occlusion

Multivariate analysis			
Variable	p value	Hazard ratio	95 % CI
Female	0.007	1.53	1.13–2.07
Liver dysfunction	0.01	2.09	1.18–3.70
Non-LMT lesion	0.005	1.54	1.14–2.08
Family history of IHD	0.02	1.52	1.07–2.17
≥4 distal anastomoses	0.04	1.34	1.01–1.77

Table 3.3 Outcomes in relation to graft occlusion

Outcomes	With all patent grafts ($n = 3235$)	With occluded graft ($n = 297$)	p value
All morbidity	932 (29 %)	106 (36 %)	0.01
Operative[a]	105 (3 %)	20 (7 %)	0.003
Infection	182 (6 %)	22 (7 %)	0.24
Neurological	59 (2 %)	4 (1 %)	0.57
Pulmonary	105 (3 %)	15 (5 %)	0.12
Renal	97 (3 %)	10 (3 %)	0.69
Others[b]	590 (18 %)	65 (22 %)	0.19
Operative death	17 (0.5 %)	1 (0.3 %)	0.98
Hospital death	44 (1.4 %)	2 (0.7 %)	0.33

[a]Perioperative myocardial infarction and reoperation for bleeding and all other causes
[b]Complete heart block, cardiac arrest, atrial fibrillation, anticoagulation-related complication, gastrointestinal complication, and DIC

to 3.70), non-left main trunk lesion (HR, 1.54: 95 % CI, 1.14–2.08), family history of ischemic heart disease (HR, 1.52: 95 % CI, 1.07 to 2.17), and more than four distal anastomoses (HR, 1.34: 95 % CI, 1.01–1.77) were risk factors (Table 3.2). Bypass occlusion was related to operative morbidity ($p = 0.003$) and all morbidity ($p = 0.01$). Bypass occlusion was not related to operative death or hospital death (Table 3.3).

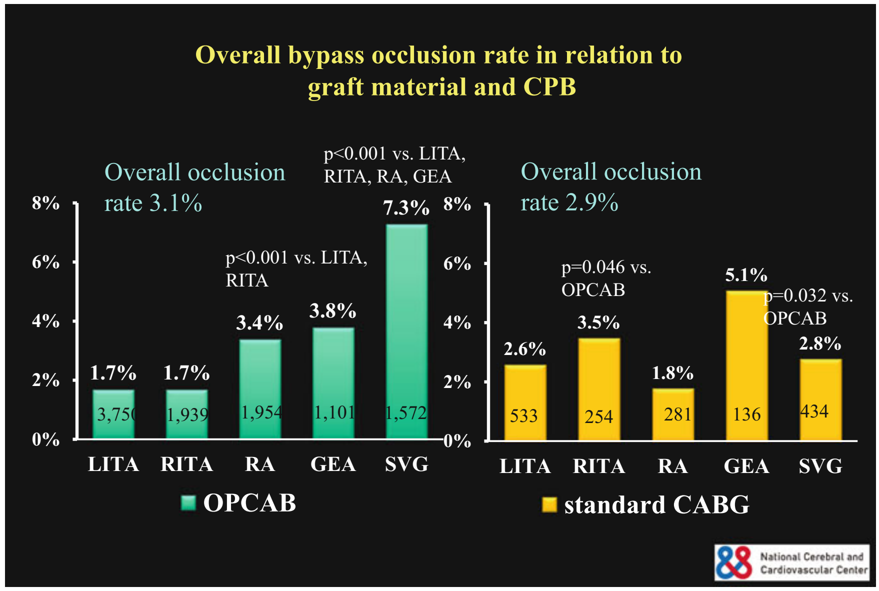

Fig. 3.2 Bypass occlusion rate

Graft occlusion rate in relation to graft material and cardiopulmonary bypass was shown in Fig. 3.2. The occlusion rate of SVG (7.3 %) was significantly ($p<0.001$) higher than LITA (1.7 %), RITA (1.7 %), RA (3.4 %), and GEA (3.8 %) in OPCAB. The occlusion rate of RA and GEA was also significantly ($p<0.001$) higher than LITA and RITA in OPCAB. In standard CABG patients, bypass occlusion rate was not statistically different between graft materials. The occlusion rate of RITA (1.7 %) in OPCAB was significantly ($p=0.046$) lower than that (3.5 %) in standard CABG. On the contrary, the occlusion rate of SVG (7.3 %) in OPCAB was significantly ($p=0.032$) higher than that (2.8 %) in standard CABG. As a whole there was no difference in the bypass occlusion rate between OPCAB (3.1 %) and standard CABG (2.9 %).

Bypass occlusion and stenosis was examined in relation to graft material and bypass area. Bypass occlusion and stenosis rate of RITA to left anterior descending artery (LAD) (6.1 %) was significantly ($p=0.013$) higher than that of LITA to LAD (3.8 %) though the difference of occlusion rate did not reach statistical significance ($p=0.053$) (Fig. 3.3). In the circumflex area bypass occlusion rate of SVG (7.1 %) was significantly higher than that of all arterial grafts of LITA (4.2 %, $p=0.030$), RITA (1.7 %, $p<0.001$), RA (2.2 %, $p<0.001$), and GEA (3.7 %, $p=0.029$). The occlusion rate of RITA was significantly lower than that of LITA ($p=0.002$) and GEA ($p=0.046$) in this area (Fig. 3.4). The occlusion rate of RA was significantly lower than that of LITA ($p=0.024$) in the circumflex area. Bypass occlusion rate in the right coronary territory was not related to graft material (Fig. 3.5). However, overall bypass occlusion rate in the right coronary area (4.8 %) was significantly ($p<0.001$, $p=0.015$) higher than that in LAD (1.8 %) and circumflex area (3.5 %).

Bypass occlusion and stenosis in relation to the site of the right coronary artery (RCA) was examined. Bypass occlusion and stenosis of the RITA to the right main coronary artery (11.1 %) was significantly higher than that of RA (0 %, $p=0.004$) and SVG (2.0 %, $p=0.013$) (Fig. 3.6). Bypass occlusion and stenosis of the GEA to the main RCA was significantly higher (13.3 %) than that of RA ($p<0.001$) and SVG ($p<0.001$). Bypass occlusion and stenosis rate of GEA to the main right coronary artery was significantly ($p=0.009$) higher than that to the posterior descending artery (5.1 %). Bypass occlusion and stenosis rate of SVG to the main RCA was significantly lower than that to the posterior descending artery (7.4 %, $p=0.045$) and atrioventricular branch (11.6 %, $p<0.001$).

Bypass occlusion of the RA in relation to composite and aortocoronary bypass configuration was examined. The occlusion rate of RA as a composite graft was significantly ($p=0.0023$) higher in the right coronary territory (5.4 %) than that in the circumflex territory (2.1 %) (Fig. 3.7). There was no significant difference in RA occlusion rate between composite and aortocoronary bypass both in the circumflex and the right coronary area.

Female gender, liver dysfunction, non-left main trunk lesion, family history of ischemic heart disease, and more than four distal anastomoses were independent risk factors in patients who had at least one bypass occlusion. Women have more severe coronary disease, higher age, higher comorbidity, lower body surface area, and lower percentage of LITA use. However, even after the risk matching of these factors, it was confirmed that female gender is an independent risk factor for adverse events and mortality after CABG [30]. Smaller body surface area and fragile coronary artery were

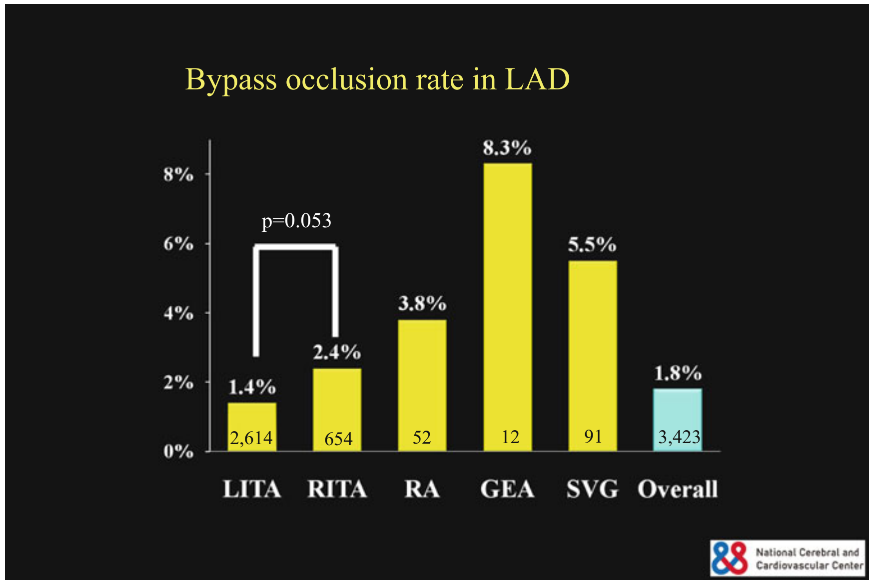

Fig. 3.3 Bypass occlusion rate in the LAD area

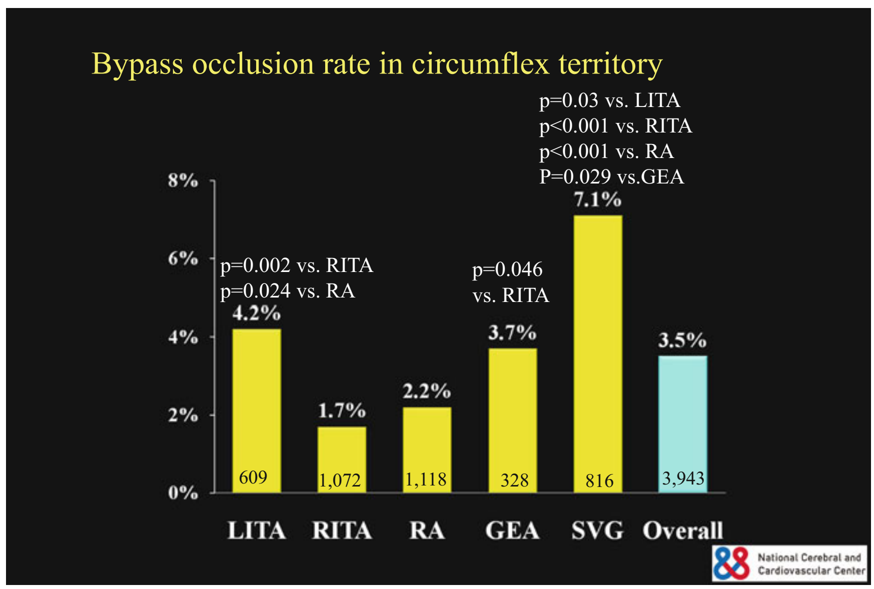

Fig. 3.4 Bypass occlusion rate in the circumflex area

the major causes of higher risk of perioperative mortality and morbidity in women [31]. Early occlusion of the bypass graft may explain the higher mortality and morbidity in women according to our results. There was no previous report regarding liver dysfunction and bypass graft patency to my knowledge. Liver dysfunction or cirrhosis may cause coagulation abnormality after CABG. Risk factors of non-left main trunk lesion, family history of ischemic heart disease, and more than four distal anastomoses may be related to the severity and diffuseness of the coronary lesion. The difficulty and many graft anastomosis sites may be attributed to bypass occlusion.

In the present study, there were several interesting results regarding the graft material and the method of its use both in OPCAB and standard CABG. First, LITA was the best graft for LAD. The RITA was not as good as the LITA as a graft for LAD. As the multivariate analysis showed that the female gender was an independent risk factor of graft occlusion, distal RITA in women might be not appropriate for LAD grafting. Second, in the circumflex area, graft patency of RITA and RA were better than LITA, GEA, and SVG. There was no difference in the graft patency of RA and RITA in this area. RITA was used as a composite graft with LITA rather than in situ graft. There was no difference in the RA graft patency in this area between the method of composite and aortocoronary bypass in the present study. RA could be used as a composite graft as well as aortocoronary bypass in some previous studies [32, 33]. However, Gaudino and associates found flow

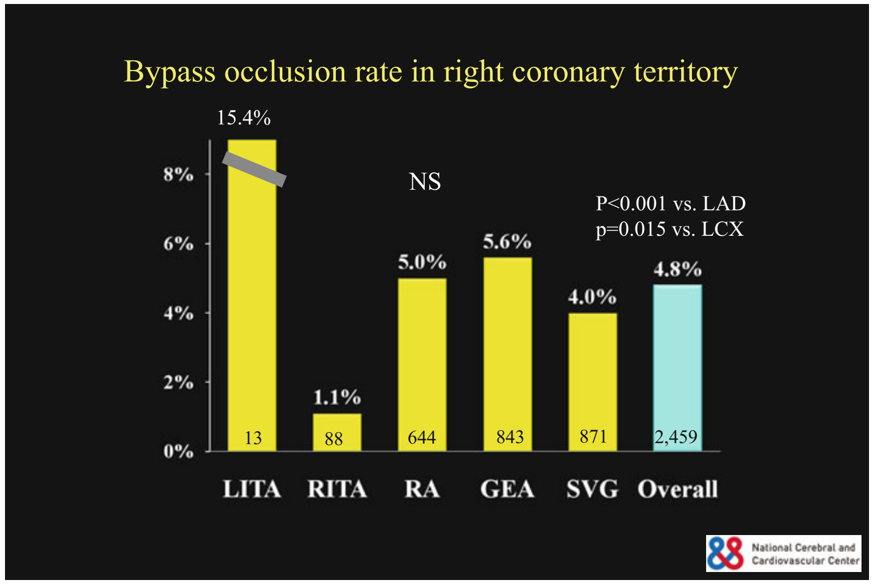

Fig. 3.5 Bypass occlusion rate in the right coronary area

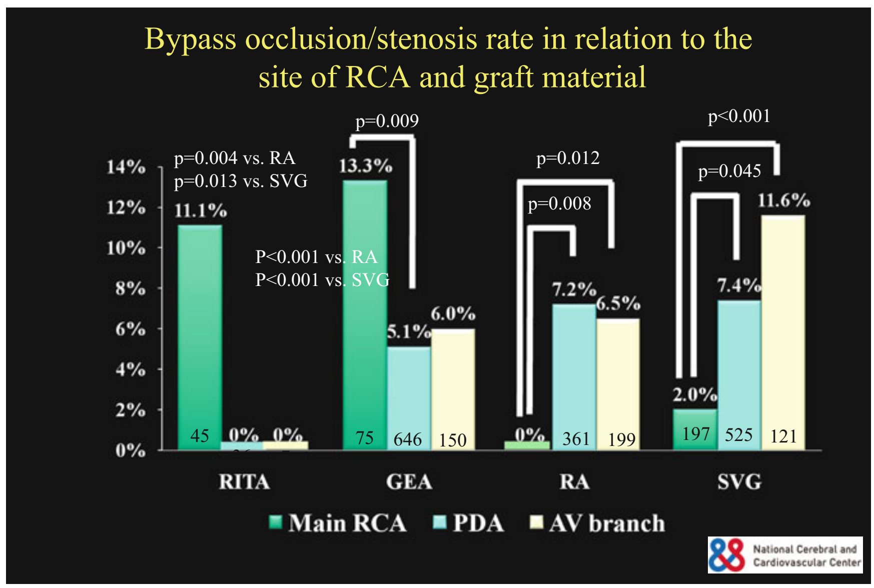

Fig. 3.6 Bypass occlusion and stenosis rate in relation to the site of right coronary artery

competition more frequently in the composite RA conduits than in the aortocoronary RA conduit [34]. RA is suitable for the second arterial graft next to LITA as composite graft at least in the circumflex area. Third, in the right coronary territory, the overall graft patency was worse than LAD and circumflex area. Bypass occlusion rate in the right coronary territory was not related to graft material. However, RITA and GEA were not suitable for the graft to the main RCA probably because the coronary arterial wall was much thicker than the wall of RITA and GEA, which might cause graft stenosis and occlusion. For the main RCA RA and SVG grafts were better than the RITA and the GEA as in situ graft. RA graft patency in this site was not better than SVG. Considering the higher occlusion rate of the composite RA in this area compared to aortocoronary RA grafting, the RA as aortocoronary bypass to the right coronary branches might be favorable when total arterial grafting is aimed.

Total arterial coronary revascularization could avoid the problems associated with vein graft failure [35, 36]. Bilateral ITAs are the conduits of first choice because of excellent short- and long-term patency and improved survival [37, 38]. However, bilateral ITA harvesting has shown a higher incidence of sternal wound infection in patients taking insulin or steroids, who are obese or have chronic obstructive lung disease [30]. RITA to LAD graft crossing the midline of the chest may obstruct future reoperation for aortic valve

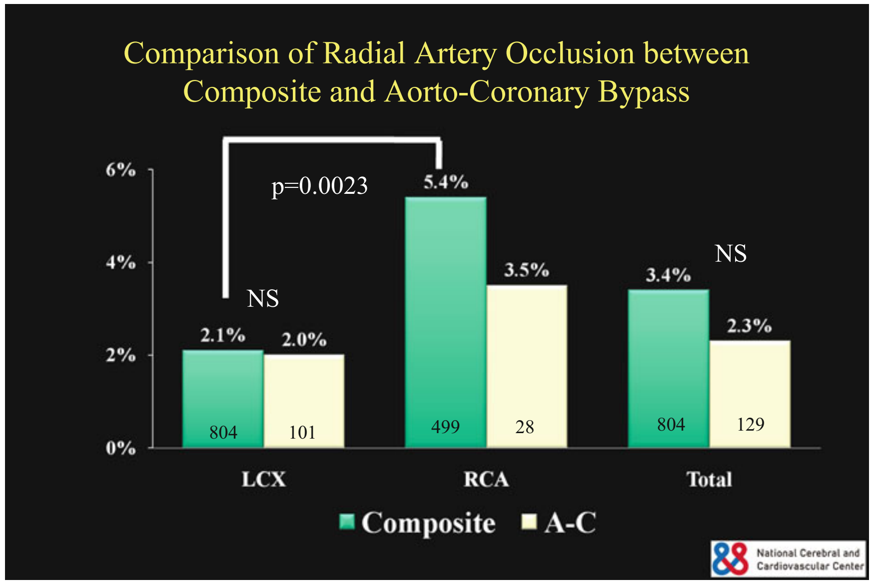

Fig. 3.7 Bypass occlusion rate of the radial artery in relation to composite and aortocoronary configuration

surgery, but to avoid this situation, the RITA is unable to reach the left ventricular posterolateral wall if it passes through the transverse sinus. As the second arterial graft in addition to LITA to LAD anastomosis, some studies comparing RITA and RA showed the same clinical and angiographic results [39, 40].

The comparative performance of RA versus SVG is of considerable interest. Previous angiographic observational studies have shown that the RA achieved excellent short- (96–100 %), mid- (94–97 %), and long-term (84–96 %) patency [41]. Patency rates of the RA have exceeded those of the SVGs at all-time points. Only the Cleveland Clinic reported worse graft patency of the RA than the SVG [42]. Randomized comparison of midterm graft patency between the RA and the SVG at 5 years showed disappointing graft patency of RA (87 %) compared to SVG (94 %) in RAPCO trial [43]. However, these results were based on the small angiographic studies. The RSVP randomized trial was designed to compare 5-year patency rates of aortocoronary RA and SVG to the circumflex coronary artery. The graft patency of the RA (98.3 %) was significantly better than that of the SVG (86.4 %) [44]. In the RAPS trial, the RA was randomly assigned to bypass the major artery in either the right coronary territory or the circumflex coronary territory, with the SVG used for the opposite territory, which had proximal lesions at least 70 % diameter narrowing [45]. The graft occlusion of the RA (8.2 %) was significantly lower than that of the SVG (13.6 %) at 1 year. Diffuse narrowing of the graft was present in 7.0 % of the RA grafts and only 0.9 % of SVGs. The absence of severe native vessel stenosis was a risk of graft occlusion and diffuses narrowing of the RA. Patency of the RA grafts was similar in RCA and circumflex arteries. In our study graft occlusion rate of the RA (2.2 %) was better than that of the SVG (7.1 %) in the circumflex area, but the same in the right coronary territory (RA: 5.0 %, SVG: 5.6 %). In our early postoperative study, composite RA grafts showed competitive flow in the setting of <75 % proximal coronary stenosis especially in the right coronary branches [46].

Graft patency of RITA and GEA was lower in standard CABG than in OPCAB in this study. The reason could be explained as follows. In OPCAB cases grafting to the main RCA might be avoided because hypotension and bradycardia occur frequently when the native coronary stenosis is moderate. The main RCA is sometimes very thick and calcified compared to other territory of right coronary branches, which are not suitable for OPCAB. Bypass occlusion rate of RITA and GEA was higher when the target area was the main RCA compared to grafting to the right coronary branches.

In summary, the LITA was the best graft for LAD, and the RA was as good as the RITA and better than SVG in the circumflex area. SVG should be avoided in OPCAB due to postoperative hypercoagulability status. Graft patency in the RCA area was not related to graft material, and the RITA and GEA should be avoided as a graft to the main RCA.

3.5 Critical Appraisal of Recent RCT in Western Countries

The operative mortality, graft patency, and long-term outcomes in OPCAB compared with conventional CABG are still controversial. The 30-day mortality after primary elective CABG with CPB was less than 1.0 % in Japan in 2011 [2].

Table 3.4 Operative mortality of isolated CABG in Japan

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
All CABG cases											
OPCAB											
No. of patients	6,950	9,981	11,609	12,018	11,110	11,021	10,979	11,222	10,352	9,510	8,807
Mortality	1.3 %	1.0 %	1.3 %	1.0 %	1.3 %	1.9 %	1.1 %	1.5 %	1.1 %	0.8 %	0.9 %
Standard CABG											
No. of patients	14,145	11,645	9,437	7,912	7,227	6,920	6,316	6,542	6,184	6,011	5,449
Mortality	2.1 %	2.5 %	2.7 %	2.5 %	3.0 %	3.5 %	2.4 %	2.4 %	2.4 %	2.3 %	2.1 %
Conversion case											
No. of patients	N/A	N/A	364	318	296	252	301	215	214	215	186
Mortality	N/A	N/A	4.4 %	7.2 %	7.8 %	8.3 %	7.3 %	5.6 %	4.7 %	6.0 %	5.4 %
Primary elective CABG											
OPCAB											
No. of patients	N/A	N/A	9,896	10,335	9,461	9,535	9,489	9,699	8,927	8,314	7,525
Mortality	N/A	N/A	0.9 %	1.0 %	0.7 %	1.3 %	0.7 %	1.0 %	0.6 %	0.5 %	0.7 %
Standard CABG											
No. of patients	10,523	18,707	7,599	6,370	5,698	5,482	5,014	5,244	4,876	4,753	4,305
Mortality	0.9 %	0.9 %	1.2 %	1.2 %	1.3 %	1.7 %	1.2 %	1.0 %	1.0 %	0.9 %	0.7 %
Conversion case											
No. of patients	N/A	N/A	273	245	229	204	239	176	158	171	147
Mortality	N/A	N/A	4.0 %	3.3 %	4.8 %	6.4 %	6.7 %	4.5 %	3.2 %	4.1 %	2.7 %

Standard CABG included on-pump beating CABG

Therefore, it is not surprising that the recent RCTs in western countries showed no difference in operative mortality between OPCAB and on-pump CABG. Puskas and associates demonstrated that OPCAB using STS database disproportionally benefits high-risk patients and female gender [47, 48]. In elective CABG cases in Japan, the operative mortality of OPCAB and standard CABG has been similar since 2008 (Table 3.4). On the contrary, in all CABG cases, the operative mortality of standard CABG was twice as high as that of OPCAB last 10 years. In the real world OPCAB has decreased the mortality in high-risk patients at least in Japan. The operative mortality in conversion cases from OPCAB to CABG with CPB has been between 2.7 and 6.7 % even in primary elective CABG. Including all cases that were converted to CABG with CPB, the operative mortality was between 4.4 and 8.3 %. Cardiac center and cardiac surgeons should be accustomed to OPCAB as a daily operation from this data, although less than 10 % of patients who have CABG really need OPCAB. Otherwise unexpected conversion from OPCAB to CABG with CPB caused deleterious outcomes.

Poorer late outcomes of repeat revascularization in OPCAB must be related to fewer number of grafts especially to the lateral wall and poorer graft patency and quality of bypass. In the ROOBY study, the conversion rate from OPCAB to on-pump CABG was 12.4 % [24], which is significantly higher than the 2.2 % found in the STS database. The rate of crossover from the off-pump to the on-pump group was 7.9 % in the CORONARY trial [25]. The conversion rate from OPCAB to CABG with CPB was only 3 % in Japan in 2011 [2]; the inexperience of surgeons has biased these RCTs. In our RCT from Japan [49], the number of grafts performed per patient (3.5 for OPCAB and 3.6 for standard CABG) and the number of arterial grafts performed per patient (3.3 for OPCAB and 3.4 for standard CABG) were similar. No patients were converted from OPCAB to CPB.

A meta-analysis of graft patency in RCT by Takagi and associates showed a 27 % increase in overall graft occlusion with OPCAB, especially a 28 % increase in saphenous vein (SV) graft occlusion [50]. Table 3.5 showed the graft patency in several RCTs [17, 18, 24, 49, 51–55]. Khan and colleagues [18] showed that the graft patency of off-pump surgery (88 %) was worse than that of on-pump surgery (98 %). These poor results in OPCAB have been explained by the fact that only 13 % of total CABG cases were performed without CPB. This may indicate that this trial was performed within the learning curve phase. In the PRAGUE-4 study,

Table 3.5 Graft patency in randomized controlled trials

Author	Interval	No. of patients	All grafts				ITA				SV			
			OPCAB	Standard CABG	Difference (95 % CI)	*p* value	OPCAB	Standard CABG	Difference (95 % CI)	*p* value	OPCAB	Standard CABG	Difference (95 % CI)	p value
Nathoe [17]	12 months	70	91 %	93 %	−2.0 % (−10.4 % to 6.5 %)	0.76	NA	NA	NA	NA	NA	NA	NA	NA
Widmsky [51]	12 months	225	70 %	74 %	NA	NA	91 %	91 %	NA	NS	49 %	59 %	NA	NS
Khan [18]	3 months	83	88 %	98 %	−10 % (−3.8 % to −16.2 %)	0.002	92 %	100 %	−8 % (−15.5 % to −0.5 %)	0.05	91 %	95 %	−4 % (6.1 % to −14.2 %)	0.42
Puskas [19, 23]	1 year	184	93.6 %	95.8 %	−2.2 % (−7.6 % to 3.3 %)	NS	94.1 %	98.1 %	−4.0 % (−10.6 % to 3.3 %)	NS	93.3 %	94.2 %	−0.9 % (−8.6 % to 6.7 %)	NS
	8 years	57	78.4 %	84.4 %	−6.0 % (−21.8 % to 9.5 %)	NS	74.4 %	78.6 %	−4.2 % (−30.7 % to 21.9 %)	NS	81.0 %	89.6 %	−8.6 % (−17.3 % to 10.2 %)	NS
Kobayashi [49]	3 weeks	167	93.2 %	96.4 %	−3.4 % (−8.2 % to 2.2 %)	0.093	92.8 %	93.8 %	−1.0 % (−9.4 % to 7.5 %)	0.81	94.1 %	100.0 %	5.9 % (−18.0 % to 5.0 %)	0.99
Al-Ruzzeh [52]	3 months	168	92.1 %	92.7 %	−1 % (−5 % to 4 %)	NS	NA	NA	NA	NA	NA	NA	NA	NA
Lingas [53]	3 months	120	88.5 %	93.3 %	−4.8 % (−13.8 % to 3.6 %)	NS	96.3 %	98.0 %	−1.7 % (−3.7 % to 5.0 %)	0.61	83.7 %	91.3 %	−7.6 % (−19.8 % to 5.6 %)	0.12
	12 months	112	85.2 %	90.2 %	−5.0 % (−14.3 % to 5.7 %)	NS	94.1 %	96.4 %	−2.3 % (−12.3 % to 8.4 %)	0.67	79.8 %	86.6 %	−6.8 % (−22.2 % to 7.5 %)	0.24
Angelini [54]	7 years	101	89.0 %	89.4 %	−0.4 % (−8.1 % to 7.4 %)	NS	94.3 %	89.7 %	5.6 % (−5.4 % to 14.5 %)	NS	85 %	89 %	−4.0 % (−15.7 % to 7.7 %)	NS
Uva [55]	5 weeks	141	89.8 %	95.0 %	−5.2 % (−11.8 % to 1.3 %)	NS	94.1 %	96.6 %	−2.5 % (−10.0 % to 4.9 %)	NS	85.7 %	93.3 %	−7.6 % (−19.9 % to 3.7 %)	NS

graft patency of SV in OPCAB was also 10 % lower than that in standard CABG though statistically not significant [51]. Lingaas also reported that although patency of LITA was 94 % in the OPCAB group and 96 % in the on-pump group 12 months after RCT, graft patency of SV was 80 % and 87 %, respectively [53]. In the BHACAS 1 and BHACAS 2 study, graft occlusion rate was similar in the standard CABG and OPCAB groups, both overall (27/255 [10.6 %] and 26/237 [11.0 %], respectively) and for arterial and SVG separately (arterial grafts, 13/126 [10.3 %] vs 8/116 [6.9 %]; SVGs, 14/129 [10.9 %] vs 18/121 [14.9 %], respectively) [54]. In the study of Uva and associates, SV graft patency was 86 % in the OPCAB group and 93 % in the standard CABG group, which was not statistically different [55]. The high occlusion rate of grafts in OPCAB must be due to high occlusion rate of SV in addition to technical difficulty.

Kim and associates compared [56] the 1-year graft patency after OPCAB with CABG under CPB. The graft patency of SVG was 88 % in patients undergoing standard CABG, 87 % in patients undergoing on-pump beating CABG, and 68 % in patients undergoing OPCAB. Poor graft patency and poor long-term results in OPCAB were related to higher SVG occlusion rate because of the hypercoagulability status after OPCAB [57, 58]. Although they conducted the study during the learning time period, this paper could not be overlooked. Proper anticoagulation and antiplatelet regimens are mandatory. We recommended that heparin was reversed at OPCAB completion, but restarted (10 unit/kg/h) in the intensive care unit after hemostasis was secured until the next evening [59]. Aspirin was continued until the operation and restarted with 162 mg/day from the next morning. Without proper perioperative medical treatment, OPCAB may sacrifice graft patency and cause late unfavorable cardiac events. Considering the high occlusion rate of SVG in OPCAB, multiple arterial OPCAB in Japan is the optimal strategy.

References

1. Kazui T, Wada H, Fujita H (2005) Thoracic and cardiovascular surgery in Japan during 2003. Jpn J Thorac Cardiovasc Surg 53:517–536
2. Amano J, Kuwano H, Yokomise H (2013) Thoracic and cardiovascular surgery in Japan during 2011. Gen Thorac Cardiovasc Surg 61:578–607
3. Kolessov VI (1967) Mammary artery-coronary artery anastomosis as method of treatment for angina pectoris. J Thorac Cardiovasc Surg 54:535–544
4. Benetti FJ, Naselli G, Wood M et al (1991) Direct myocardial revascularization without extracorporeal circulation. Experience in 700 patients. Chest 100:312–316
5. Buffolo E, Andrade JCS, Branco JNR et al (1996) Coronary artery bypass grafting without cardiopulmonary bypass. Ann Thorac Surg 61:63–66
6. Cartier R, Brann S, Dagenais F et al (2000) Systematic off-pump coronary artery revascularization in multivessel disease: experience of three hundred cases. J Thorac Cardiovasc Surg 119:221–229
7. Zenati M, Cohen HA, Griffith BP (1999) Alternative approach to multivessel coronary disease with integrated coronary revascularization. J Thorac Cardiovasc Surg 117:439–446
8. Arom FV, Flavin TF, Emery RW et al (2000) Safety and efficacy of off-pump coronary artery bypass grafting. Ann Thorac Surg 69:704–710
9. Cleveland JC, Shroyer AL, Chen AY et al (2001) Off-pump coronary artery bypass grafting decreases risk-adjusted mortality and morbidity. Ann Thorac Surg 72:1282–1288
10. Plomondon ME, Cleveland JC Jr, Ludwig ST et al (2001) Off-pump coronary artery bypass is associated with improved risk adjusted outcomes. Ann Thorac Surg 72:114–119
11. Sabik JF, Gillinov AM, Blackstone EH et al (2002) Does off-pump coronary surgery reduce morbidity and mortality? J Thorac Cardiovasc Surg 124:698–707
12. Cheng W, Denton TA, Fontana GP et al (2002) Off-pump coronary surgery: effect on early mortality and stroke. J Thorac Cardiovasc Surg 124:313–320
13. Puskas J, Cheng D, Knight J et al (2005) Off-pump versus conventional coronary artery bypass grafting: a meta-analysis and consensus statement from the 2004 ISMICS consensus conference. Innovations 1:3–27
14. Kuss O, von Salviati B, Börgermann J (2010) Off-pump versus on-pump coronary artery bypass grafting: a systemic review and meta-analysis of propensity score analyses. J Thorac Cardiovasc Surg 140:829–835
15. van Dijk D, Nierich AP, Jansen EW et al (2001) Early outcome after off-pump versus on-pump coronary artery bypass surgery. Results from a randomized study. Circulation 104:1761–1766
16. Angelini GD, Taylor FC, Reeves BC et al (2002) Early and midterm outcome after off-pump and on-pump surgery in beating heart against Cardioplegic Arrest Studies (BHACAS 1 and 2): a pooled analysis of two randomized controlled trials. Lancet 359:1194–1199
17. Nathoe HM, van Dijk D, Jansen EW et al (2003) A comparison of off-pump and on-pump coronary bypass surgery in low-risk patients. N Engl J Med 348:394–402
18. Khan NE, De Souza A, Mister R et al (2004) A randomized comparison of off-pump and on-pump multivessel coronary-artery bypass surgery. N Engl J Med 350:21–28
19. Puskas JD, Williams WH, Duke PG et al (2003) Off-pump coronary artery bypass grafting provides complete revascularization with reduced myocardial injury, transfusion requirements, and length of stay: a prospective randomized comparison of 200 unselected patients undergoing off-pump versus conventional coronary artery bypass grafting. J Thorac Cardiovasc Surg 125:797–808
20. Légaré JF, Buth KJ, King S et al (2004) Coronary bypass surgery performed off pump does not result in lower in-hospital morbidity than coronary artery bypass grafting performed on pump. Circulation 109:887–892
21. Chen DC, Bainbridge D, Martin JE et al (2005) Does off-pump coronary artery bypass reduce mortality, morbidity, and resource utilization when compared with conventional coronary artery bypass? A meta-analysis of randomized trials. Anesthesiology 102:188–203
22. Møller CH, Penninga L, Wetterslev J et al (2008) Clinical outcomes in randomized trials of off- vs. on-pump coronary artery bypass surgery: systematic review with meta-analyses and trial sequential analyses. Eur Heart J 29:2601–2616
23. Puskas JD, Williams WH, O'Donnell R et al (2011) Off-pump and on-pump coronary artery bypass grafting are associated with similar graft patency, myocardial ischemia, and freedom from

re-intervention: long-term follow-up of a randomized trial. Ann Thorac Surg 92:1836–1843
24. Shroyer AL, Grover FL, Hattler B et al (2009) On-pump versus off-pump coronary-artery bypass surgery. N Engl J Med 361:1827–1837
25. Lamy A, Devereaux PJ, Prabhakaran D et al (2012) Off-pump or on-pump coronary-artery bypass grafting at 30 days. N Engl J Med 366:1489–1497
26. Lamy A, Devereaux PJ, Prabhakaran D et al (2013) Off-pump or on-pump coronary-artery bypass grafting at 1 year. N Engl J Med 368:1179–1188
27. Afilalo J, Rasti M, Ohayon SM et al (2012) Off-pump vs. on-pump coronary artery bypass surgery: an updated meta-analysis and meta-regression of randomized trials. Eur Heart J 33:1257–1267
28. Møller CH, Perko MJ, Lund JT et al (2010) No major differences in 30-day outcomes in high-risk patients randomized to off-pump versus on-pump coronary bypass surgery. The Best Bypass Surgery Trial Circ 121:498–504
29. Diegeler A, Börgermann P, Kappert U et al (2013) Off-pump versus on-pump coronary-artery bypass grafting in elderly patients. N Engl J Med 368:1189–1198
30. Hills LD, Smith PK, Anderson JL 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 124:e652–e735
31. Blankstein R, Ward RP, Arnsdorf M et al (2005) Female gender is an independent predictor of operative mortality after coronary artery bypass graft surgery: contemporary analysis of 31 Midwestern hospitals. Circulation 112:1323–1327
32. Maniar HS, Barner HB, Bailey MS et al (2003) Radial artery patency: are aortocoronary conduits superior to composite grafting? Ann Thorac Surg 76:1498–1504
33. Caputo M, Dphil BR, Marchetto G et al (2003) Radial versus right internal thoracic artery as a second arterial conduit for coronary surgery: early and midterm outcomes. J Thorac Cardiovasc Surg 126:39–47
34. Gaudino M, Alessandrini F, Pragliola C et al (2004) Effect of target artery location and severity of stenosis on mid-term patency of aorta-anastomosed versus internal-artery anastomosed radial artery grafts. Eur J Cardio Thorac Surg 25:424–428
35. Loop FD, Lytle BW, Cosgrove DM, Stewart RW, Goormastic M, William GW, Golding LA, Gill CC, Taylor PC, Sheldon WC (1986) Influence of the internal mammary artery graft on 10-year survival and other cardiac events. N Engl J Med 314:1–6
36. Lytle BW, Loop FD, Cosgrove DM, Ratliff NB, Easley K, Taylor PC (1985) Long-term (5 to 12 years) serial studies of internal mammary artery and saphenous vein coronary artery bypass grafts. J Thorac Cardiovasc Surg 89:248–258
37. Pick AW, Orszulak TA, Anderson BJ, Schaff HV (1997) Single versus bilateral internal mammary artery grafts: 10-year outcome analysis. Ann Thorac Surg 64:599–605
38. Lytle BW, Blackstone EH, Loop FD, Houghtaling PL, Arnold JH, Akhrass R, McCarthy PM, Cosgrove DM (1999) Two internal thoracic arteries are better than one. J Thorac Cardiovasc Surg 117:855–872
39. Calafiore AM, Di Mauro M, D'Alessandro S, Teodori G, Vitolla G, Contini M, Iacò AL, Spira G (2002) Revascularization of the lateral wall: long-term angiographic and clinical results of radial artery versus right internal thoracic artery grafting. J Thorac Cardiovasc Surg 123:225–231
40. Lemma M, Gelpi G, Mangini A, Vanelli P, Carro C, Condemi A, Antona C (2001) Myocardial revascularization with multiple arterial grafts: comparison between the radial artery and the right internal thoracic artery. Ann Thorac Surg 71:1969–1973
41. Kobayashi J (2009) Radial artery as a graft for coronary artery bypass grafting. Circ J 73:1178–1183
42. Khot UN, Friedman DT, Pettersson G, Smedira NG, Li J, Ellis SG (2004) Radial artery bypass grafts have an increased occurrence of angiographically severe stenosis and occlusion compared with left internal mammary arteries and saphenous vein grafts. Circulation 109:2086–2091
43. Buxton BF, Raman JS, Ruengsakulrach P, Gordon I, Rosalion A, Bellomo R, Horrigan M, Hare DL (2003) Radial artery patency and clinical outcomes: five-year interim results of a randomized trial. J Thorac Cardiovasc Surg 125:1363–1371
44. Collins P, Webb CM, Chong CF, Moat NE (2008) Radial artery versus saphenous vein patency randomized trial. Five-year angiographic follow-up. Circulation 117:2859–2864
45. Desai ND, Naylor CD, Kiss A, Cohen EA, Feder-Elituv R, Miwa S, Radhakrishnan S, Dubbin J, Schwartz L, Fremes SE (2007) Impact of patient and target-vessel characteristics on arterial and venous bypass graft patency. Insight from a randomized trial. Circulation 115:684–691
46. Nakajima H, Kobayashi J, Funatsu T, Shimahara Y, Kawamura M, Kawamura A, Yagihara T, Kitamura S (2007) Predictive factors for the intermediate-term patency of arterial grafts in aorta no-touch off-pump coronary revascularization. Eur J Cardio Thorac Surg 32:711–717
47. Puskas JD, Thourani VH, Kilgo P et al (2009) Off-pump coronary artery bypass disproportionately benefits high-risk patients. Ann Thorac Surg 88:1142–1147
48. Puskas JD, Kilgo PD, Kutner M et al (2007) Off-pump techniques disproportionately benefit women and narrow the gender disparity in outcomes after coronary artery bypass surgery. Circulation 116(Suppl I):I-192–I-199
49. Kobayashi J, Tashiro T, Ochi M et al (2005) Early outcome of a randomized comparison of off-pump and on-pump multiple arterial coronary revascularization. Circulation 112(Suppl I):I-338–I-343
50. Takagi H, Tanabashi T, Kawai N, Kato T, Umemoto T (2007) Off-pump coronary artery bypass sacrifices graft patency: meta-analysis of randomized trials. J Thorac Cardiovasc Surg 133:e2–e3
51. Widimsky P, Straka Z, Stros P et al (2004) One-year coronary bypass graft patency: a randomized comparison between off-pump and on-pump surgery. angiographic results of the PRAGUE-4 trial. Circulation 110:3418–3423
52. Al-Ruzzeh S, George S, Bustami M et al (2006) Effect of off-pump coronary artery bypass surgery on clinical, angiographic, neurocognitive, and quality of life outcomes: randomised controlled trial. BMJ 332:1365–1368
53. Lingaas PS, Hol PK, Lundblad R et al (2006) Clinical and Radiologic Outcome of Off-Pump Coronary Surgery at 12 Months Follow-Up: A Prospective Randomized Trial. Ann Thorac Surg 81:2089–2096
54. Angelini GD, Culliford L, Smith DK et al (2009) Effects of on- and off-pump coronary artery surgery on graft patency, survival, and health-related quality of life: long-term follow-up of 2 randomized controlled trials. J Thorac Cardiovasc Surg 137:295–303
55. Uva MS, Cavaco S, Oliveira AG et al (2010) Early graft patency after off-pump and on-pump coronary bypass surgery: a prospective randomized study. Eur Heart J 31:2492–2499
56. Kim KB, Lim C, Lee C et al (2001) Off-pump coronary artery bypass may decrease the patency of saphenous vein grafts. Ann Thorac Surg 72:S1033–S1037
57. Kurlansky PA (2003) Is there a hypercoagulable state after off-pump coronary artery bypass surgery? What do we know and what can we do? J Thorac Cardiovasc Surg 126:7–10
58. Vedin J, Antovic A, Ericsson A, Vaage J (2005) Hemostasis in off-pump compared to on-pump coronary artery bypass grafting: a prospective randomized study. Ann Thorac Surg 80:586–593
59. Kobayashi J, Sasako Y, Bando K et al (2002) Multiple off-pump coronary revascularization with "Aorta No-Touch" technique using composite and sequential methods. Heart Surg Forum 5:114–118

Part II

OPCAB Procedures and Management

4 Indication and Safe Strategy

Hitoshi Yokoyama

Abstract

Off-pump coronary artery bypass grafting is a safe procedure even in the early period of a surgeon's learning curve, but only if both the surgeon and anesthesiologist set up a decision-making algorithm that includes the careful monitoring of the beating heart and optimized integrated backup with mechanical hemodynamic support. In this chapter, the "routine off-pump" strategy is introduced. Using this strategy, over 98 % of the coronary artery bypass surgery candidates underwent off-pump coronary artery bypass grafting with a rate of intra-operative pump conversion as low as 0–1 %, even with relatively inexperienced surgeons. This strategy enables most coronary artery bypass surgeries to be performed safely and achieves complete revascularization at the end of surgery.

Keywords

Routine off-pump strategy • Scheduled IABP • Prophylactic IABP • Urgent pump conversion • Decision-making algorithm

4.1 Introduction

Indications that warrant off-pump coronary artery bypass are controversial. There are various treatments for coronary artery occlusive disease, including medical therapy, percutaneous coronary intervention (PCI), and coronary artery bypass with (on-pump coronary artery bypass, ONCAB) or without (off-pump coronary artery bypass, OPCAB) cardiopulmonary bypass. Guidelines for the treatment of ischemic heart disease have been described and disseminated; however, the choice of treatment depends on the quality of PCI, ONCAB, and OPCAP, all of which vary from surgeon to surgeon and from institution to institution. In this decade, several clinical observational studies, large database analyses, and controlled randomized trials have been reported to elucidate what kind of patients should undergo OPCAB, as well as what kind of surgeon should perform the procedure.

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4.2 Who Will Benefit Most from Off-Pump Coronary Bypass Surgery?

Indication for a certain procedure depends on the balance of risk and benefit. The main advantage of OPCAB is to avoid cardiopulmonary bypass and global cardiac ischemia.

The cardiopulmonary bypass has detrimental effects on the whole human body. Exposure of blood cells and complement in the bloodstream to the surface of the extracorporeal circuit of the cardiopulmonary bypass results in the activation of leucocytes, platelets, and the complement systems, as well as the destruction of red blood cells [1]. Consequently, this adverse phenomenon results in multiple organ dysfunctions. There are several kinds of candidates for CABG, some of whom are considered vulnerable to cardiopulmonary

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bypass. Recent clinical studies have demonstrated that OPCAB is recommended in high-risk patients undergoing CABG with cardiopulmonary bypass and cardiac arrest. These include elderly patients, women, as well as patients with diabetes, renal insufficiency, chronic lung disease, preoperative cerebrovascular disease, reoperation, emergency coronary artery bypass surgery, unstable angina, myocardial infarction, or left main disease [2–12].

The establishment of cardiopulmonary bypass requires cannulation to the aorta, the complications of which are often fatal. Such complications include aortic injury, aortic dissection, and thromboembolism of the cerebral arteries. Patients with atheromatous aorta in particular are at high risk [2]. Off-pump coronary bypass surgery with aorta non-touch technique is described in Chap. 12: Graft Planning. Additionally, aorta minimal-touch technique with a proximal anastomotic device is described in Chap. 18: Proximal Anastomosis.

Global cardiac ischemia in heart surgery results in ischemia-reperfusion injury of the myocardium. Though myocardial protection during cardiac arrest has improved recently, global myocardial ischemia given to the heart with depressed ventricular function still poses a considerable risk of post-bypass low output syndrome [13]. Recent observational studies have shown the benefits of OPCAB in patients with ongoing myocardial ischemia or acute coronary syndrome [10, 11], in which additional ischemia-reperfusion injury by cardiac arrest poses further detrimental effects on the myocardium.

Predicted mortality and morbidity for on-pump CABG (ONCAB) are indicators of the usefulness of OPCAB [14–16]. Puskus and colleagues reported that patients with a predicted mortality of more than about 3 % would benefit from OPCAB through analysis of the Society of Thoracic Surgery database in the United States [14].

4.3 Indication of Off-Pump CABG: Several Considerations

4.3.1 Patient Risk-Based Decision-Making

A patient risk-based decision-making is seemingly appropriate. In this case, "risk" means risk for on-pump CABG (ONCAB) that can be represented by predicted mortality and morbidity for ONCAB. Regarding the institute or surgeon carrying out patient risk-based decision-making, OPCAB is performed rarely because the numbers of patients with high risk for ONCAB and candidates of OPCAB for that reason are small [14]. The infrequency of OPCAB increases its difficultly for the surgeon and prevents the surgical team from gaining significant off-pump experience. This situation would have multiple effects on the quality of OPCAB, such as the rate of complete revascularization and graft patency, and the training of future generations in OPCAB surgery [17]. As a result, this "occasional OPCAB" strategy yields fewer benefits and does not lend itself well to being passed on to future generations of surgeons.

4.3.2 Graftability-Based Decision-Making

Some surgeons perform OPCAB using graftability-based decision-making. In this case, the issue is the possibility of exposure and graftability for each target coronary artery. For example, this type of strategy recommends on-pump CABG when the surgeon finds small calcified coronary arteries, even after the completion of other grafting with the off-pump technique. Thus, difficult coronary arteries or risk of cardiac dislocation requires many OPCAB cases to be performed on partly on-pump, meaning that the patients cannot fully receive the benefits of OPCAB.

In the following section, "off-pump first strategy" or "routine off-pump strategy" is described. This principle is recommended if the surgeon is seeking the way to provide their patients with full OPCAB benefits.

4.4 Routine Off-Pump Strategy

Here the author introduces "integrated coronary artery revascularization decision-making algorithm" [18] (Fig. 4.1). "Integrated" means that this is a strategy that utilizes a combined set of available coronary artery bypass techniques and hemodynamic supports. In other words, all candidates for surgical coronary revascularization are supposed to receive the "off-pump first" strategy or "routine off-pump" strategy. This strategy has three goals: The first goal is to avoid cardiopulmonary bypass and global cardiac ischemia if possible; the second is to prevent urgent pump conversion during OPCAB; and the third is to achieve complete revascularization at the end of surgery. In our experience, over 98 % of CABG patients have undergone OPCAB by this strategy.

[A]; At first, all patients who need CABG are candidates for OPCAB. The surgeon has to make first decision on selecting a patient who needs cardiopulmonary bypass by evaluating preoperative hemodynamic instability: Patients with hemodynamic instability such as cardiogenic shock with low systemic blood pressure (<80 mmHg), recent ventricular fibrillation (VF), or tachycardia (VT) undergo on-pump CABG. A heart with suboptimal performance must not have additional myocardial ischemia with coronary artery occlusion for anastomosis without hemodynamic support by cardiopulmonary bypass. All patients with stable hemodynamics are scheduled to undergo OPCAB.

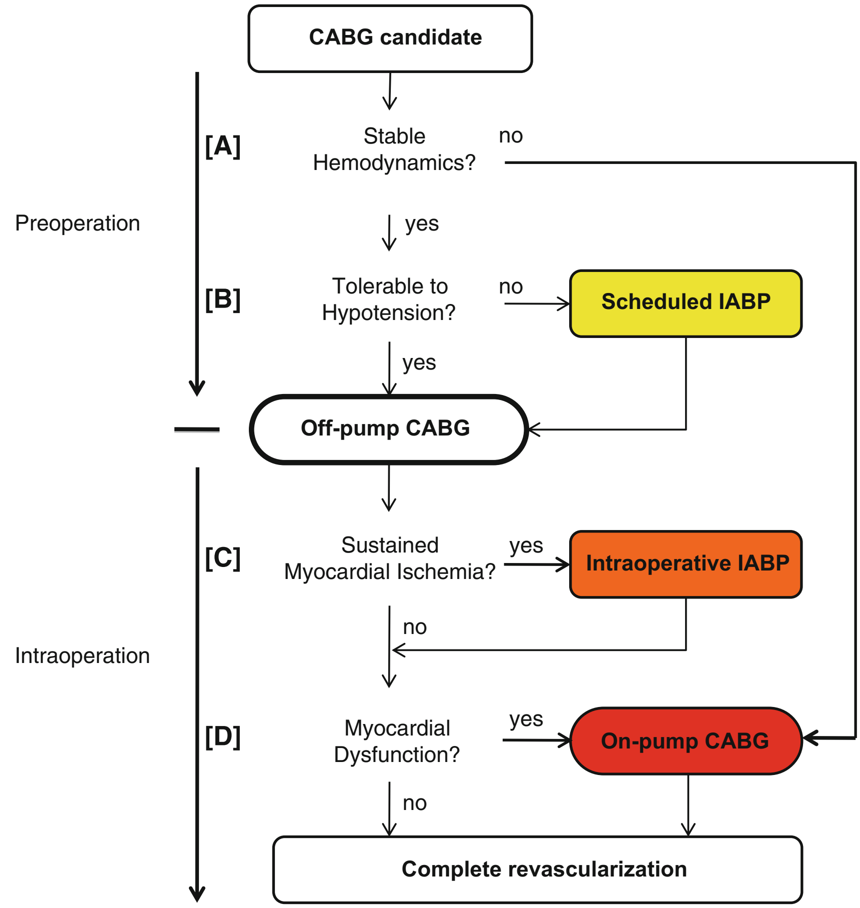

Fig. 4.1 Routine off-pump strategy (See [A], [B], [C], and [D] in the manuscript)

[B]; Before induction of general anesthesia with tracheal intubation, the surgeon has to make a second decision on whether the patient needs a preoperative, scheduled intra-aortic balloon pump (IABP), the usefulness of which for OPCAB has been demonstrated by several clinical observational studies [19–22].

Tracheal intubation under general anesthesia possibly deteriorates patient's hemodynamics, causing severe hypotension followed by coronary ischemia, bradycardia, arrhythmia, or cardiac arrest. Patients with poor cardiac reserve or an intolerable heart for systemic hypotension and coronary artery low perfusion should have scheduled IABP. IABP increases coronary artery perfusion and decreases myocardial oxygen consumption for improved cardiac contractility during OPCAB. Regarding cardiac reserve, two factors are taken under consideration: the degrees of coronary artery stenosis and cardiac contractility. Patients with critical left main disease (>95 % stenosis) or poor left ventricular function (0.35 < left ventricular ejection fraction) undergo scheduled IABP at our institute. Placement of IABP before tracheal intubation in the operation room is a simple and safe procedure: The patient on the operating table receives local anesthesia in the groin, followed by insertion of a 7-French IABP with a guide-wire technique through the femoral artery using mobile C-arm fluoroscopy with image intensifiers. We have determined from our experience that it is possible for this procedure to be performed within 10 min. Thanks to the recent innovation of IABP devices, complications such as aortic injury, thromboembolism, or femoral artery bleeding have not been observed in our series.

[C]; During OPCAB surgery, the monitoring of a patient's hemodynamics is mandatory. OPCAB is a unique procedure where the surgeon is manipulating a beating heart, which, itself included, is maintaining the blood supply to the whole of the patient's body. It is vitally important for the surgeon and anesthesiologist to keep a close watch on the cardiac rhythm, contractility, and myocardial blood perfusion while making best efforts to keep the beating heart within the physiological range (Fig. 4.2). At our institute, the anesthesiologist monitors the following: electrocardiogram (ECG), femoral artery blood pressure, Swan-Ganz catheter, and intraesophageal echocardiography. The femoral artery cannula can be used later for insertion of intraoperative IABP or percutaneous cardiopulmonary support (PCPS) if necessary.

Any subtle sign of myocardial ischemia, such as bradycardia, change in the ST segment on ECG, elevated pulmonary artery blood pressure, and paroxysmal ventricular contractions (PVC), must not be ignored. Each event listed

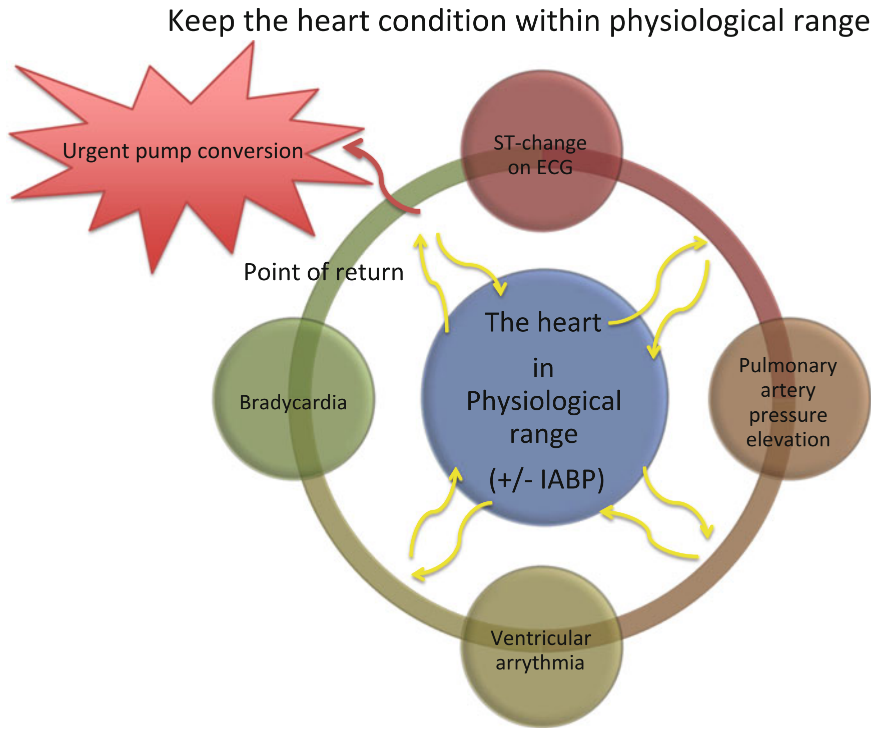

Fig. 4.2 Principle to keep the beating heart in the physiological range during off-pump coronary artery bypass grafting to avoid urgent pump conversion

above should be treated immediately by the anesthesiologist with modification of the anesthetic drugs and administration of coronary vasodilator drugs and anti-arrhythmic drugs or by the surgeon, dislocation of the heart to the normal position, using an intracoronary shunt instead of simple coronary artery occlusion. Again, neglect of these subtle signs results in hemodynamic collapse followed by urgent pump conversion (Fig. 4.2). This topic is also discussed in the "Intraoperative Management and Anesthesia" section of Chap. 6 and the "Urgent Pump Conversion" section of Chap. 8 in detail.

[D]; In cases where intraoperative myocardial failure is found by combined systemic hypotension and elevated pulmonary artery pressure, it is imperative that the surgical team takes urgent action. The surgeon should call a perfusionist to set up the cardiopulmonary bypass or PCPS system immediately. The anesthesiologist should, by all means, try to maintain the heart beat and systolic blood pressure until the establishment of cardiopulmonary support. Urgent pump conversion with hemodynamic collapse and cardiac massage leads to unfavorable outcomes with extremely high incidence of stroke, renal failure, and death [23–26].

We do recommend "unhurried pump conversion," but not "urgent pump conversion." Although these two words have the same abbreviation, they are quite different procedures followed by quite different outcomes. For unhurried pump conversion, careful monitoring of the status of cardiac performance and ischemia is mandatory as described above. We experienced 4 cases of unhurried pump conversion in the first 500 consecutive OPCAB surgeries. One patient (case 1) suffered sudden ventricular fibrillation just after the opening of the pericardium. DC shock was applied immediately and successfully. The patient then underwent 4-vessel on-pump CABG without morbidity. Two patients (cases 2 and 3) suffered elevated pulmonary artery pressure and slight systemic hypotension with an elevated ST segment on ECG after completion of coronary anastomosis. These two patients underwent unhurried pump conversion and subsequent CABG. The remaining patient (case 4) with intramyocardial left anterior descending coronary artery suffered bleeding from the right ventricle. All of these patients underwent unhurried pump conversion with complete coronary artery revascularization without morbidity.

The impact of an "integrated coronary artery revascularization decision-making algorithm" on the rate of pump conversion in a surgeon's learning period is summarized in Fig. 4.3. In the early stages of the learning curve, scheduled IABP was often employed due to the inexperience of the surgeon or high-risk patients for off-pump surgery estimated by anesthesiologists. The rate of scheduled, prophylactic IABP decreased as the surgical team gained more experience with OPCAB and reached a plateau after the team had experienced around 200 cases. What is significant about this is that unhurried pump conversion remained at a very low rate at 0–1 % throughout the learning period, even in the earliest stage. No urgent pump conversion by sustained hemodynamic collapse with major morbidity or mortality was observed in this series.

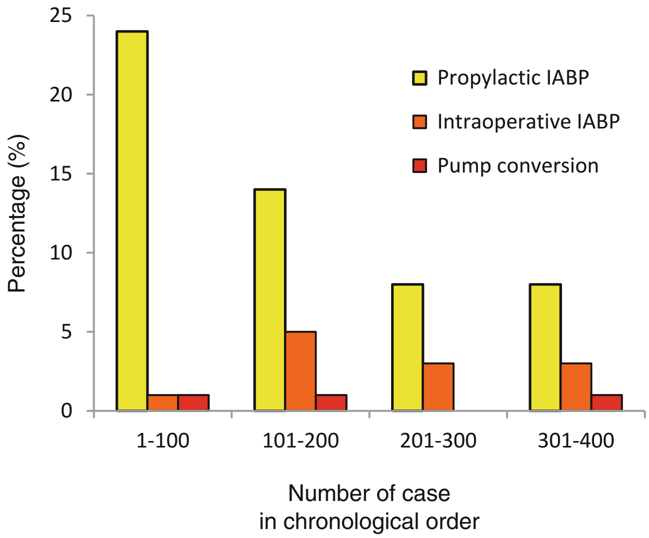

Fig. 4.3 Results of integrated coronary artery bypass surgery strategy in the learning period. Note the low rate of pump conversion even in the early stage of the learning period

4.5 Conclusions

OPCAB is a safe procedure even in the very early stage of a surgeon's learning curve, but only if the surgeon and anesthesiologist design a decision-making algorithm that includes careful monitoring of the beating heart and optimized integrated mechanical hemodynamic support.

References

1. Butler J, Rocker GM, Westaby S (1993) Inflammatory response to cardiopulmonary bypass. Ann Thorac Surg 55(2):552–559
2. Mishra M, Malhotra R, Karlekar A, Mishra Y, Trehan N (2006) Propensity case-matched analysis of off-pump versus on-pump coronary artery bypass grafting in patients with atheromatous aorta. Ann Thorac Surg 82(2):608–614
3. Demaria RG, Carrier M, Fortier S, Martineau R, Fortier A, Cartier R, … Perrault LP (2002) Reduced mortality and strokes with off-pump coronary artery bypass grafting surgery in octogenarians. Circulation 106(12 Suppl 1):I–5
4. Takase S, Yokoyama H, Satokawa H, Sato Y, Kurosawa H, Seto Y, … Igarashi T (2010) Short-term and long-term outcomes of octogenarians after off-pump coronary artery bypass surgery. Gen Thorac Cardiovasc Surg 58(11):561–567
5. Magee MJ, Dewey TM, Acuff T, Edgerton JR, Hebeler JF, Prince SL, Mack MJ (2001) Influence of diabetes on mortality and morbidity: off-pump coronary artery bypass grafting versus coronary artery bypass grafting with cardiopulmonary bypass. Ann Thorac Surg 72(3):776–781
6. Sajja LR, Mannam G, Chakravarthi RM, Sompalli S, Naidu SK, Somaraju B, Penumatsa RR (2007) Coronary artery bypass grafting with or without cardiopulmonary bypass in patients with preoperative non–dialysis dependent renal insufficiency: a randomized study. J Thorac Cardiovasc Surg 133(2):378–388
7. Virani SS, Lombardi P, Tehrani H, Masroor S, Yassin S, Salerno T, … Katariya K (2005) Off-pump coronary artery grafting in patients with left main coronary artery disease. J Card Surg 20(6):537–541
8. Chamberlain MH, Ascione R, Reeves BC, Angelini GD (2002) Evaluation of the effectiveness of off-pump coronary artery bypass grafting in high-risk patients: an observational study. Ann Thorac Surg 73(6):1866–1873
9. Halkos ME, Puskas JD, Lattouf OM, Kilgo P, Guyton RA, Thourani VH (2008) Impact of preoperative neurologic events on outcomes after coronary artery bypass grafting. Ann Thorac Surg 86(2):504–510
10. Biancari F, Mahar MAA, Mosorin M, Heikkinen J, Pokela M, Taskinen P, … Lepojärvi, M (2008) Immediate and intermediate outcome after off-pump and on-pump coronary artery bypass surgery in patients with unstable angina pectoris. Ann Thorac Surg 86(4):1147–1152
11. Fattouch K, Guccione F, Dioguardi P, Sampognaro R, Corrado E, Caruso M, Ruvolo G (2009) Off-pump versus on-pump myocardial revascularization in patients with ST-segment elevation myocardial infarction: a randomized trial. J Thorac Cardiovasc Surg 137(3):650–657
12. Puskas JD, Kilgo PD, Kutner M, Pusca SV, Lattouf O, Guyton RA (2007) Off-pump techniques disproportionately benefit women and narrow the gender disparity in outcomes after coronary artery bypass surgery. Circulation 116(Suppl 11):1-192
13. Algarni KD, Maganti M, Yau TM (2011) Predictors of low cardiac output syndrome after isolated coronary artery bypass surgery: trends over 20 years. Ann Thorac Surg 92(5):1678–1684
14. Puskas JD, Thourani VH, Kilgo P, Cooper W, Vassiliades T, Vega JD, … Lattouf OM (2009) Off-pump coronary artery bypass disproportionately benefits high-risk patients. Ann Thorac Surg 88(4):1142–1147
15. Lemma MG, Coscioni E, Tritto FP, Centofanti P, Fondacone C, Salica A, … Genoni M (2012) On-pump versus off-pump coronary artery bypass surgery in high-risk patients: operative results of a prospective randomized trial (on-off study). J Thorac Cardiovasc Surg 143(3):625–631
16. Polomsky M, He X, O'Brien SM, Puskas JD (2013) Outcomes of off-pump versus on-pump coronary artery bypass grafting: impact of preoperative risk. J Thorac Cardiovasc Surg 145(5):1193–1198
17. Bakaeen FG, Kelly RF, Chu D, Jessen ME, Ward HB, Holman WL (2013) Trends over time in the relative use and associated mortality of on-pump and off-pump coronary artery bypass grafting in the veterans affairs system off-and on-pump coronary artery bypass grafting off-and on-pump coronary artery bypass grafting. JAMA Surg
18. Yokoyama H, Takase S, Misawa Y, Hagiwara K, Tanji M, Takahashi S, … Kondo S (2009) Integrated coronary artery bypass strategy prevents urgent pump conversion during off-pump coronary artery bypass grafting. Kyobu geka. Jpn J Thorac Surg 62(1):28–33
19. Craver JM, Murrah CP (2001) Elective intraaortic balloon counterpulsation for high-risk off-pump coronary artery bypass operations. Ann Thorac Surg 71(4):1220–1223
20. Kim KB, Lim C, Ahn H, Yang JK (2001) Intraaortic balloon pump therapy facilitates posterior vessel off-pump coronary artery bypass grafting in high-risk patients. Ann Thorac Surg 71(6):1964–1968
21. Mishra M, Shrivastava S, Dhar A, Bapna R, Mishra A, Meharwal ZS, Trehan N (2003) A prospective evaluation of hemodynamic instability during off-pump coronary artery bypass surgery. J Cardiothorac Vasc Anesth 17(4):452–458
22. Suzuki T, Okabe M, Handa M, Yasuda F, Miyake Y (2004) Usefulness of preoperative intraaortic balloon pump therapy during off-pump coronary artery bypass grafting in high-risk patients. Ann Thorac Surg 77(6):2056–2059

23. Edgerton JR, Dewey TM, Magee MJ, Herbert MA, Prince SL, Jones KK, Mack MJ (2003) Conversion in off-pump coronary artery bypass grafting: an analysis of predictors and outcomes. Ann Thorac Surg 76(4):1138–1143
24. Patel NC, Patel NU, Loulmet DF, McCabe JC, Subramanian VA (2004) Emergency conversion to cardiopulmonary bypass during attempted off-pump revascularization results in increased morbidity and mortality. J Thorac Cardiovasc Surg 128(5):655–661
25. Légaré JF, Buth KJ, Hirsch GM (2005) Conversion to on pump from OPCAB is associated with increased mortality: results from a randomized controlled trial. Eur J Cardiothorac Surg 27(2):296–301
26. Reeves BC, Ascione R, Caputo M, Angelini GD (2006) Morbidity and mortality following acute conversion from off-pump to on-pump coronary surgery. Eur J Cardiothorac Surg 29(6):941–947

Approach

5

Takeshiro Fujii and Yoshinori Watanabe

Abstract

The approach for coronary artery bypass grafting (CABG) is determined based on chest-related factors such as the target coronary artery, the number of anastomoses, the graft that is used, other concomitant surgeries, re-surgery, heart function, and myocardial remodeling. A questionnaire review performed in Japan in 2012 indicated that off-pump coronary artery bypass (OPCAB) is performed in 63.5 % of CABG, and a full sternotomy approach is used in 99.7 % of them. This is an indication that serious cases including three-vessel disease and long-term chronic pathology are increasing, necessitating multivessel revascularization. However, in some cases, minimally invasive direct coronary artery bypass (MIDCAB) is indicated for left anterior descending artery (LAD) and left circumflex artery (LCX) revascularization, and we receive many requests from internists and patients. For the inexperienced surgeon, it may be difficult to detach the internal thoracic artery (ITA) and isolate the target vessel, with a resulting decrease in the quality of the bypass. As minimally invasive methods, various small incision methods have been reported, but to perform a proper revascularization procedure, adequate preparation and skill are considered necessary. It is necessary to perform proper revascularization using the best approach based on the abovementioned factors and well-practiced skills.

Keywords

Full sternotomy • Mini sternotomy • Left thoracotomy • Transdiaphragmatic approach

5.1 Full Sternotomy

Full sternotomy has been the traditional method used to access the heart and is also considered the standard approach for CABG. On the one hand, it has many advantages including (1) providing a good field of view for detaching the internal thoracic arteries bilaterally and to harvest the right gastroepiploic artery, although it involves extension surgery; (2) making it easier to use cardiopulmonary bypass and cardioplegic arrest; (3) making it possible to expose multiple coronary arteries to perform multivessel revascularization; and (4) making it possible to perform concomitant procedures for cardiomyopathy, valvular disease, or those involving the thoracic aorta. However, due to sternotomy, it also has the disadvantages of such complications as flail chest, osteomyelitis, and mediastinitis. In recent years, minimally invasive procedures involving small incision methods have become popular as a way to prevent sternal and wound complications. These procedures, however, cause damage to the left internal thoracic artery (LITA), and due to the inadequate view of the work field and the narrow working space, LITA to LAD surgery, which has the greatest effect on patients' life expectation and prognosis, tends to be very risky, and the need for the present method has been reconfirmed.

With actual full sternotomy (Fig. 5.1), the intercostal spaces are palpated bilaterally to mark the midline of the sternum. The skin incision is made from one finger width

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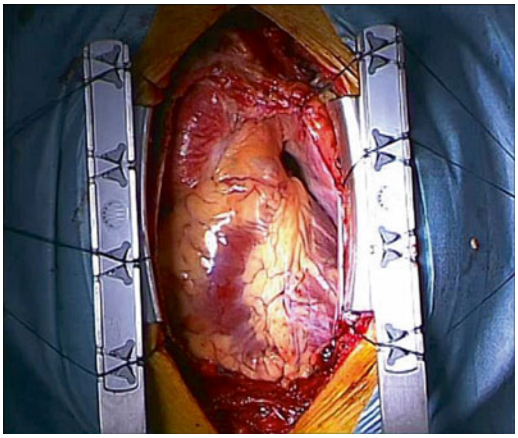

Fig. 5.1 Standard approach for CABG

Fig. 5.2 An approximate 8 cm skin incision is made in the fourth or fifth intercostal space

below the sternal notch to the xiphoid process. The superficial cervical vein, which passes above the sternum, is ligated and separated. The interclavicular ligament above the sternum and linea alba on the caudal side of the xiphoid process are both divided, and the index finger is then used to digitally develop the superior and inferior spaces at the back of the sternum. To prevent entering the pleura when the longitudinal incision is made, the pleura is separated from the posterior surface of the sternum bilaterally. An electric saw is used to divide the sternum longitudinally. Thymic adipose tissue is also carefully divided with electrocautery, and venous branches at the inferior margin of the innominate vein are controlled. It is actually possible to divide the thymic tissue to the left and right without incising it, but there are many blood vessels that have to be carefully ligated or clipped and separated. The pericardium is approached by dissecting it from the cranial side and incising it to the left and the right of the ascending aorta. On the caudal side, it is opened on the left and the right side to the diaphragm, and the heart is exposed. The use of bone wax to stop bleeding at the cut surface of the sternum is inappropriate, taking the presence of foreign matter and the perfusion of the cut surface of the sternum into consideration, and it is possible to use argon beam coagulation or electrocautery instead to control bleeding on the cut surface of the sternum.

5.2 Mini Sternotomy

5.2.1 Mini Left Thoracotomy

With the spread of OPCAB, mini left anterior thoracotomy and OPCAB of the left anterior descending branch have come to be called the "left anterior small thoracotomy" (LAST) approach, as coined by Calafiore et al. [1]. When OPCAB is performed by a small incision method, it is defined as minimally invasive direct coronary artery bypass (MIDCAB) surgery, and MIDCAB and LAST are considered to be synonymous. CABG [2] is basically only performed by this method for diagonal branches including LAD, and when detachment of ITA is difficult, or the target vessel cannot be identified, the procedure has to be converted to full sternotomy; therefore, more institutes are performing full sternotomy from the start.

The body is placed at approximately 30° in a right lateral decubitus position. It is necessary to take a chest X-ray and a CT before the procedure to decide on the optimal intercostal space, but the skin incision is usually approximately 8 cm long at the fourth or fifth intercostal space (Fig. 5.2). The anterior chest muscle layer is incised, the pleura is opened from the outside, and once the lung has collapsed, the incision proceeds toward the midline, and the fourth or fifth costal cartilage is dissected for approximately 2 cm (Fig. 5.3). A small rib retractor is positioned, and while the intercostal space is slightly opened, the position of the LITA is confirmed (Fig. 5.4). If the rib retractor is opened widely at this time, care should be taken not to damage LITA by pulling it. While carefully cauterizing small branches with electrocautery, the rib retractor is gradually opened to free the LITA from the cranial and the caudal side over the width of one rib. Adequate working space can then be assured by positioning a special rib retractor or traction hook (Fig. 5.5). After the LITA has been detached, the pericardium is incised, and the target coronary artery is then identified (Fig. 5.6).

5.2.2 Lower-End Sternal Splitting Approach

In order to overcome the problem of detaching the ITA and exposing the target vessel with mini left thoracotomy, Niinami et al. [3] have reported the lower-end sternal splitting (LESS) method using a small incision of the lower part that does not transverse the sternum. The body is positioned as with the standard median sternotomy method, and an approximate 8 cm skin incision from close to the 4th rib to a

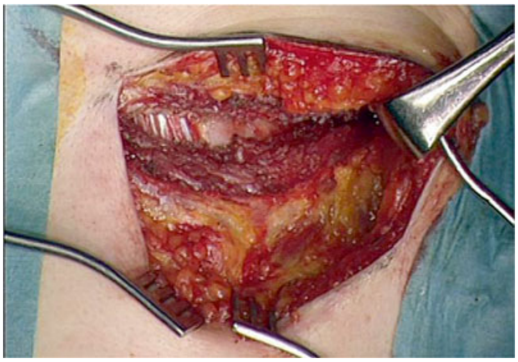

Fig. 5.3 The anterior muscle layer of the chest is incised, and the pleura is opened from the outside

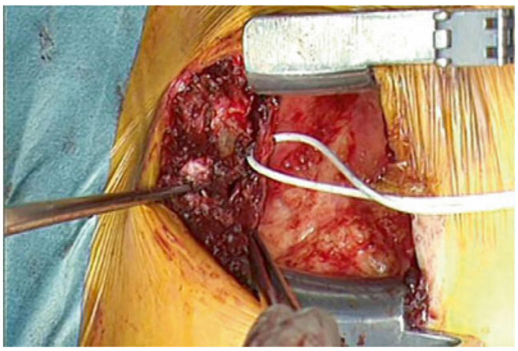

Fig. 5.4 A small rib retractor is inserted, and the position of LITA is confirmed while opening it slightly

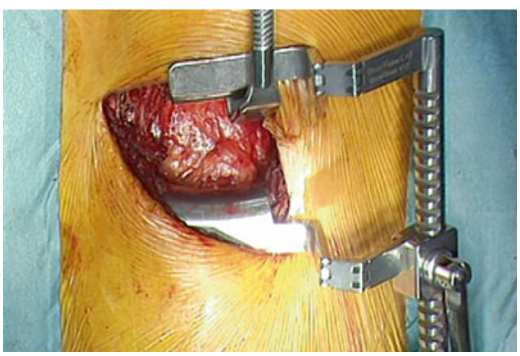

Fig. 5.5 A special rib retractor or traction hook is used to secure adequate working space

point slightly cranial of the xiphoid process is made. If the right gastroepiploic artery (RGEA) is used as the graft, the incision has to be extended caudally. The soft tissues close to the third intercostal space and underneath the xiphoid process are detached, and the lower part of the sternum is cut in the midline with an oscillating saw close to the third intercostal space. However, transverse incisions like a T-shaped or inverted L-shaped incision are not made in the sternum. By lifting the sternum with the retractor used to detach the ITA, it is possible to detach the ITA from close to the 2nd rib

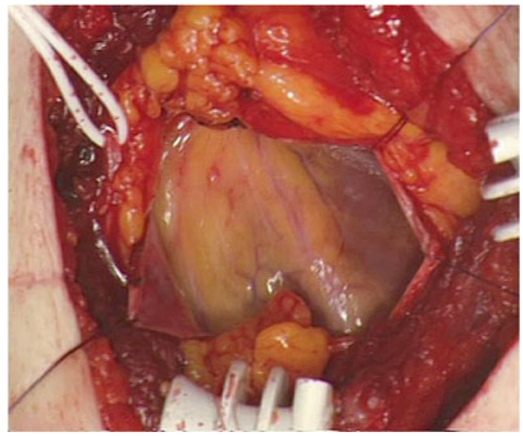

Fig. 5.6 The pericardium is incised, and the target coronary artery is identified

to close to the xiphoid process. When the LITA has been detached, the LAST rib retractor is used. Even without splitting the sternum transversely, the sternum has become pliable by lifting it to detach the LITA, and by opening the rib retractor gradually, the field of view can be expanded. Usually an adequate field of view from the root of the ascending aorta and the main pulmonary artery on the cranial side to the diaphragm on the caudal side can be obtained. Even if the ITA retractor is used to lift the sternum in this way, the ITA is not damaged, and the postoperative complication of a false sternal joint does not occur, and this method has the further advantage that the longitudinal incision of the sternum can simply be extended if it suddenly becomes necessary to change the procedure to a full sternotomy.

5.2.3 T-Shaped Incision

By the lower thoracic incision method [4], a skin incision is made from the third intercostal space to approximately 5 cm cranial from the xiphoid process, and a transverse incision is made at the height of the second intercostal space. By this method, with a longitudinal incision of approximately 10–12 cm of the sternum and a transverse incision at the height of the second intercostal space, it is possible to expose the right coronary artery (RCA) and LAD. Since the ascending aorta and right auricle can be visualized directly, it is possible to perform cannulation in this operative field and immediately start assisted circulation in case the hemodynamics become unstable.

However, it is still possible to damage the ITA, which runs close to the second intercostal space, when a transverse incision has been made in the sternum and a retractor intended for use when detaching the ITA is used to lift the sternum. If the ITA is harvested bilaterally, there is the danger of the postoperative complications of deformation of the sternum and the formation of a false sternal joint.

5.2.4 Reverse J-Shaped Incision

By the reverse J-shaped method [5], a skin incision is made from the third intercostal space to the xiphoid process, and the lower half of the sternum is cut in the midline and then diagonally toward the left third intercostal space. With this method, not only the RCA and LAD but also the diagonal branch can be exposed. The abovementioned danger of deformation of the sternum and the formation of a false sternal joint with the T-shaped incision is also decreased, and since the upper part of the sternum is not cut, the postoperative recovery can be accelerated.

5.3 Left Thoracotomy

Left thoracotomy has been reported as a useful and safe method to prevent ischemia of the posterior wall [6, 7]. This approach has the advantages that it is not necessary to derotate the heart while the anastomosis is performed, it is easy to maintain the hemodynamics, it is easier to identify the anastomotic part with re-surgery despite pericardial adhesions, and it is easy to decide on the length of the graft [8]. As the inflow source, not only the ascending aorta, aortic arch, and descending aorta [9, 10] (Figs. 5.7 and 5.8) but also the left subclavian artery [11], the left axillary artery, and the splenic artery [7] can be used. If revascularization of the LAD and the left circumflex artery (LCX) is performed concomitantly, the body is placed at approximately 45° in a half right lateral decubitus position, and right anterior thoracotomy is performed, but if only LCX is reconstructed, right thoracotomy is performed in the right lateral decubitus position to obtain the best field of view (Fig. 5.9). The thorax is opened in the fourth or fifth intercostal space, but this depends on the patient, and the intercostal space that provides the best access based on the chest X-ray and CT findings should be selected. The shape of the chest varies from patient to patient, and it is extremely important to inspect the course to be followed preoperatively. Special care should be taken in patients with an enlarged heart and those with a large chest, because work on the coronary arteries may be difficult and take more time.

5.4 Transdiaphragmatic Approach

When performing a revascularization procedure on the right coronary artery without using cardiopulmonary bypass, MIDCAB by a transdiaphragmatic approach is effective [12]. This method is effective as a route to reach the RCA region in case of re-surgery, and its greatest advantage is that fatal intraoperative complications like damage to the graft and heart tissue are minimized.

With this method, the position of the body plays a very important role in the operative field. An upper abdominal

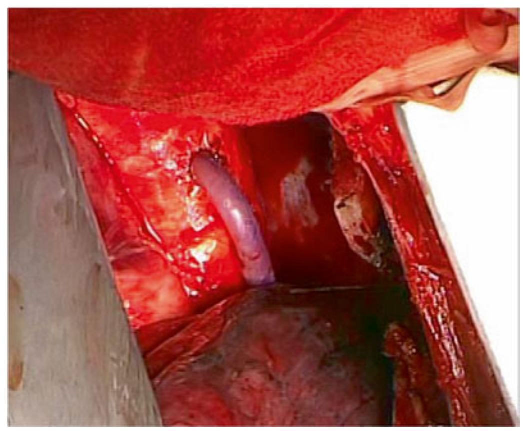

Fig. 5.8 An automatic anastomosis stapler is used depending on the properties of the descending aorta

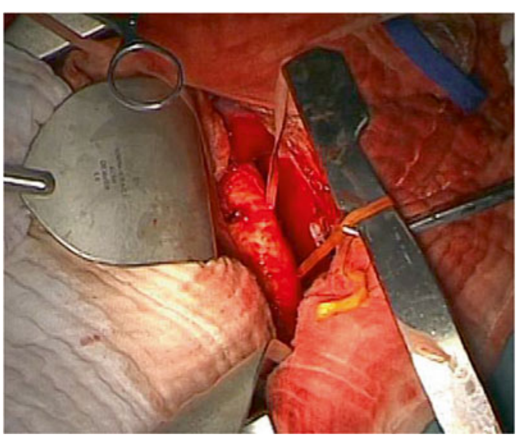

Fig. 5.7 It is possible to use the descending aorta as the inflow source of the graft

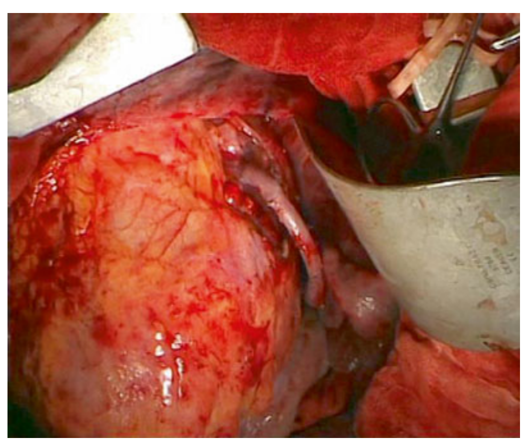

Fig. 5.9 For reconstruction of LCX, right thoracotomy in the right lateral decubitus position is used to obtain the best field of view

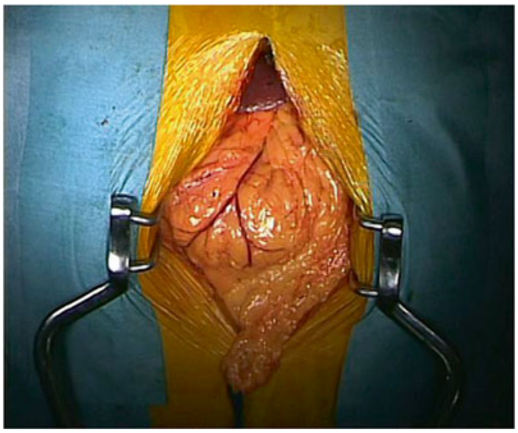

Fig. 5.10 An upper abdominal midline incision is made, and the xiphoid process is resected

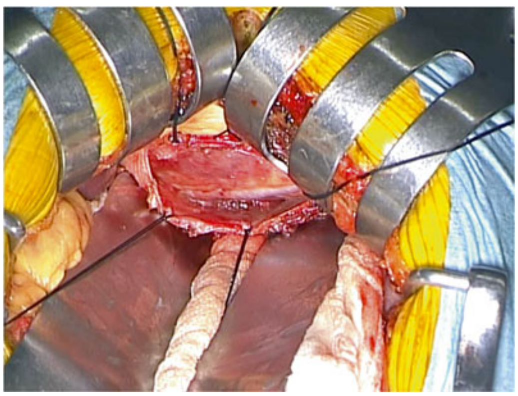

Fig. 5.11 Kent hooks are attached to the left and right costal arches and are pulled upward to create a large space between the diaphragm and the liver, and the abdominal side of the diaphragm can be clearly visualized

midline incision is made, and the xiphoid process is resected (Fig. 5.10). A cushion is placed beside the back at the level of the liver so that the patient can adequately bend backward. Kent hooks are attached to the left and right costal arches and are pulled upward to create a large space between the diaphragm and the liver, and the abdominal side of the diaphragm can be clearly visualized. An approximate 5 cm long transverse incision is made in the diaphragm along the upper edge of the left lobe of the liver, and the RCA can be visualized (Fig. 5.11). It is useful to use RGEA as the bypass graft for the RCA. However, if the RGEA cannot be used because it is in a poor condition or the patient has had a gastrectomy, it is also possible to create a bypass by anastomosing a free graft like the radial artery or great saphenous vein with the gastroduodenal artery [13].

References

1. Calafiore AM, Di Giammarco GD, Teodori G et al (1996) Left anterior descending coronary artery grafting via left anterior small thoracotomy without cardiopulmonary bypass. Ann Thorac Surg 61:1658–1665
2. Watanabe Y, Koyama N (2000) Minimally invasive direct coronary artery bypass (MIDCAB). Ann Thorac Cardiovasc Surg 6:356–360
3. Niinami H, Takeuchi Y, Suda Y et al (2000) Lower splitting approach for off-pump coronary artery bypass grafting. Ann Thorac Surg 70:1431–1433
4. Arom KV, Emery RW, Nicoloff DM (2000) Ministernotomy for coronary artery bypass grafting. Ann Thorac Surg 61:1271–1272
5. Grandjean JG, Canosa C, Mariani MA et al (1999) Reversed-J inferior sternotomy for beating heart coronary surgery. Ann Thorac Surg 67:1505–1506
6. Mack MJ, Dewey TM, Magee MJ (2002) Facilitated anastomosis for reoperative circumflex coronary revascularization on the beating heart through a left thoracotomy. J Thorac Cardiovasc Surg 123:816–817
7. Baumgartner FJ, Gheissari A, Panagiotides GP et al (1999) Off-pump obtuse marginal grafting with local stabilization; thoracotomy approach in reoperations. Ann Thorac Surg 68:946–948
8. Nishizaki K, Seki T (2003) Off-pump redo coronary artery bypass grafting from descending aorta to the posterolateral area through a left thoracotomy in patent internal thoracic artery graft. Jpn J Thorac Cardiovasc Surg 51:622–625
9. Minakawa M, Takahashi K, Kondo N et al (2003) Left thoracotomy approach in reoperative off-pump coronary revascularization: bypass grafting from the left axillary or descending aorta. Jpn Thorac Cardiovasc Surg 51:582–587
10. Watanabe Y, Fujii T, Hara M et al (2010) Redo CABG for ACS via the left thoracotomy using the PAS-Port system to the descending thoracic aorta: a case report. Ann Thorac Cardiovasc Surg 16:367–369
11. Kawata T, Kameda Y, Taniguchi S (1999) Modification of repeat coronary bypass grafting for the left anterior descending artery with a minimally invasive direct coronary artery bypass technique. J Card Surg 14:366–369
12. Takahashi K, Minakawa M, Kondo N et al (2002) Coronary artery bypass surgery by the transdiaphragmatic approach. Ann Thorac Surg 74:700–703
13. Takahashi K, Daitoku M, Minakawa M et al (2006) Coronary artery bypass grafting using an abdominal artery as an inflow. Ann Thorac Surg 82:69–73

6 Intraoperative Management and Anesthesia

Yoshihiko Ohnishi

Abstract

General anesthesia using continuous infusion of remifentanil and propofol (or inhalational anesthetic drug) is the most popular anesthetic technique during off-pump coronary artery bypass (OPCAB) surgery due to established early awareness and extubation. Maintain of peripheral temperature using a warming system and continuous infusion of vasodilator is also important. Monitoring of transesophageal echocardiography is essential to diagnose not only ventricular systolic function but also ventricular diastolic function in most patients. Measurement of pulmonary artery catheter including continuous monitoring of central venous oxygen saturation is more useful during OPCAB pulmonary surgery compared with conventional coronary artery bypass (on-pump CABG) surgery. During anastomosis of circumflex artery or right coronary artery, Trendelenburg position is effective to maintain venous return. Preoperative induction of intra-aortic balloon pumping is effective for patients with acute coronary syndrome or severe heart failure. In patients with severe mitral regurgitation or low diastolic function, it is important to determine elective conversion to on-pump CABG.

Keywords

Anesthesia • Transesophageal echocardiography • Pulmonary artery catheter • Diastolic function • Intra-aortic balloon pumping

6.1 Anesthesia

6.1.1 Anesthetic Concept

Off-pump coronary artery bypass (OPCAB), which was introduced in Japan in the mid-1990s, is now used in more than 60 % of coronary artery bypass grafting (CABG) surgery. Recently, due to the advancement of medical devices such as stabilizers and positioners, the development of more efficacious anesthetics and cardiovascular management, and improvements in blood volume control, most OPCAB patients can be well managed intraoperatively without the use of emergency heart-lung assist devices. Blood loss and transfusion volume in OPCAB are markedly lower than those in on- pump conventional CABG, which requires cardiopulmonary bypass circulation. The risks of an inflammatory response and aortic injury are also reduced. Moreover, OPCAB is favorable from a cost perspective because an extracorporeal circulation is not used. However, prognosis is poor for OPCAB patients who emergently need a heart-lung assist device [1]. OPCAB involves more techniques and higher skill levels in terms of cardiovascular control and anesthetic technique compared to conventional cases involving heart-lung machines [2]. Early extubation and ambulation are also often required.

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6.1.2 Preoperative Cardiac Evaluation

Since an extracorporeal circulation is not used in OPCAB, cardiac valve surgery cannot be performed concomitantly. Intraoperative management of patients with severe mitral regurgitation is difficult, and tricuspid regurgitation also greatly affects cardiovascular hemodynamics when the heart is reversed to the vertical position; therefore, accurate preoperative evaluation of cardiac function is important. In patients with severe atrioventricular valve regurgitation, OPCAB with simultaneous heart valve repair using an extracorporeal circulation is indicated. Moderate aortic regurgitation or aortic stenosis can be managed without an extracorporeal circulation. If a patient has definite patent foramen ovale (PFO), open heart surgery should be performed using a cardiopulmonary bypass.

The size of diastolic and systolic diameter and the ejection fraction (EF) of the left ventricle are evaluated precisely. At our institution, we consider on-pump CABG surgery for patients with a left ventricular EF <25 % [3]. Intraoperative management is often more difficult for patients with both ventricular wall hypertrophy and small left ventricular blood volume. In patients with diminished diastolic function, such as those with severe mitral or tricuspid annular calcification or thickening of the pericardium, intraoperative management is also often difficult. Since the left ventricular preload is related to the right ventricular EF, a decline in the right ventricular function markedly affects cardiac output [4]. In patients with severe left main coronary artery stenosis, strict maintenance of systemic blood pressure is required.

In patients who have carotid artery stenosis or occlusion of the cerebral arteries, the order of surgery needs to be considered in terms of priority. In many cases, OPCAB, in which systemic blood pressure is maintained somewhat higher than normal, is performed first [5].

In patients with renal failure, dialysis is performed on the day prior to surgery. Since atherosclerotic lesions can be severe in patients with renal failure, there is increased variation in blood pressure; therefore, strict blood volume control is required. Postoperative renal impairment is a severe potential complication of OPCAB, so preoperative evaluation of renal function is important.

6.1.3 Intraoperative Anesthetic Management

General anesthesia is the norm, but general plus epidural anesthesia is effective for reducing postoperative pain. OPCAB surgery can also be performed with only epidural anesthesia in some cases. However, catheter insertion into the epidural space is unlikely to be the best method for delivering anesthesia because there is a risk of intraoperative epidural hematoma due to the use of high-dose heparin. For intraoperative systemic anesthesia management, inhalational anesthetics are effective in protecting cardiac function as a part of anesthetic preconditioning. However, the heart rate should be maintained at less than 80 bpm during anastomosis in OPCAB. Therefore, the use of inhalational anesthetics often requires administration of short-acting β-blockers such as landiolol to slow the heart rate. Preconditioning with tourniquet compression of the upper arm during CABG has been reported to have a cardioprotective effect.

With the introduction of remifentanil, a potent ultrashort-acting analgesic infusion drug in Japan since 2006, heart rate control has been more effective. On the contrary, intraoperative pacing is still often required [6]. Due to the recent development of reliable mechanical stabilization devices such as the Octopus Tissue Stabilizer and apical suction devices such as Starfish Heart Positioner, heart rate control requirements are not as strict as before.

For anesthetic induction, benzodiazepines, such as midazolam (0.02–0.1 mg/kg), diazepam (0.02–0.1 mg/kg), and fentanyl (2–5 μg/kg), are commonly used intravenous agents. For maintenance of intravenous anesthesia, continuous infusion of remifentanil (0.3–0.6 μg/kg/min) and propofol (5–6 μg/kg/min) is preferred. For maintenance, inhalational anesthetic drugs, isoflurane (0.5–1 %) or sevoflurane (1–2 %) combined with remifentanil, are administered in anticipation of preconditioning effects.

The purpose of intraoperative anesthesia management is twofold: to minimize the effort on the heart as much as possible and to maintain systemic blood pressure at a level that ensures appropriate coronary blood flow. Maintaining the heart rate at an appropriately low level is crucial for minimizing the effort on the heart. Continuous administration of remifentanil can control the heart rate at a stable level. Selective β1 blockers are effective for controlling tachycardia. Appropriately decreasing systemic vascular resistance is effective for reducing the strain on left ventricular function because of afterload reduction. Phosphodiesterase (PDE) III inhibitors are useful because they not only reduce systemic vascular resistance but also slightly increase cardiac contractility [7]. Since it takes approximately one hour for PDE III inhibitors to achieve effective concentration, continuous administration should be started during graft anastomosis so that they take effect at the end of anastomosis. Milrinone (0.5 μg/kg/min) and olprinone (0.3 μg/kg/min) are frequently used PDE III inhibitors. However, over-reduction of systemic vascular resistance can cause a decline in systemic diastolic blood pressure, thereby reducing coronary blood flow. To maintain systemic blood pressure, continuous administration of phenylephrine or small doses of noradrenaline is effective. Under low-stimulation conditions, such as between anesthetic induction and the start of surgery, reductions in blood pressure are likely to occur; thus, continuous administration of phenylephrine is effective. For blood pressure drops during and after graft anastomosis, continuous administration of noradrenaline is effective.

Table 6.1 Anesthetic considerations for OPCAB surgery

1.	Continuous infusion of propofol and remifentanil is recommended for maintenance of anesthesia
2.	Pulmonary artery catheter is a useful monitoring system while the heart is in a vertical position
3.	Transesophageal echocardiography is essential in all patients unless there are contraindications
4.	The use of a warming system to maintain normothermia is important
5.	Fast-track anesthesia technique including postoperative pain management is favorable
6.	Prevention of severe atrioventricular valve regurgitation and ventricular outflow tract stenosis using conventional stabilizer and positioner is needed
7.	Trendelenburg position during Cx or RCA anastomosis is effective

While fentanyl (5–10 μg/kg) is administered as necessary toward the end of surgery, administration of remifentanil is gradually discontinued. Continuous propofol combined with dexmedetomidine is started, and the patient is subsequently transferred to the intensive care unit (ICU). The total dose of fentanyl is set to 500–800 μg and early extubation should be the goal (Table 6.1).

6.1.4 Intraoperative Monitoring

As with most cardiac surgical procedures, monitoring of electrocardiography using leads II and V5, pulse oximeter, capnometer, and direct arterial and central venous pressure is needed. Electroencephalography such as bispectral analysis is used to monitor anesthetic depth. Core body temperature is usually monitored using pharyngeal or bladder temperature. Tympanic temperature is occasionally used for this purpose. Peripheral temperature is monitored through the surface temperature of the palm or forearm.

It has been reported that there were no significant differences in mortality and morbidity based on whether a pulmonary artery catheter monitoring is used in CABG surgery involving a cardiopulmonary bypass. In OPCAB surgery, however, a pulmonary artery catheter is often useful for monitoring abrupt increases in pulmonary arterial pressure and decreases in central venous oxygen saturation (SvO_2). A pulmonary artery catheter is also needed for postoperative management in some cases [11]. Transesophageal echocardiography (TEE) is needed to evaluate mitral and tricuspid regurgitation and ventricular wall motion, as well as to diagnose narrowing of the pulmonary artery and left ventricular outflow tract. TEE is also useful for evaluating diastolic ventricular function.

In the OPCAB procedure, anastomoses are generally performed in the following order: left anterior descending coronary artery (LAD), circumflex artery (Cx), and right coronary artery (RCA).

During LAD anastomosis, SvO_2 and cardiac output sometimes decrease. If pulmonary arterial pressure increases significantly, left ventricular compression and pulmonary venous obstruction should be suspected. On the other hand, low pulmonary arterial pressure indicates the possibility of right ventricular outflow tract stenosis and right heart compression. To diagnose these conditions, TEE is used to evaluate the shape and motion of the left and right ventricles.

The electrocardiographic output voltage decreases when the heart is in a vertical position during Cx or RCA anastomosis, and thus ST changes cannot be identified. Additionally, SvO2 is almost always markedly decreased when the heart is in a vertical position, reflecting a decrease in cardiac output. Decreased pulmonary arterial pressure indicates that there is a high likelihood of right ventricular outflow tract obstruction, right heart failure, or exacerbation of tricuspid regurgitation. In contrast, elevated pulmonary arterial pressure suggests left heart failure or exacerbation of mitral regurgitation. To diagnose these conditions, TEE is useful to evaluate the degree of mitral and tricuspid regurgitation.

Moreover, TEE is important for intraoperative evaluation of left ventricular diastolic function. Diastolic dysfunction and pseudonormalization are diagnosed by the evaluation of left ventricular inflow waveforms (Fig. 6.1). By combining them with measurements of tissue Doppler and pulmonary venous inflow waveforms, a more accurate diagnosis becomes possible. If the ratio of the E-wave velocity from the left ventricular inflow waveform to the tissue Doppler-derived velocity (E/e') is ≤ 8, then left ventricular diastolic function is considered normal. If E/e' is ≥ 15, then diastolic dysfunction is present (Fig. 6.2). Since diastolic dysfunction significantly affects cardiovascular management in OPCAB surgery, identifying diastolic dysfunction is important.

During OPCAB surgery, evaluation of right ventricular function is also of importance. Central venous pressure and waveforms are useful for the evaluation of the right heart. Pulmonary arterial pressure waveforms, determined using a pulmonary artery catheter, are also useful for monitoring right ventricular function. Although the evaluation of right ventricular EF with TEE is difficult because the right ventricle is not round like the left ventricle, TEE provides important information. TEE is also needed for the evaluation of right ventricular diastolic function. The myocardial performance index, which is a ratio related to the right ventricular systolic time interval, is useful for evaluating right ventricular function. For monitoring right ventricular systolic

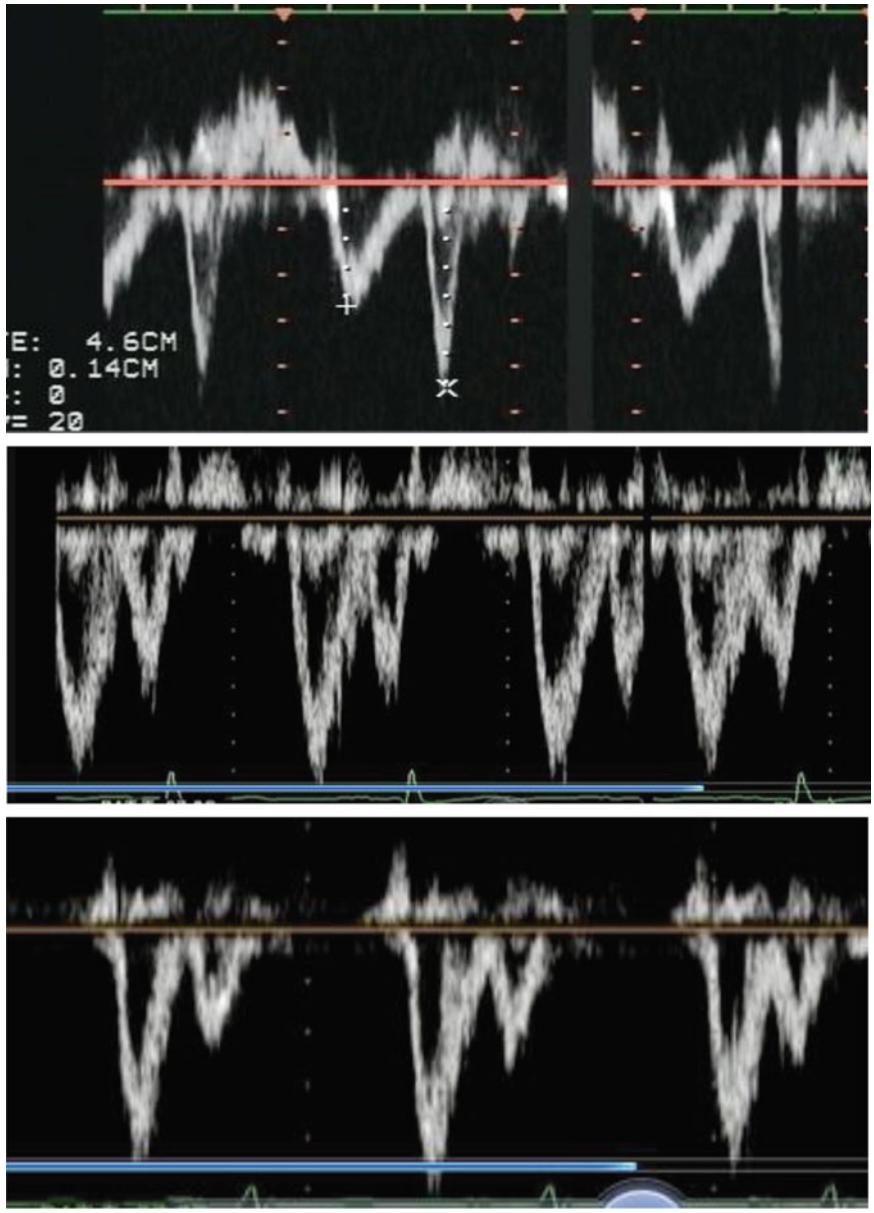

Fig. 6.1 Intraoperative left ventricular diastolic function is evaluated by transesophageal echocardiography. Mitral inflow pattern is measured using a pulse wave Doppler. (**a**) Abnormal relaxation pattern showed that peak E-wave is decreased and deceleration time is expanded, and peak A-wave is increased. (E/A wave ratio <1). (**b**) Pseudonormalization pattern showed increasing of peak E-wave and decreasing of peak A-wave. Deceleration time of E-wave is gradually reduced (E/A wave ratio >1). (**c**) Restrictive pattern showed high-peak E-wave. E/A wave ratio increased >2. Early diastolic pressure of left ventricle is rapidly increased

function, measurement of tricuspid annular plane systolic excursion (TAPSE) is also useful.

To monitor brain function in patients with carotid stenosis or cerebrovascular occlusion, near-infrared spectroscopy is performed.

6.1.5 Postoperative Anesthesia

After surgery, patients are generally managed in the ICU. Continuous infusion of both propofol (2–3 mg/kg/h) and dexmedetomidine (0.2–0.4 μg/kg/h) is applied for sedation. Appropriate fluid administration is needed to maintain diuresis. Once the peripheral temperature has sufficiently recovered, early extubation is attempted. Spontaneous breathing returns soon after patients are transferred to the ICU, and extubation is commonly performed within 3–6 h after surgery. In most cases, patients are discharged from the ICU the next day. Fentanyl is continuously infused to relieve postoperative pain.

6.2 Intraoperative Management

6.2.1 Intraoperative Cardiovascular Control

Following anesthetic induction, the dose of remifentanil is reduced to 0.05–0.1 μg/kg/min until the start of surgery. For patients with a decrease in systemic blood pressure, phenylephrine (0.1–0.2 mg) is administered intravenously to

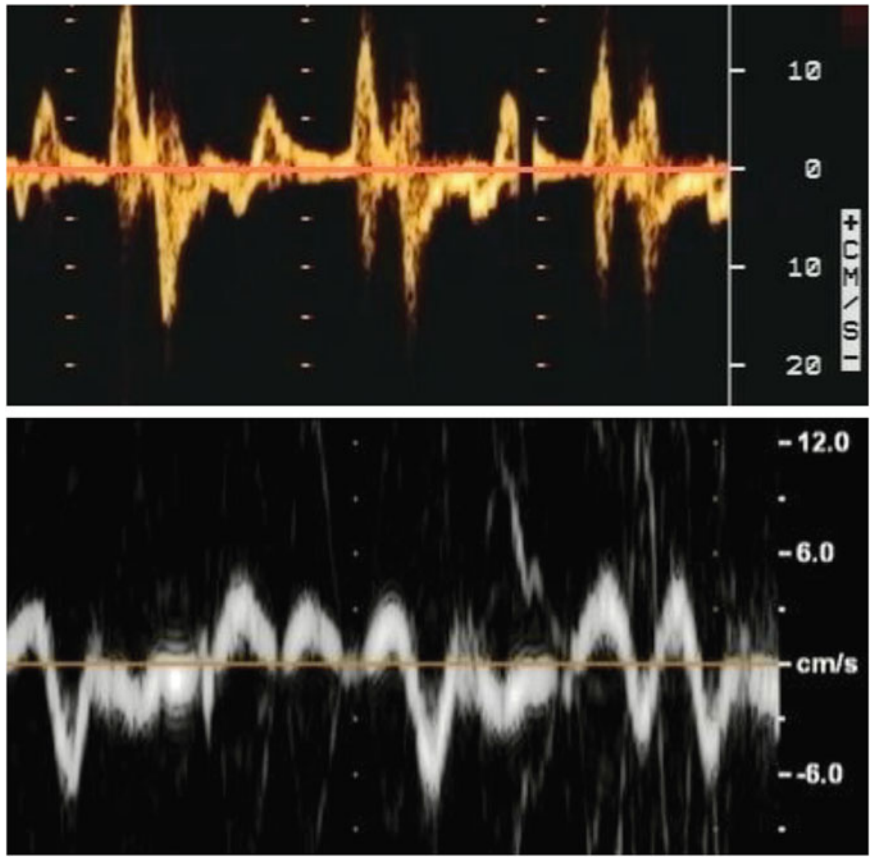

Fig. 6.2 Tissue Doppler pattern is measured at lateral mitral annulus using 4-chamber view. (**a**) Abnormal relaxation pattern of tissue Doppler showed increasing of a′-wave and decreasing of e′-wave. However, e′-wave remained over 8 mm/s. (**b**) Restrictive pattern of tissue Doppler showed decreasing of e′-wave under 8 mm/s

maintain the blood pressure. If peripheral vascular resistance declines with anesthetic induction, crystalloid solution should generally be given.

During internal thoracic artery or radial artery harvesting, fluid replacement should be sufficient to compensate for blood loss. The size of the heart, EF, and diastolic function are monitored using TEE. Mitral and tricuspid regurgitation are also evaluated. During internal thoracic artery harvesting, thoracic motion due to breathing may, in some cases, interfere with surgical manipulation. Increasing the respiratory rate to 30–50/min while decreasing tidal volume to 100–200 ml may reduce such respiratory motion.

Before the anastomosis procedure, low-dose heparin (100–150 u/kg) is infused and activated clotting time (ACT) is maintained over 250 s. During LAD anastomosis, a sling is inserted under the inferior part of the pericardium or a piece of gauze is inserted under the inferior part of the heart, and the left ventricle is lifted slightly. Compression of the LAD with a stabilizer may cause mitral regurgitation and diastolic dysfunction of both ventricles. After a small incision is made in the LAD, an intraluminal coronary shunt is inserted into the LAD coronary artery to maintain blood flow to the LAD; therefore, blood flow to the distal side of the anastomosis is maintained [8]. During end-to-side anastomosis, reducing volume overload and maintaining coronary blood flow by raising blood pressure with vasoconstrictors such as phenylephrine are recommended. The same procedure is also applied during diagonal branch anastomosis.

During Cx anastomosis, the patient is placed in the Trendelenburg position to increase venous return flow. The apex is pulled with a positioner so that the heart is in a vertical position (Fig. 6.3). For Cx anastomosis, torsion of the heart may exacerbate mitral and tricuspid regurgitation. Mitral and tricuspid valve regurgitation is markedly increased when the heart is in a vertical position, which reduces cardiac output remarkably [9]. When regurgitation is severe, changing the direction of the positioner and reducing the torsion may reduce regurgitation. Although compression with a stabilizer does not have a significant effect, there are negative effects on circulation when the heart is extensively twisted or vertically positioned (Fig. 6.4). Since cardiac output decreases when the heart is positioned vertically, transfusion is needed to maintain preload. Continuous infusion of vasopressors such as dopamine or noradrenaline is necessary in many cases.

Most of the time, the RCA is anastomosed to the atrioventricular node branch and the posterior descending coronary artery when the heart is vertically positioned. Although the heart is pulled into a vertical position with a positioner during RCA anastomosis, there is less twisting and thus less

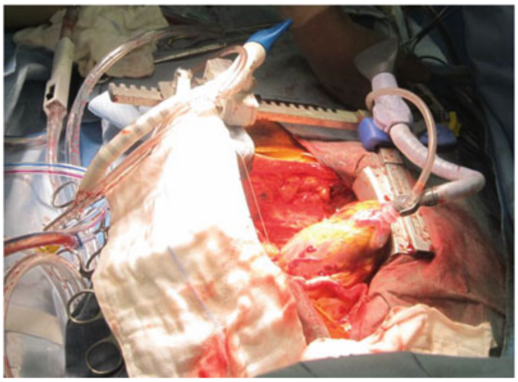

Fig. 6.3 The apex of a heart is absorbed and retracted to the vertical position using a heart positioner

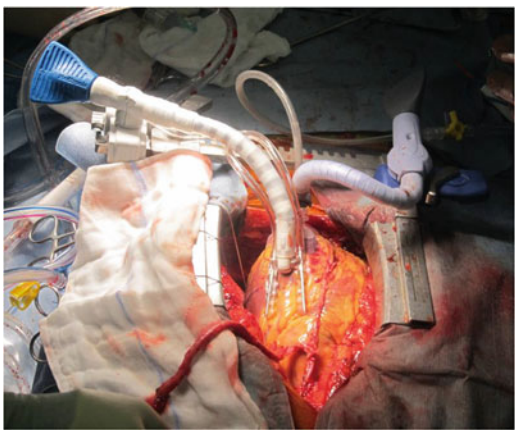

Fig. 6.4 Cx coronary artery is stabilized using a heart stabilizer

atrioventricular valve regurgitation than during Cx anastomosis. Transfusion becomes important due to the continuous decrease in cardiac output. In such cases, inotropes with vasodilatory effects, such as PDE III inhibitors and dobutamine (3–5 μg/kg/min), are used.

After the completion of the anastomoses, the heart is returned to its original position and hemostasis is performed before the chest is closed. In order to raise body temperature back to normal, the operating room temperature is raised and hot-air warming devices are applied. Infusion of amino acid preparations may also help with body temperature recovery [10]. Low doses of calcium antagonists such as nicardipine and diltiazem are continuously infused to prevent spasm of the arterial grafts. In many cases, it is helpful to administer a small dose of vasopressors such as catecholamine for cardiac function support, as well as vasodilators for afterload reduction.

6.2.2 Transfusion Management

Colloidal solutions are most commonly used, but crystalloid solutions may also be applied. Since stabilizers restrict diastolic function during LAD anastomosis, intraoperative management entails controlling infusion volume. A transfusion is required during Cx anastomosis because the heart is reversed and positioned vertically. However, during RCA anastomosis, a higher transfusion load is needed. The risk of postoperative atrial fibrillation can be reduced with an appropriate transfusion load.

As blood transfusions may enhance the inflammatory response, it is desirable to postpone transfusion until the LAD anastomosis is completed. However, it is also necessary to avoid anemia because it markedly affects the balance between oxygen supply and demand. Due to the increasing number of elderly patients and small female patients, nearly half of the patients receive blood transfusions during OPCAB surgery.

Among elderly patients and patients with arteriosclerotic lesions, there is an increasing number of cases in which achieving hemostasis is difficult due to bleeding from calcified areas. Excessive fresh frozen plasma and platelet transfusions should be avoided, but achieving hemostasis may be difficult.

It is reported that minimizing the transfusion volume reduces the incidence of several complications [12]. If cardiac output is somewhat maintained, smaller transfusion loads can effectively reduce the number of pulmonary complications. During LAD anastomosis, bloodletting may alleviate mitral regurgitation in cases where it is exacerbated by compression of the heart due to the use of a stabilizer or positioning device. Strict blood volume control is often needed in patients with diminished ventricular diastolic function, because there may be little reserve for controlling the circulating blood volume.

Control of urine volume is also necessary. The incidence of renal failure is lower with OPCAB compared to CABG with cardiopulmonary bypass. However, postoperative renal failure can be serious. Intravenous furosemide and continuous administration of human atrial natriuretic peptide (hANP) can be effective.

6.2.3 Cardiovascular Agonists

Catecholamines such as phenylephrine (0.1–0.4 μg/kg/min) with α-agonist activity and noradrenaline (0.01–0.1 μg/kg/min) are often used prior to and during LAD anastomosis to support cardiac function. It is not preferable to use catecholamines with β-agonist activity, such as dopamine and dobutamine, before LAD anastomosis.

After the LAD anastomosis is completed, anastomosis in the Cx region is initiated while the heart is vertically positioned. If cardiac output is markedly reduced, administration of β-agonists such as dopamine should be considered. When arterial grafts are used, continuous administration of calcium antagonists such as diltiazem (2–5 mg/h) and nicardipine (1–2 mg/h) is preferable. The administration of PDE III inhibitors, such as olprinone and milrinone, is indicated to reduce high afterload. Continuous noradrenaline is given for the patients with systemic hypotension.

During RCA anastomosis, α- and/or β-agonists are administered in order to maintain systemic blood pressure if necessary. hANP (0.01–0.05 μg/kg/min), which has a diuretic effect, is continuously infused when indicated.

After the anastomosis is completed, β-antagonists are often continuously infused to maintain adequate heart rhythm and cardiac output. Landiolol (0.005–0.02 μg/kg/min) is continuously infused to treat tachycardia and prevent postoperative atrial fibrillation. PDE III inhibitors are also effective for reducing afterload.

6.2.4 Management of Patients with Heart Failure

Cardiovascular control is more challenging in patients with heart failure. With lower left ventricular EF, afterload reduction using vasodilators and preload reduction using appropriate infusion are needed. However, a lower left ventricular EF does not portend worse prognosis if some degree of cardiac output is maintained. At our institution, we consider performing on-pump CABG when EF is ≤25 % or when moderate mitral regurgitation is present. In patients with EF >25 %, the following three factors are taken into account: the size of the heart, the presence or absence of dyskinetic areas, and the severity of mitral annular calcification. However, OPCAB is often possible. In general, low EF is not likely to be an intraoperative risk factor of hemodynamic management because there is a smaller angle of reversal and less torsion in the enlarged heart with low EF when positioned vertically than in a smaller heart. In cases where mitral or tricuspid regurgitation is exacerbated by positioning during Cx anastomosis, the direction of pulling by the positioner at the apex is adjusted to alleviate regurgitation. Some volume overload is needed when the heart is vertically positioned. Appropriate α-agonists are continuously administered in order to maintain coronary perfusion pressure. In patients with large dyskinetic areas, functional mitral regurgitation, or severe mitral or tricuspid annular calcification, it is difficult to control intraoperative cardiovascular hemodynamics.

In patients with low left ventricular diastolic function, the heart is compressed with a stabilizer during anastomosis, which diminishes cardiac output and SvO2. During anastomosis or when vertical positioning exacerbates mitral or tricuspid regurgitation, cardiac output is excessively reduced. An increase in E/e′ measured by echocardiography is used as an index of diastolic function. In general, diastolic function is considered normal when E/e′ is ≤8 and markedly deteriorated when E/e′ is ≥15. It has been reported that significantly more postoperative cardiovascular events occur in cases with E/e′ ≥15 compared to E/e′ ≤8. Mortality is also significantly higher in the former case [13]. Intraoperative declines in cardiac output require more time to return to baseline in patients with E/e′ ≥15. In hearts with diastolic dysfunction, both intraoperative and postoperative management are often difficult.

6.2.5 Management of Patients Who Have an Intra-aortic Balloon Pump

Patients with acute coronary syndrome and unstable cardiovascular hemodynamics or severe heart failure with very low cardiac output often have an intra-aortic balloon pump (IABP) placed preoperatively. An increase in diastolic blood pressure due to IABP support has a positive effect on coronary blood flow. The elevation of systemic mean arterial pressure is effective for stabilizing cardiovascular hemodynamics when the heart is reversed and vertically positioned. Since higher systemic blood pressures and increased cardiac output are appropriately maintained, no additional transfusion is needed in many cases [14].

IABP is usually operated to assist with every heartbeat (1:1) counter pulsation. As electric cautery is performed in surgery, IABP is often used with an arterial pressure trigger mode. The beating position of the IABP balloon is confirmed intraoperatively using TEE. The optimal position is 2–3 cm distal to the origin of the left subclavian artery. In cases where thrombi adhere to the intimal vessel in atherosclerotic lesions, postoperative renal failure and embolic events in the lower extremities are potential complications. Heparin may cause hemorrhage at the IABP insertion site.

6.2.6 Conversion to On-Pump CABG

The prognosis for patients with cardiovascular hemodynamic collapse during anastomosis and thus requiring an extracorporeal circulation is sevenfold worse compared to patients without such hemodynamic deterioration. Intraoperative conversion to the use of an extracorporeal circulation consists of two types: elective conversion and emergency conversion due to hemodynamic compromise. Between 2000 and 2005 when OPCAB became popular, the conversion rate to on-pump CABG due to hemodynamic collapse was 6–8 %, and the emergency conversion rate was 3 %. Recent advancements in devices used in OPCAB along with improvements of surgical skill contributed to a reduction in the conversion rate; however, approximately 2 % of cases are still converted to on-pump CABG, and the emergency conversion rate is approximately 1 %.

Elective conversion to on-pump CABG is more common with moderate to severe mitral regurgitation or organic problems such as the presence of a patent foramen ovale. In addition, electively converted cases include the following scenarios: arterial dissection, the coronary arteries to be anastomosed are buried, and cases in which OPCAB was determined to be impossible due to very low right ventricular function or diastolic function [15]. A stiff heart or a heart with a thickened wall is also likely to collapse. Patients with left main coronary artery stenosis, heart failure with diastolic dysfunction, or cases of repeat CABG or semi-emergency nature are also likely to be converted to on-pump CABG.

The use of intraluminal coronary shunting during LAD anastomosis is useful for preventing conversion. Additionally, IABP use can prevent conversion, and the temporary application of percutaneous cardiopulmonary support and ventricular assist devices is helpful.

Emergency conversion occurs most frequently during Cx anastomosis, most commonly due to severe mitral regurgitation when the heart is in a reversed, vertical position, leading to low cardiac output and hemodynamic collapse [16]. However, recent advancements in devices such as stabilizers and positioners have improved cardiovascular hemodynamics in the reversed, vertically positioned heart, thereby reducing the rate of hemodynamic compromise. On the other hand, compression with a stabilizer in patients with diastolic dysfunction or decreased right ventricular function is associated with hemodynamic collapse and conversion to on-pump CABG during LAD anastomosis.

References

1. Chassot PG, Linden P, Zaugg M et al (2004) Off-pump coronary artery bypass surgery: physiology and anesthetic management. Br J Anaesth 92:400–413
2. Shim JK, Choi YS, Chun DH et al (2009) Relationship between echocardiographic index of ventricular filling pressure and intraoperative haemodynamic changes during off-pump coronary bypass surgery. Br J Anesth 102:316–321
3. Keeling WB, Williams ML, Slaughter MS et al (2013) Off-pump and on-pump coronary revascularization in patients with low ejection fraction: a report from the society of thoracic surgeons national database. Ann Thorac Surg 96:83–89
4. Michaux I, Filipovic M, Skarvan K et al (2006) Effects of on-pump versus off-pump coronary artery bypass graft surgery on right ventricular function. JTCS 131:1281–1288
5. Marui A, Okabayashi H, Komiya T et al (2012) Benefits of off-pump coronary artery bypass grafting in high-risk patients. Circulation 126:s151–s157
6. Ono N, Ono T, Asakura T et al (2005) Usefulness of unipolar epicardial ventricular electrogram for triggering of intraaortic balloon counterpulsation during off-pump coronary artery surgery in patients with hemodynamic instability complication acute coronary syndrome. Anesth Analg 100:937–941
7. Omae T, Kakihana Y, Mastunaga A et al (2005) Hemodynamics changes during off-pump coronary artery bypass anastomosis in patients with coexisting mitral regurgitation: Improvement with Milrinone. Anesth Analg 101:2–8
8. Bergsland J, Lingaas PS, Skulstad H et al (2009) Intracoronary shunt prevents ischemia in off-pump coronary artery bypass surgery. Ann Thorac Surg 87:54–61
9. Couture P, Denault A, Limoges P et al (2002) Mechanisms of hemodynamic changes during off-pump coronary artery bypass surgery. Can J Anesth 49:835–849
10. Zangrillo A, Pappalardo F, Corno GTC et al (2006) Temperature management during off-pump coronary artery bypass graft surgery: a randomized clinical trial on the efficacy of a circulating water system versus a forced-air system. J Cardiothorac Vasc Anesth 20:788–792
11. Lavi R, Chung D (2012) Pro: continuous cardiac output and SvO2 monitoring should be routine during off-pump coronary artery bypass graft surgery. J Cardiothorac Vasc Anesth 26:1131–1135
12. Shahian DM, Normand SLT (2008) Low-volume coronary artery bypass surgery: measureing and optimizing performance. JTCS 135:1202–1209
13. Lee EH, Yun SC, Chin JH et al (2012) Prognostic implications of preoperative E/e′ ratio in patients with off-pump coronary artery surgery. Anesthesiology 116:562–571
14. Mannacio V, Tommaso LD, Amicis VD et al (2012) Preoperative intraaortic balloon pump for off-pump coronary arterial revascularization. Ann Thorac Surg 93:804–809
15. Mukherjee D, Ahmed K, Baig K et al (2011) Conversion and safety in off-pump coronary artery bypass: a system failure that needs reemphasis. Ann Thorac Surg 91:630–639
16. Chowdhury R, White D, Kilgo P et al (2012) Risk factor for conversion to cardiopulmonary bypass during off-pump coronary artery bypass. Ann Thorac Surg 93:1936–1942

Controversy: Volume Load vs. Vasopressor

7

Shinju Obara and Masahiro Murakawa

Abstract

Off-pump coronary artery bypass (OPCAB) can cause hypotension during anesthetic management, particularly because of displacement of the heart. While hypotension is mainly treated with fluid volume loading and vasopressors, few studies have investigated which is the more effective of the two treatments. Methods based on volume loading are logical because they aim to replenish the decreased ventricular preload, which is the main cause of the decrease in blood pressure. These methods avoid the damage caused by hypovolemia and the side effects caused by vasopressors, such as increased circulatory dysfunction. In contrast, methods using vasopressors are consistent with recent trends in fluid restriction, which aim to avoid complications caused by fluid overload while also maintaining organ perfusion. Anesthesiologists must have a thorough knowledge of the advantages and disadvantages of each method and employ one or both in accordance with each patient's needs.

Keywords

Off-pump coronary artery bypass • Anesthesia • Fluid management • Volume loading • Vasopressor

7.1 Introduction

According to a survey conducted in 2012 by the National Academic Questionnaire Survey Committee of the Japanese Association for Coronary Artery Surgery (responding facilities: 319, response rate: 69.5 %), the off-pump CABG (OPCAB) rate during coronary artery bypass surgery is 63.5 %. Most (87 %) answered "use of heart positioner" when asked how to overturn the heart. With regard to methods for stabilizing the heart, 100 % of respondents answered "use of tissue stabilizer." Using a combination of these measures is a standard procedure for heart surgery in Japan. Accordingly, anesthesiologists involved in such procedures need to understand artificially modified hemodynamics and should have the skills to maintain adequate anesthesia.

To maintain the appropriate oxygen transport volume suited for the oxygen demand of major organs such as the heart and brain, organ perfusion is necessary while the patient is under anesthesia. Therefore, arterial pressure and cardiac output must be maintained. Because blood flow volume in the coronary artery is high during the diastolic phase, it is important to not only secure adequate diastolic time but also maintain adequate perfusion pressure [1]. In particular, coronary artery blood flow in the presence of stenosis is dependent on coronary artery perfusion (mean blood pressure or diastolic phase pressure). Brain blood flow is autoregulated, maintaining the mean blood pressure at a relatively fixed level of 70–160 mmHg. While reports have indicated that the brain metabolic rate during sedation is lower than that during the awake state [2] and that it can cope with decreased perfusion to some extent, it is best that a necessary and sufficient amount of perfusion is present when safety margins are considered. During OPCAB, in addition to suppressed heart function caused by the underlying disease, blood pressure tends to decrease further because of the heart-

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inhibiting action and peripheral vasodilation action of the anesthetics. Furthermore, the functional mechanism mentioned below leads to a marked decrease in blood pressure, requiring action to be taken during displacement of the heart for revascularization during OPCAB.

Therefore, a worsened hemodynamic state (inability to maintain a mean blood pressure of >50 mmHg) and intractable arrhythmia [3] during OPCAB can necessitate emergency surgical conversion from OPCAB to on-pump CABG. The results of the aforementioned survey showed a conversion rate of 2.5 %. The results also indicated that the mortality rate associated with OPCAB was 0.45 %, whereas the mortality rate increased to 2.72 % when OPCAB was converted to on-pump CABG. Although these statistics do not indicate the reason for the conversion, a review of 14 randomized controlled trials [4] found that the reasons for conversion were circulatory instability and intramyocardial coronary target. Conversion is also likely prevalent in Japan for the same reasons. "Circulatory instability" refers to the situation where the anesthesiologist finds it difficult to maintain the patient's blood pressure. It is difficult to judge if this problem can be resolved with anesthetic management skills alone. However, it is essential to avoid unnecessary increased mortality rates due to conversion as a result of the anesthesiologists' lack of skills.

The aforementioned survey also asked about countermeasures for hypotension during OPCAB. The results indicated that 43.1 % respondents used volume loading and 54.2 % used vasopressor drugs. It is also likely that in actual clinical practice, combinations of these methods are used to respond to the anatomical and physiological causes of the changes in hemodynamics [5, 3]. For example, if circulatory instability occurs because of hypovolemia or heart chamber compression, then volume loading is performed. If myocardial ischemia or heart chamber compression is present or if hypotension continues despite other attempts, then phenylephrine or norepinephrine is administered.

Management of the volume required during normal anesthesia and peripheral vascular resistance is simple. Specifically, maintaining coronary artery and cerebrovascular perfusion pressure while also maintaining the preload to avoid low perfusion depends upon blood pressure maintenance with vasopressors and inotropes if necessary. These types of circulatory management are aimed at managing the patient's hemodynamic abnormality. For example, if the patient has preoperatively exhibited marked dehydration, fluid transfusion would be prioritized. If an anesthetic with strong peripheral vasodilatory action is used, then vasopressors will probably be selected. Furthermore, another factor with OPCAB that can inhibit circulation is manipulation of the heart, which often impedes the ventricular preload. If decreased blood pressure is caused by extreme pressure on the atrium, then it is best to select a method that solves this issue first.

When implementing these measures, one can also rely on the patient's reserve to some extent; the anesthetic records of the patient under anesthesia can be checked to confirm infusion and catecholamine volume. However, it is likely that methods employed in clinical practice can sometimes contradict textbook recommendations. Large volumes of fluids are administered to patients who have to undergo perioperative fluid restriction because of conditions such as heart failure, and vasopressors are administered to patients with valvular regurgitation in whom increased afterload should be avoided. These methods may be used if they offer more advantages than disadvantages and are required for intraoperative circulation maintenance. Furthermore, even with recent advances in monitoring technology, one cannot reliably and objectively observe circulating blood volume and changes during anesthesia in real time. Even in such circumstances, anesthesiologists must implement measures in a matter of minutes or seconds to cope with abnormalities. Before confirming the cause, they may also have to implement measures including treatment and diagnosis, such as a volume challenge (load a fixed amount of fluid and, if hemodynamics improve, diagnose insufficient preload). Anesthesiologists conduct "titration" in order to determine an accurate plan of action on the basis of the information available to them. Therefore, anesthesiologists' preferences may play a big role in treatment.

In either case, invasive arterial blood pressure is used as a real-time index, and blood pressure is increased via (a) increased fluid volume or (b) increased peripheral vascular resistance induced by vasopressors. One can retrospectively debate whether blood pressure should have been increased with either (a) or (b) after taking into account infusion volume and/or maximum vasopressor dosage as per anesthetic records. Real-time anesthesia can sometimes appear similar to a "black box," which can often be targeted for debate by nonexperts. Moreover, many anesthesiologists are likely to be concerned with the volume that should be added, the amount that can be added before heart manipulation causes large hemodynamic changes along with increased peripheral resistance when vasopressors are used, and the extent to which the vasopressor dose can be increased. However, not enough data on this topic is available to allow for debate because no randomized clinical trials targeting human subjects or meta-analyses have yet been conducted.

This section aims to outline the advantages and disadvantages of each type of circulation management method and provide information that will help anesthesiologists in selecting a management method that best suits individual patient needs.

7.2 Pro: Vasopressors Should Be Used as Little as Possible, and Their Administration Should Be Managed in Terms of Volume

7.2.1 Preload Maintenance Is Physiologically Logical

While reviews of anesthesia methods and textbooks recommend increasing pressure with volume infusion and vasopressor administration during OPCAB, there is often no specific mention of the optimal situation for using these methods or the order in which they should be prioritized [3, 6–9].

In general, preoperative dehydration is corrected not only during OPCAB but also during the induction of anesthesia. When correcting dehydration, it is thought that a relative preload decrease due to peripheral vasodilation caused by general anesthetics is simultaneously corrected.

When performing OPCAB vascular anastomosis, the heart is elevated from the pericardium in the left anterior descending artery (LAD) region. Peripheral revascularization of the left circumflex artery (LCX) and right coronary artery (RCA) on the posterior surface of the heart requires that the heart be elevated to a nearly perpendicular angle. These different heart positions can cause a variety of hemodynamic changes. Rotation of the heart to the right places pressure on the right atrium, decreasing right ventricular inflow. While particularly marked in the obtuse marginal artery anastomosis position, right ventricular pressure and deformation cause right ventricular outflow obstruction, resulting in decreased left ventricular filling pressure. Decreased cardiac output (CO) causes decreased coronary blood flow [10], which may lead to ischemia. An experiment that elevated pig hearts with the “octopus” device found that LAD artery blood flow decreased by 34 %, the LCA blood flow decreased by 50 %, and the RCA blood flow decreased by 25 % [10]. Decreased coronary blood flow can cause further decreased cardiac contractile force. Therefore, these blood flow patterns are all monitored as decreased blood pressure.

The aforementioned causes result in decreased left ventricular preload. Accordingly, they may be treated with volume loading and the Trendelenburg position or leg elevation. The table may also be rotated to the right and downward to relieve pressure on the right atrium caused by surgical manipulation. Directly applied contractile force caused by fitting a stabilizer and diastolic heart failure can also be treated with the above measures. Preload optimization is required when conducting fluid management for heart failure patients. According to the Frank–Starling curve, the observation of an increase in CO levels with volume loading is a logical approach.

During OPCAB, manipulation of the heart allows the blood pressure to drop easily, even if the blood pressure has been maintained until then. If appropriate blood volume is not maintained in advance, it will be more difficult to follow and correct circulatory disturbances. Furthermore, there have been recent advances in devices for predicting fluid responsiveness, including pulse wave analysis for predicting if hemodynamics will improve with fluid loading. These devices may help in improving blood volume [11]. In general, fluids are administered until the pulmonary artery systolic pressure reaches 20 mmHg or higher before displacement of the heart. Reports also indicate that pulse pressure variation (PPV) assessed by pulse wave analysis is an indicator of fluid responsiveness directly after heart displacement during OPCAB [12]. In this study, PPV was measured after LAD anastomosis and directly after heart displacement; 6 % hydroxyethyl starch (HES) preparation was loaded at 10 ml/kg in 10 minutes, and patients whose cardiac index improved by 15 % or more were deemed to be “responders” (relatively hypovolemic cases). PPV differed significantly between responders and nonresponders, with a PPV of >7.69 % detected in responders with a sensitivity of 86 % and a specificity of 83 %. Methods that analyze fluid responsiveness can be useful indices for preventing circulatory disturbances caused by heart displacement while avoiding excessive fluid infusion. An index that can predict circulatory disturbances caused by displacement at an earlier stage needs to be developed.

We were unable to locate previous studies that investigated appropriate fluid volume for maintaining circulation during OPCAB. The dosage was mentioned in a small number of studies reporting on other topics. Reports that only mentioned the absolute values included the report by Mueller et al. [13] in 2002, in which 2,800 ± 800 ml of crystalloid solution and 850 ± 230 ml of colloidal solution were administered. In the 2005 report by Staton et al. [14], 3934 ± 1311 ml of fluid was administered. Reports that mentioned surgical duration include the 2001 report by Yoshida et al., which indicated that 3,649 ± 972 ml of crystalloid solution, 623 ± 224 ml of colloidal solution, 128 ± 256 ml of erythrocyte transfusion, and 227 ± 168 ml of recovery type autotransfusion (surgical duration: 285 ± 61 min) were administered [15]. In 2005, Kesseler et al. [16] reported the administration of 1,532 ± 382 ml of Ringer’s lactate solution and 896 ± 55 ml of HES preparation (surgical duration: 110 ± 34 min), after which 5 of 28 patients required norepinephrine administration. Yoshida et al. and Kesseler at al. both reported that only crystalloid and colloidal solutions were administered at 899 ml/h and 1324 ml/h, respectively. While the body weight of patients in these groups remains unclear and there is little information on the concomitant use of cardiovascular drugs, one can see that relatively large amounts of fluids are required and that the preload is proactively maintained when the results are compared with those of general surgical procedures. Moreover, more recent data needs to be reported because much of the currently available data is old.

Sufficient preload maintenance during OPCAB requires the use of crystalloid and colloidal solutions. As of August 2013, Hespander® and Salinhes® are being used in Japan but are limited to cases of excessive bleeding or hemodilution in extracorporeal circulation. While it remains unclear whether volume loading in the absence of massive bleeding during OPCAB meets these indications, it appears to be in widespread use.

Furthermore, many Japanese cardiac anesthesia manuals (not cited) for beginners sold in Japan state that the head-down tilt position should be used after sufficient volume loading, and if blood pressure still does not reach the target values, vasopressors should be used.

7.2.2 Disadvantages of Hypovolemia

Intraoperative hypovolemia is related to the disruption of the balance between oxygen supply and demand, an increase in cardiac events due to tachycardia, a risk of renal dysfunction, and exertion of harmful effects on digestive tract function, such as postoperative nausea and vomiting or ileus [17, 18]. Because heart surgery is highly invasive, there is a risk of pulmonary disorder or heart failure caused by intraoperative volume overload. However, this is usually not managed with hypovolemia to the extent that further risks are involved. In patients with preoperative heart or renal dysfunction, there is a risk of postoperative volume overload that may cause a pulmonary disorder. However, this can be managed on the basis of appropriate respiratory care.

Hypovolemia causes tachycardia in a compensatory manner. Even with technological advances in stabilizers, tachycardia during OPCAB makes surgical manipulation difficult and can increase myocardial oxygen consumption. In recent years, short-acting beta-blockers have come into use, but as they inhibit tachycardia to compensate and mask hypovolemia, they can cause extreme decreases in blood pressure after the patient's condition has further worsened. Therefore, preload should be secured with a significant safety margin.

7.2.3 Side Effects of Vasopressors

Vasopressors are useful for adjusting "apparent" blood pressure. However, they should be used with an understanding of side effects caused by peripheral vasoconstriction, such as further exacerbation of peripheral circulatory failure during a state of low cardiac output, and the fact that overdosage can cause marked hypertension or cardiovascular decompensation. In 1998, US guidelines for the localized use of vasopressors in operating theaters were released [19]. These guidelines reported that the localized use of phenylephrine for hemostasis during otorhinolaryngological surgery caused hypertension, leading to death in 3 of 8 patients with pulmonary edema. Secondary hypertension due to alpha-sympathetic nerve stimulation increases peripheral vascular resistance, causing blood to shift from the peripheral systemic circulation to the pulmonary circulation, which has low sensitivity to vasopressors. As a result, left ventricular filling pressure increases, and increased afterload causes left ventricular end-diastolic volume (pressure) to increase. While increased cardiac contractile force and heart rate (HR) are effective in coping with the above state in a compensatory manner, the mechanism is impaired when beta-blockers are used for treating hypertension, leading to pulmonary congestion. There have been no reports on pulmonary edema caused by systemic administration of vasopressors alone during OPCAB. However, because the mechanism of action is the same with local and systemic administration, beta-blockers tend to be commonly used for heart rate control during OPCAB. While recently used beta-blockers exert minimal inhibitory effects on cardiac contractile force, a latent risk may be present.

Moreover, during left coronary artery anastomosis in OPCAB in particular, patients with mitral regurgitation (MR) exhibit worsened regurgitation and unstable hemodynamics. The phosphodiesterase III inhibitor milrinone has cardiotonic and vasodilation effects, and its administration has been linked to decreased MR during anastomosis and stable hemodynamics [20]. Blind administration of vasopressors in such situations, without an accurate diagnosis, can exacerbate MR.

Phenylephrine, which is used as a vasopressor, can cause loss of coronary flow [21] and works in a manner contradictory to the primary goal of OPCAB, which improves coronary flow.

The effects of vasopressors on perfusion in organs other than the heart also need to be considered. Blood flow to the digestive tract is easily affected by decreased CO, and, because alpha-receptors are distributed predominantly in digestive tract arterioles, vasopressors can easily cause decreased blood flow. A number of reports on nonocclusive mesenteric ischemia after OPCAB have been released [22, 23], and both decreased CO caused by intraoperative manipulation of the heart and the use of vasopressors were discussed as possible causes.

7.3 Pro: Vasopressors Should Be Actively Used While Volume Overload Should Be Avoided

7.3.1 Volume Restriction During General Anesthesia Is Commonly Employed

Until the late twentieth century, methods of fluid management during major surgery were based on concepts that easily led to excessive fluid volume. These methods included those termed as liberal fluid strategies that mainly used a crystalloid solution and related to the "third space" theory [24] proposed in the 1960s. The methods involved the replenishment of a maintenance dose in accordance with the level of surgical invasiveness or correction with crystalloid solution equivalent to three times the amount of blood lost [25]. While these methods may be useful in maintaining blood volume during anesthesia, they also carry the risk of hypostasis and harmful effects on cardiac function in patients with impaired cardiac or renal function. This occurs when anesthetic administration is terminated and the patient recovers from venous vasodilation and suppression of myocardial contractile force or when fluid returns from interstitial tissue to an effectively functioning circulatory system after recovery from postoperative systemic inflammation. Furthermore, fluid does not simply accumulate in the third space before being eliminated after a number of days; rather, it exerts a harmful influence when trapped in the interstitial tissue. For example, it is possible that digestive tract dysfunction caused by excessive crystalloid administration is caused by increased interstitial fluid in the submucosal layer, which prevents intestinal movement [26].

In recent years, enforced recovery after surgery [27] (ERAS) has been introduced for overall general anesthesia management. ERAS refers to a comprehensive concept that includes surgical procedure selection, anesthetic management method, perioperative nutritional management, and rehabilitation for enhancing postoperative recovery. While it only targeted gastrointestinal tract surgery at first, it has gradually been applied to surgeries for other organs. ERAS recommends that excessive sodium and water infusion before surgery should be avoided. It also recommends vasopressor administration rather than volume infusion to treat blood pressure decreases caused by epidural anesthesia. Epidural anesthesia blocks the effective range of sympathetic nerve activity and expands peripheral veins in particular, thereby causing decreased cardiac output (relative volume loss) because of a decrease in venous return. Therefore, this condition has traditionally been treated with volume overloading rather than vasoactive drugs. This approach can probably be applied to the theme of this report. Therefore, when treating peripheral vasodilation accompanying general anesthesia, one should consider not only volume loading but also vasopressor use. Furthermore, the concepts of (a) restrictive fluid strategy [28, 25, 29] and (b) fluid optimization [30] in order to maintain appropriate plasma volume have been introduced into intraoperative fluid management. The former involves a strategy to decrease patient risk by preventing overbalance and administering the minimum required infusion volume. The latter refers to a strategy of intravenous fluid administration while using indices that directly (venous oxygen saturation) or indirectly (stroke volume and pulse wave respiratory fluctuation) reflect oxygen transport volume as indicators to achieve an adequate fluid volume. While these two strategies use different techniques and indices as references, they are essentially based on the same concept, i.e., "aiming for a fluid volume appropriate for the patient's condition." In recent years, while this concept has not been clearly defined, it has grown into the concept of goal-directed fluid management (GDFM) [31], which potentially includes methods (a) and (b). This series of strategies emerged from the existing liberal fluid strategy through clinical actions of anesthesiologists. However, not enough research has been conducted on the usefulness of these strategies during OPCAB. While ERAS appears useful because it was first developed from the fast-track surgery concept developed in the 1990s in the field of cardiovascular anesthesia, researchers focused on anesthetic selection for early weaning from mechanical ventilation and did not give much priority to fluid management. Despite this, it appears that more studies will be conducted in this field in the future, and these should include OPCAB as a research topic. Many anesthesiologists were taught about the liberal fluid strategy before any new fluid management strategies appeared. Therefore, they may feel that treating insufficient preload with vasopressors is physiologically unreasonable and may find it difficult to employ these new strategies. However, recent trends for fluid restriction based on evidence-based medicines should be accepted and vasopressors should be proactively used to maintain coronary flow.

7.3.2 Preload Maintenance Is Important, but Physiological Rationality Must Not Be Lost

If perpendicular heart elevation causes increased right ventricular outflow tract (RVOT) resistance, which results in little blood flow from the right ventricle (also causing extreme decreases in CO), then this can be treated by returning the heart to its original position. Therefore, it is irrational to blindly conduct preloading when the flow tract is blocked.

Stabilizer pressure, suction, and fitting of a heart positioner for heart elevation can affect heart systolic and diastolic function. In particular, the anterior and lateral walls have a physiologically higher degree of freedom of wall movement compared with the septum and inferior wall and contribute markedly to CO. Fitting a stabilizer in these regions can deter local wall movement, influencing hemodynamics [13]. This state can also be physically called diastolic dysfunction. In order to increase blood pressure in this situation, only volume loading is not rational. Rather, one should use inotropic or vasoactive drugs as necessary.

7.3.3 Advantages of Vasopressors

Vasopressors are advantageous because they prevent volume overload by increasing organ perfusion pressure and coronary flow without altering circulating blood volume. Furthermore, vasopressors also exert some volume loading effects because capacitance vein constriction increases venous return and SV as a result [32].

Vasopressors used during OPCAB include phenylephrine and norepinephrine. Norepinephrine causes secondary expansion of coronary vessels by increasing blood pressure, while beta-2 stimulation of coronary vessels increases coronary flow [33]. Moreover, norepinephrine offers stronger beta-1 stimulation compared with phenylephrine, and it can offer a good balance when preoperatively administered beta-blockers exert overly strong effects. However, the disadvantages of norepinephrine are increased cardiac contractile forces caused by beta-1 stimulation effects, the fact that it makes surgery more difficult, and the fact that it prevents increased myocardial oxygen demand. Moreover, because vasopressors increase preload for the abovementioned reasons, they also slightly increase the cardiac contractile force. Kurozawa et al. used three-dimensional motion capture and reconstruction technology on a pig off-pump bypass model to analyze movement at the coronary artery anastomosis site and found that the use of phenylephrine as a vasopressor caused less movement compared with norepinephrine [34].

With OPCAB, blood pressure may decrease immediately after surgery for reasons other than the effects of anesthesia or manipulation of the heart. Matsuura et al. [35] indicated that a low systemic vascular resistance (indexed systemic vascular resistance <1,800 dyne · s · cm$-^{5}$ · m$-^{2}$) can occur after OPCAB, probably because of a systemic inflammatory response. The report stated that the use of vasopressors was a more reasonable option compared with volume loading for managing this condition.

7.4 Conclusion

Volume loading and vasopressor used to combat hypotension have their own advantages and disadvantages, and the selection of the more appropriate strategy is challenging.

The two perspectives can be visualized on an image based on the Frank–Starling curve (Figs. 7.1, 7.2).

The perspective that hypotension can be treated with volume loading alone (Fig. 7.1) is based on the assumption that an imaginary “preload volume at which manipulation of the heart causes circulatory collapse” (dotted line C) is less than

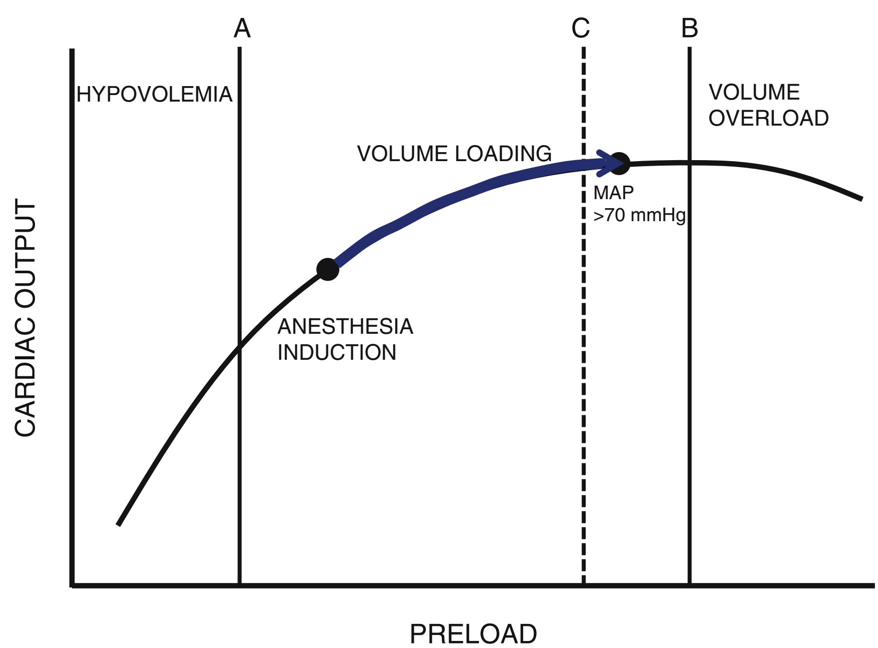

Fig. 7.1 Conceptual diagram of high blood pressure management with volume loading alone

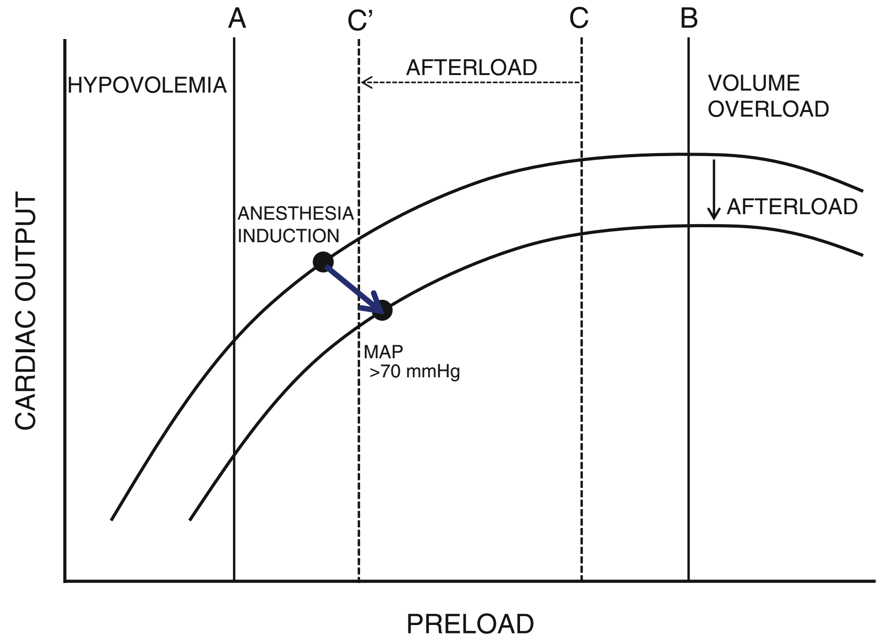

Fig. 7.2 Conceptual diagram of high blood pressure management with the proactive use of vasopressors

(left side) the boundary (perpendicular line B) showing harmful volume overload. However, with this method, it is difficult to judge in advance whether the target blood pressure (e.g., MAP >70 mmHg [3]) will be achieved without causing volume overload using fluids alone. In addition, post-volume loading preload (right dot) is further removed from the level at which hypovolemia is caused (perpendicular line A), indicating that any decrease in blood pressure is unlikely to have been caused by hypovolemia.

In contrast, the standpoint of proactive vasopressor use (Fig. 7.2) shows that increased afterload causes the Frank–Starling curve to move downward. It also hypothesizes an imaginary "preload volume at which manipulation of the heart causes circulatory collapse" (dotted line $C \rightarrow C'$). Here, the target blood pressure, i.e., tissue oxygen demand, can be achieved without increasing preload with fluids. The fact that this standpoint also shows that preload (right dot) after vasopressor use is further moved compared with volume overload (perpendicular line B) is significant, making the aforementioned risks associated with vasopressor use acceptable.

Whatever standpoint is selected, one should not pay attention to blood pressure values alone. Rather, indices showing hemodynamic changes over time (CO, pulmonary capillary wedge pressure, transesophageal echocardiography findings, etc.) should be used to judge where the patient's condition would fit in the figures described and manage the patient accordingly. Further research should be conducted on more accurate indices that can predict the effects of heart manipulation on hemodynamics.

When circulation management is not progressing well, it is important to conduct an objective assessment and alter or incorporate changes into the adopted strategy without being fixated on a certain type of management. Furthermore, when extreme increases in pressure or blockage of flow pathways occur during heart surgery, their management should be prioritized, requiring careful observation of the surgical field with close communication between the anesthesiologist and the surgeon. The use of an intra-aortic balloon pump should also be considered if necessary.

References

1. Guyton RA, McClenathan JH, Newman GE, Michaelis LL (1977) Significance of subendocardial S-T segment elevation caused by coronary stenosis in the dog. Epicardial S-T segment depression, local ischemia and subsequent necrosis. Am J Cardiol 40(3):373–380. doi:0002-9149(77)90159-X [pii]
2. Alkire MT (1998) Quantitative EEG correlations with brain glucose metabolic rate during anesthesia in volunteers. Anesthesiology 89(2):323–333
3. Virmani S, Tempe DK (2007) Anaesthesia for off-pump coronary artery surgery. Ann Card Anaesth 10(1):65–71
4. Urso S, Sadaba JR, Pettinari M (2012) Impact of off-pump to on-pump conversion rate on post-operative results in patients undergoing off-pump coronary artery bypass. Interact Cardiovasc Thorac Surg 14:188–193
5. Couture P, Denault A, Limoges P, Sheridan P, Babin D, Cartier R (2002) Mechanisms of hemodynamic changes during off-pump coronary artery bypass surgery. Can J Anaesth 49(8):835–849. doi:10.1007/BF03017418 [doi]
6. Chassot PG, van der Linden P, Zaugg M, Mueller XM, Spahn DR (2004) Off-pump coronary artery bypass surgery: physiology and anaesthetic management. Br J Anaesth 92(3):400–413. doi:10.1093/bja/aeh064 [doi] 92/3/400 [pii]
7. Bojar RM (ed) (2005) Manual of perioperative care in adult cardiac surgery, 4th edn. Blackwell Publishing, Oxford

8. Heames RM, Gill RS, Ohri SK, Hett DA (2002) Off-pump coronary artery surgery. Anaesthesia 57(7):676–685. doi:2613 [pii]
9. Hemmerling TM, Romano G, Terrasini N, Noiseux N (2013) Anesthesia for off-pump coronary artery bypass surgery. Ann Card Anaesth 16(1):28–39. doi:AnnCardAnaesth_2013_16_1_28_105367 [pii] 10.4103/0971-9784.105367 [doi]
10. Grundeman PF, Borst C, van Herwaarden JA, Verlaan CW, Jansen EW (1998) Vertical displacement of the beating heart by the octopus tissue stabilizer: influence on coronary flow. Ann Thorac Surg 65 (5):1348–1352. doi:S0003497598002264 [pii]
11. Hofer CK, Muller SM, Furrer L, Klaghofer R, Genoni M, Zollinger A (2005) Stroke volume and pulse pressure variation for prediction of fluid responsiveness in patients undergoing off-pump coronary artery bypass grafting. Chest 128(2):848–854. doi:128/2/848 [pii] 10.1378/chest.128.2.848 [doi]
12. Lee JH, Jeon Y, Bahk JH, Gil NS, Kim KB, Hong DM, Kim HJ (2011) Pulse-pressure variation predicts fluid responsiveness during heart displacement for off-pump coronary artery bypass surgery. J Cardiothorac Vasc Anesth 25(6):1056–1062. doi:S1053-0770(11)00532-5 [pii] 10.1053/j.jvca.2011.07.013 [doi]
13. Mueller XM, Chassot PG, Zhou J, Eisa KM, Chappuis C, Tevaearai HT, von Segesser LK (2002) Hemodynamics optimization during off-pump coronary artery bypass: the 'no compression' technique. Eur J Cardiothorac Surg 22(2):249–254. doi:S1010794002002701 [pii]
14. Staton GW, Williams WH, Mahoney EM, Hu J, Chu H, Duke PG, Puskas JD (2005) Pulmonary outcomes of off-pump vs on-pump coronary artery bypass surgery in a randomized trial. Chest 127(3):892–901. doi:127/3/892 [pii] 10.1378/chest.127.3.892 [doi]
15. Yoshida M, Seo K, Miyawaki H, Muranaka K, Kakumoto S, Mizutani H, Itaya M, Nitta K (2001) Coronary artery bypass grafting without cardiopulmonary bypass in patients receiving hemodialysis. Cardiovasc Anesth 5(1):87–93
16. Kessler P, Aybek T, Neidhart G, Dogan S, Lischke V, Bremerich DH, Byhahn C (2005) Comparison of three anesthetic techniques for off-pump coronary artery bypass grafting: general anesthesia, combined general and high thoracic epidural anesthesia, or high thoracic epidural anesthesia alone. J Cardiothorac Vasc Anesth 19(1):32–39. doi:S1053077004002770 [pii] 10.1053/j.jvca.2004.11.006 [doi]
17. Grocott MP, Mythen MG, Gan TJ (2005) Perioperative fluid management and clinical outcomes in adults. Anesth Analg 100 (4):1093–1106. doi:100/4/1093 [pii] 10.1213/01.ANE.0000148691.33690.AC [doi]
18. Mythen MG (2005) Postoperative gastrointestinal tract dysfunction. Anesth Analg 100(1):196–204. doi:100/1/196 [pii] 10.1213/01.ANE.0000139376.45591.17 [doi]
19. Groudine SB, Hollinger I, Jones J, DeBouno BA, The Phenylephrine Advisory Committee (2000) New York state guidelines on the topical use of phenylephrine in the operating room. Anesthesiology 92(3):859–864
20. Omae T, Kakihana Y, Mastunaga A, Tsuneyoshi I, Kawasaki K, Kanmura Y, Sakata R (2005) Hemodynamic changes during off-pump coronary artery bypass anastomosis in patients with coexisting mitral regurgitation: improvement with milrinone. Anesth Analg 101(1):2–8, table of contents. doi:101/1/2 [pii] 10.1213/01.ANE.0000155262.37491.6A [doi]
21. Antonopoulos A, Nikolopoulos D, Georgiou EK, Kyriakidis M, Proukakis C (2002) Blood pressure elevation after phenylephrine infusion may adversely affect myocardial perfusion in patients with coronary artery disease. Int J Cardiol 84(2–3):201–209. doi:S0167527302001468 [pii]
22. Hanada T, Obo H, Morimoto N, Matsuhisa H, Maruo A, Minami H, Nakagiri K, Yoshida M, Mukohara N, Shida T (2004) Nonocclusive Mesenteric Ischemia after Off-Pump CABG. Jpn J Cardiovasc Surg 33(2):94–97
23. Katz MG, Schachner A, Ezri T, Kravtsov V, Freidman V, Hauptman E, Sasson L (2006) Nonocclusive mesenteric ischemia after off-pump coronary artery bypass surgery: a word of caution. Am Surg 72(3):228–231
24. Shires T, Williams J, Brown F (1961) Acute change in extracellular fluids associated with major surgical procedures. Ann Surg 154:803–810
25. Joshi GP (2005) Intraoperative fluid restriction improves outcome after major elective gastrointestinal surgery. Anesth Analg 101(2):601–605. doi:101/2/601 [pii] 10.1213/01.ANE.0000159171.26521.31 [doi]
26. Marjanovic G, Villain C, Juettner E, zur Hausen A, Hoeppner J, Hopt UT, Drognitz O, Obermaier R (2009) Impact of different crystalloid volume regimes on intestinal anastomotic stability. Ann Surg 249(2):181–185. doi:10.1097/SLA.0b013e31818b73dc [doi] 00000658-200902000-00001 [pii]
27. Fearon KC, Ljungqvist O, Von Meyenfeldt M, Revhaug A, Dejong CH, Lassen K, Nygren J, Hausel J, Soop M, Andersen J, Kehlet H (2005) Enhanced recovery after surgery: a consensus review of clinical care for patients undergoing colonic resection. Clin Nutr 24(3):466–477. doi:S0261-5614(05)00023-3 [pii] 10.1016/j.clnu.2005.02.002 [doi]
28. Brandstrup B, Tonnesen H, Beier-Holgersen R, Hjortso E, Ording H, Lindorff-Larsen K, Rasmussen MS, Lanng C, Wallin L, Iversen LH, Gramkow CS, Okholm M, Blemmer T, Svendsen PE, Rottensten HH, Thage B, Riis J, Jeppesen IS, Teilum D, Christensen AM, Graungaard B, Pott F (2003) Effects of intravenous fluid restriction on postoperative complications: comparison of two perioperative fluid regimens: a randomized assessor-blinded multicenter trial. Ann Surg 238(5):641–648. doi: 10.1097/01.sla.0000094387.50865.23 [doi]
29. Nisanevich V, Felsenstein I, Almogy G, Weissman C, Einav S, Matot I (2005) Effect of intraoperative fluid management on outcome after intraabdominal surgery. Anesthesiology 103(1):25–32. doi:00000542-200507000-00008 [pii]
30. Benes J, Chytra I, Altmann P, Hluchy M, Kasal E, Svitak R, Pradl R, Stepan M (2010) Intraoperative fluid optimization using stroke volume variation in high risk surgical patients: results of prospective randomized study. Crit Care 14(3):R118. doi:cc9070 [pii] 10.1186/cc9070 [doi]
31. Forget P, Lois F, de Kock M (2010) Goal-directed fluid management based on the pulse oximeter-derived pleth variability index reduces lactate levels and improves fluid management. Anesth Analg 111(4):910–914. doi:ANE.0b013e3181eb624f [pii] 10.1213/ANE.0b013e3181eb624f [doi]
32. Gelman S, Mushlin PS (2004) Catecholamine-induced changes in the splanchnic circulation affecting systemic hemodynamics. Anesthesiology 100(2):434–439. doi:00000542-200402000-00036 [pii]
33. Sun D, Huang A, Mital S, Kichuk MR, Marboe CC, Addonizio LJ, Michler RE, Koller A, Hintze TH, Kaley G (2002) Norepinephrine elicits beta2-receptor-mediated dilation of isolated human coronary arterioles. Circulation 106(5):550–555
34. Kurosawa H, Seto Y, Wakamatsu H, Sato Y, Takase S, Omata S, Yokoyama H (2013) Effects of phenylephrine and noradrenaline on coronary artery motion in an open-chest porcine beating heart model. Surg Today. doi:10.1007/s00595-013-0639-9 [doi]
35. Matsuura K, Imamaki M, Ishida A, Shimura H, Fujita H, Niitsuma Y, Miyazaki M (2008) Low systemic vascular resistance state following off-pump coronary artery bypass grafting. Ann Thorac Cardiovasc Surg 14(1):15–21. doi:atcs/2008_14_1/15 [pii]

Urgent Pump Conversion: When Does It Occur and How Can We Prevent It?

8

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Abstract

Off-pump coronary artery bypass grafting is widely performed to prevent cardiopulmonary bypass complications. However, on-pump conversion occurs unexpectedly and is associated with high morbidity and mortality. We have determined the preoperative risk factors that predict conversion based on a large number of off-pump cases that we experienced. Careful intraoperative displacement of the heart and snaring of the coronary arteries are essential to prevent the hemodynamic instability that results in the need for an urgent institution of cardiopulmonary bypass. Transesophageal echocardiography is very useful for proper heart positioning. With this imaging modality, we can observe pulmonary artery obstruction, right ventricular obstruction, mitral regurgitation, and other conditions that can cause hemodynamic instability. If there are ST-segment changes on the electrocardiogram, an intracoronary shunt should be used. The grafting sequence is also important. When there is hemodynamic collapse despite several preventive measures, the patient must be converted to on-pump coronary artery bypass grafting (CABG). The increase in morbidity and mortality with conversion can be reduced by converting rapidly from off-pump to on-pump CABG before encountering significant hemodynamic instability.

Keywords

Urgent conversion • Heart displacement • Myocardial ischemia

8.1 Introduction

Off-pump coronary artery bypass grafting (OPCAB) is widely performed to prevent the complications that occur with cardiopulmonary bypass (CPB). However, on-pump conversion occurs unexpectedly and is associated with high morbidity and mortality [1–3]. The operative mortality in conversion cases ranges from 1.6 to 13.3 % [1–8]. In this chapter, we present our experience of the need for urgent pump conversion and the ways in which it can be prevented.

8.2 When Does Urgent Pump Conversion Occur?

8.2.1 Preoperative Predictors

Several preoperative predictors of the need for conversion have been reported in literature. Low ejection fraction (EF), congestive heart failure (CHF), myocardial infarction, emergent cases, and other predictors have also been reported. The preoperative predictors are described in Table 8.1 [1, 2, 5, 7, 8]. It is of our opinion that the most important variables are impaired cardiac function and extreme chamber dilation. If a patient scheduled for coronary artery bypass grafting

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Table 8.1 Preoperative predictors of conversion

Surgeon's prior experience with OPCAB
Previous CABG
Congestive heart failure
Previous myocardial infarction
Urgent states
Low ejection fraction
Preoperative hemodynamic instability
Extremely dilated heart
Higher New York Heart Association class
Mitral regurgitation
Chronic obstructive pulmonary disease
Cardiomegaly
Smaller body surface area

(CABG) has several predictors of on-pump conversion, the patient should be scheduled for on-pump rather than off-pump CABG.

8.2.1.1 Intraoperative Factors

On-pump conversion during OPCAB occurs unexpectedly. Urgent conversion to CPB may be needed during positioning of the heart or grafting or in patients with acute ischemia when there is hemodynamic collapse or ventricular arrhythmias. Conversion needs to be performed most frequently during an attempt to expose the posterior-lateral wall of the heart. Heart displacement to expose the posterior-lateral wall causes mechanical alterations of the normal cardiac geometry such as right ventricular compression, right ventricular outflow tract obstruction, mitral annular deformation leading to functional mitral regurgitation, and impaired left ventricular filling [5]. These changes take place whenever there is displacement of the heart, even when there is normal cardiac function preoperatively.

The other cause of hemodynamic instability is ischemia. Coexistent ischemia compounds the effects of mechanical dysfunction resulting in the need for urgent institution of CPB. During anastomosis, the proximal coronary artery is snared with a silicon-coated suture in our institute for adequate visualization. When the target coronary artery is large, ischemia may be a major cause for conversion, especially in cases with poor collateral vessels. Ischemia in cardiac conduction system supplied by the right coronary artery sometimes causes severe bradycardia. The surgical techniques for prevention of hemodynamic instability are described in the next paragraph.

To achieve a clear field to perform the anastomosis, a low-pressure carbon dioxide gas blower is used widely. It is very helpful, but results in a drop in myocardial temperature that may cause arrhythmias. Excess use of low-pressure carbon dioxide gas should be avoided. In emergent cases, especially acute myocardial infarction, the hemodynamics are sometimes unstable before CABG. In such cases, on-pump CABG should be selected rather than OPCAB, because ventricular arrhythmias and hypotension occur easily. The other circumstances leading to pump conversion intraoperatively are described in Table 8.2 [5].

Table 8.2 Intraoperative circumstances leading to conversion

Inappropriate heart displacement
Ongoing ischemia
Hypothermia
Deep intramyocardial vessels
Calcified or diffusely diseased target arteries
Diminutive vessels
Need for extended endarterectomy of the target vessel
Cardiomegaly
Arrhythmias

8.3 How Can We Prevent Urgent Pump Conversion?

8.3.1 Operative Monitoring

8.3.1.1 Parameters

For intraoperative monitoring, a combination of leads II and V5 is continuously displayed and used for ST-segment trend analysis. Radial artery pressure and central venous pressure are also monitored. In patients with poor left ventricular function (LVEF <35 %), pulmonary artery pressure should be monitored via a Swan-Ganz catheter, and the femoral artery cannulation site should be secured for emergency insertion of an intra-aortic balloon pumping (IABP). Patient temperature is constantly monitored via a properly placed rectal or bladder temperature probe and maintained at >35 °C. Normothermia also helps to achieve hemostasis and early postoperative extubation. Parameters are recorded at baseline, with the heart in the normal position. A CPB setup is kept ready, but not primed, and a perfusionist is readily available.

8.3.1.2 Transesophageal Echocardiography (TEE)

Continuous intraoperative TEE monitoring is very useful. A baseline TEE examination should be done before sternotomy to assess the following: (1) global left ventricular function, (2) regional ventricular wall motion, (3) mitral regurgitation, (4) right ventricular function, (5) right ventricular outflow tract and pulmonary artery, (6) tricuspid regurgitation, (7) aortic valve, and (8) thoracic aorta [7, 9].

TEE during heart displacement and grafting is used to monitor the following parameters: (1) deterioration of global left ventricular function, (2) regional wall motion abnormalities and left ventricular filling, (3) deterioration of mitral regurgitation, (4) right ventricular outflow tract and pulmonary artery obstruction, (5) right atrial filling and tricuspid regurgitation, and (6) aortic regurgitation [7, 9]. Multiple views are monitored during the anastomosis because of difficulties in imaging due to movement of the heart, pericardial traction, and vertical positioning of the heart.

8.3.2 Surgical Techniques

8.3.2.1 Sequence of Anastomosis

The grafting strategy plays an important role in preventing ischemia that potentiates hemodynamic compromise. The anteroseptal vessels are revascularized and perfused first, especially in patients with poor left ventricular function or acute ischemia preoperatively. Heart positioning for exposure of the left anterior descending coronary artery is easy and seldom causes hemodynamic compromise. After revascularization of the anteroseptal vessels, the heart is displaced to graft the remaining target vessels [4]. With a free graft, the proximal anastomosis should be completed before tackling another stenosed vessel if hemodynamics are unstable. In addition, the collateralized vessels should be grafted before collateralizing vessels.

8.3.2.2 Prevention of Ischemia

In our institute, the anastomosis is performed by snaring the proximal coronary artery with a silicon-coated suture and the use of a low-pressure gas blower. They provide adequate visualization; however, simple proximal snaring causes more ischemia of the myocardium. When ischemia causes left ventricular mechanical dysfunction, we use an intracoronary shunt. The use of an intracoronary shunt is good for preventing ischemia but makes the anastomosis difficult due to restriction of visualization.

There is good collateral formation in patients with chronic ischemia; however, in patients with acute ischemia, there is an insufficient collateral formation. In those with insufficient collateral formation, regional wall motion deteriorates after snaring the proximal coronary artery. This abnormal regional wall motion can be confirmed by TEE. Furthermore, the color of blood that flows retrograde after arteriotomy in these patients is dark compared with that in patients who have sufficient collateral vessel formation. We use an intracoronary shunt in such cases with insufficient collateral vessel formation. After snaring the proximal right coronary artery, the severe bradycardia that sometimes occurs requires a temporary pacemaker and an intracoronary shunt.

Ischemic preconditioning is reported to be effective in protecting the myocardium from ischemic injury [10]. However, it is not useful for emergent ischemic cases and wastes time.

8.3.2.3 Heart Displacement

The following techniques are used to prevent urgent conversion when the heart is displaced, especially when exposure of the posterior-lateral wall is necessary: (1) extensive right pleurectomy and deep vertical right pericardiotomy are performed to allow cardiac herniation into the right pleural cavity; (2) patients are placed in a right decubitus Trendelenburg position to provide good access to the target arteries [7]; and (3) TEE is used to monitor the right ventricular chamber, outflow tract, pulmonary artery, and mitral valve. If there is an increase in mitral regurgitation or right ventricular outflow tract and pulmonary artery obstruction that leads to hemodynamic compromise during displacement of the heart, these changes can be reversed by repositioning the heart. The right ventricular outflow tract and pulmonary artery are easily collapsed just by slightly shifting the heart.

In some cases, hemodynamic collapse occurs despite these preventive measures during the anastomosis. The adequate use of inotropes and fluid management may improve hemodynamics in such cases. If bradycardia occurs, pacemaker leads are attached to the right atrium or ventricle. However, if hemodynamic instability continues after pharmacological therapy, the heart should be placed in the normal anatomical position [5, 7]. If hemodynamics is improved by placing the heart in the normal anatomical position, the surgeon can continue with the CABG procedure. In most cases, the anastomosis can be completed without further hemodynamic instability. If hemodynamics fail to improve after placing the heart in the normal anatomical position along with the administration of adequate inotropic drugs and volume management, then rapid conversion to on-pump CABG is necessary.

8.3.3 Hemodynamic Management

8.3.3.1 Pharmacological Management

To prevent hemodynamic instability due to mechanical dysfunction and ischemia, dopamine, norepinephrine, dobutamine, or epinephrine is used. They can help maintain blood pressure; however, they contribute to a hyperdynamic cardiac state that makes it difficult to perform the anastomosis. Furthermore, fluid management is an important factor for maintaining hemodynamic stability. To prevent arrhythmias during manipulation of the heart and coronary occlusion, administration of lidocaine or a short-acting β-blocker is useful. Patients are given potassium if their serum K^+ is less than 4.0 mEq/L. The arterial pressure and cardiac index should be restored to baseline levels before the surgeon attempts the next anastomosis. The details of pharmacological and fluid management are presented in another chapter.

8.3.3.2 IABP

The insertion of IABP preoperatively has been reported as an effective measure to prevent on-pump conversion [11]. In the setting of OPCAB, preoperative IABP improves cardiac performance and facilitates access to the target vessels, while maintaining hemodynamic stability, even in high-risk patients such as those with impaired cardiac function or acute ischemia.

Intraoperatively, if the hemodynamic changes are not corrected with fluids and pharmacological management with the heart in the normal anatomical position, urgent IABP insertion is one of the measures that should be considered before on-pump conversion. Of course, the thoracoabdominal aorta and aortic valve must be evaluated preoperatively before urgent IABP insertion.

8.3.3.3 Communication with the Operating Room Staff

Intraoperative pharmacological and volumetric management is left to the anesthesiologist and the nursing staff. One of the most important factors to prevent urgent conversion is close communication between surgeons and anesthesiologists, nursing staff, and operating room technicians. During displacement of the heart and anastomosis of the coronary artery, the operating room staff should report even slight hemodynamic changes. Needless to say, in order to convert to on-pump CABG rapidly, a CPB setup and perfusionist must be readily available in the operating room.

8.4 Conversion

When there is hemodynamic collapse despite the preventative measures described above, conversion to on-pump CABG is necessary. When conversion is needed, the CPB machine should be set up as soon as possible. Surgeons and perfusionists should practice daily in preparation for urgent conversion cases. If a surgeon has experience with only a few OPCAB cases, he/she should have a low threshold for urgent conversion to on-pump CABG. Conversion should be initiated if there are any early indicators of electrical or hemodynamic instability, especially in high-risk cases.

8.5 Conclusions

The following factors should be considered to avoid potential hemodynamic problems resulting in the need for urgent institution of CPB: (1) careful preoperative patient evaluation and selection, (2) appropriate sequence of grafting, (3) extensive right pleurectomy and deep vertical right pericardiotomy, (4) correct positioning of the patient on the operating table, (5) careful heart displacement and positioning, (6) early recognition of mechanically induced cardiac collapse after heart displacement, (7) early recognition of ischemia induced by snaring, and (8) a prompt response to these problems. If hemodynamics is still unstable after these preventive measures, the surgeon should not hesitate to convert from off-pump to on-pump CABG. The increase in morbidity and mortality due to conversion can be prevented by converting rapidly before significant hemodynamic instability is encountered.

References

1. Edgerton JR, Dewey TM, Magee MJ et al (2003) Conversion in off-pump coronary artery bypass grafting: an analysis of predictors and outcomes. Ann Thorac Surg 76:1138–1143
2. Chowdhury R, White D, Kilgo P et al (2012) Risk factors for conversion to cardiopulmonary bypass during off-pump coronary artery bypass surgery. Ann Thorac Surg 93:1936–1942
3. Patel NC, Patel NU, Loulmet DF et al (2004) Emergency conversion to cardiopulmonary bypass during attempted off-pump revascularization results in increased morbidity and mortality. J Thorac Cardiovasc Surg 128:655–661
4. Keeling WB, Williams ML, Slaughter MS et al (2013) Off-pump and on-pump coronary revascularization in patients with low ejection fraction: a report from the society of thoracic surgeons national database. Ann Thorac Surg 96:83–89
5. Dewey TM, Edgerton JR (2003) Complications related to off-pump bypass grafting. Semin Thorac Cardiovasc Surg 15:63–70
6. Emmert MY, Salzberg SP, Seifert B et al (2010) Routine off-pump coronary artery bypass grafting is safe and feasible in high-risk patients with left main disease. Ann Thorac Surg 89:1125–1130
7. Mishra M, Shrivastava S, Dhar A et al (2003) A prospective evaluation of hemodynamic instability during off-pump coronary artery bypass surgery. J Cardiothorac Vasc Anesth 17:452–458
8. Tabata M, Takanashi S, Horai T et al (2006) Emergency conversion in off-pump coronary artery bypass grafting. Interact Cardiovasc Thorac Surg 5:555–559
9. Gurbuz AT, Hecht ML, Arslan AH (2007) Intraoperative transesophageal echocardiography modifies strategy in off-pump coronary artery bypass grafting. Ann Thorac Surg 83:1035–1040
10. Laurikka J, Wu ZK, Iisalo P et al (2002) Regional ischemic preconditioning enhances myocardial performance in off-pump coronary artery bypass grafting. Chest 121:1183–1189
11. Suzuki T, Okabe M, Handa M et al (2004) Usefulness of preoperative intraaortic balloon pump therapy during off-pump coronary artery bypass grafting in high-risk patients. Ann Thorac Surg 77:2056–2060

Exposure

9

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Abstract

Exposure of the target coronary artery is the first step in successful off-pump coronary artery bypass grafting (OPCAB). Deep pericardial suture ("Lima suture") and other modified techniques have contributed to the widespread use of OPCAB. In the basic deep pericardial stitch technique, the posterior pericardium is lifted up with three sutures and the heart is displaced. OPCAB has become more widely used since suction-assisted heart positioning devices were developed. Apical suction devices are only applied at the apex, and the heart is lifted and rotated to expose the target coronary artery. Our group developed a multi-suction heart positioner, Tentacles, which can facilitate this exposure. Patient positioning is also effective in any heart displacement technique. The operating table should be tilted in the Trendelenburg position and rotated sideways to the right for exposure of the left circumflex territory and the inferior territory. Heart displacement can cause hemodynamic instability in any heart positioning technique. Positioning for the left circumflex territory results in the greatest impairment to circulation compared to other territories. The main cause of hypotension is right ventricular kinking/obstruction, regional wall motion abnormality caused by compression and regional ischemia, and mitral regurgitation caused by mitral annular distortion. Fluid redistribution, patient positioning, catecholamine infusion, coronary perfusion during distal anastomosis, and pacing are effective in improving circulation.

Keywords

Off-pump coronary artery bypass grafting • Deep pericardial stitch • Heart positioner

9.1 Exposure

The key to successful off-pump coronary artery bypass grafting (OPCAB) is exposure of the target coronary artery under stable and acceptable circulation, effective stabilization of the local area, and identification of an optical anastomotic site with or without coronary perfusion. Exposure and visualization of the target coronary artery is the first and most essential step. If the target coronary artery cannot be visualized, the off-pump coronary bypass procedure must be converted to an on-pump procedure or bypass grafting to the target vessel must be omitted. When the heart is in an anatomical position, the left circumflex artery (LCx) (such as the obtuse marginal artery {OM} and the posterior lateral artery {PL}) is positioned on the back side of the heart, the posterior descending artery (PD) and the atrioventricular branch (AV) are adjoined to the diaphragm, and the left anterior descending artery (LAD) and diagonal branch (D) are adjoined to the left lung. Only the main trunk of the right coronary artery (RCA) can be approached in the anatomical position. To visualize all other coronary arteries, the heart must be displaced using

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various techniques and devices. For successful OPCAB, cardiac surgeons and anesthesiologists must cooperate to obtain an optical operative field and maintain stable patient circulation during anastomosis.

9.2 Deep Pericardial Stitch and Other Non-Device-Based Techniques

There are two types of heart displacement techniques. Before heart positioning devices were developed, deep pericardial stitch, the so-called Lima stitch, was the basic technique used to displace the beating heart. In this technique, three deep sutures are placed at the posterior pericardium: one at the junction between the pericardium and the left superior pulmonary vein, one at the junction of the pericardium and the left inferior pulmonary vein, and one in the middle portion of the pericardium between the left inferior pulmonary vein and the inferior vena cava [1]. The posterior pericardium is lifted with these three sutures and the heart is displaced. Various target coronary territories can be exposed using different combinations of elevations of the three deep pericardial stitches and lateral displacement. At this time, the position of the patient is important for proper access to the target artery. The table is set in the Trendelenburg position for the inferior territories (PD and AV branch), and the table is rotated sideways to the right for the posterior territories (OM and PL). The body is placed in the horizontal position for the anterior territories. The target anastomotic site is then stabilized with a suction-type stabilizer.

During placement of the deep pericardial sutures, great care should be taken to avoid a deep puncture. The stitch can cause serious bleeding from the large vessels of the posterior mediastinum such as the pulmonary veins [2] and descending aorta [3]. The stitch can also injure the esophagus. To avoid these serious complications, the suture should be passed through the posterior pericardium twice. At first, the suture should be passed superficially. The assistant should pull the thread in such a way as to give the pericardium a convex shape, moving it away from the structures of the posterior mediastinum. Then, the surgeon should pass the thread more deeply through the pericardium [1].

The “single-suture” technique is a modification of the “Lima suture.” This suture is similar to the third suture of aforementioned technique [4, 5]. The heart is elevated with one hand, and a single stitch (0 silk or no. 1 monofilament suture) is placed in the oblique sinus (pericardium between the left inferior pulmonary vein and the inferior vena cava), and the suture is passed through a folded 15 in. vaginal tape at the end, which doubles over on itself. Then, the suture is snared, pushing the vaginal pack flush with the pericardium. The suture is clamped to the snare and is pulled caudally in the midline and clamped to the drapes. Tension of the vaginal pack at 90° to the retractor on the left side allows elevation of the heart outside the chest. The vaginal pack is clamped to the drapes and is used for visualization of the LAD, diagonal branch, and intermediate artery. When the vaginal pack is opened into two arms and tension is placed on one of the arms toward the right and the tension is placed on the other toward the left, the apex of the heart is pointed toward the ceiling and the PD, PL, and OM can be exposed. Opening the right pleuropericardial space allows the heart to herniate into the right chest, and exposure of the LCx can be facilitated. This “single-suture” technique is arranged in various ways by some surgeons to obtain a better optical anastomotic site and maintain the patients’ hemodynamic condition during anastomosis [6]. At the time of heart displacement for the expose of the posterior and inferior territories, the right ventricle (RV) is likely to be kinked and compressed, and the diastolic filling of the RV might be disturbed, followed by hemodynamic instability [7].

9.3 Apical Suction Device and Multi-suction Device

Deep pericardial stitch techniques used to expose various coronary territories have contributed greatly to the increased use of OPCAB. However, after apical suction devices such as Starfish® (Medtronic, Inc, Minneapolis, MN) and X-pose® (MAQUE, Cupertino, CA) were developed, many surgeons began to use these devices because of their easy manipulation and reliable function (Fig. 9.1). To expose the target coronary artery, the vacuum-assisted apical suction device is applied at the apex of the heart to elevate and rotate the left ventricle into the midline. The level of vacuum pressure typically needed to maintain capture of the heart varies between

Fig. 9.1 A representative of an apical suction heart positioner: X-pose® (MAQUE) and other devices for off-pump coronary artery bypass grafting (MAQUE)

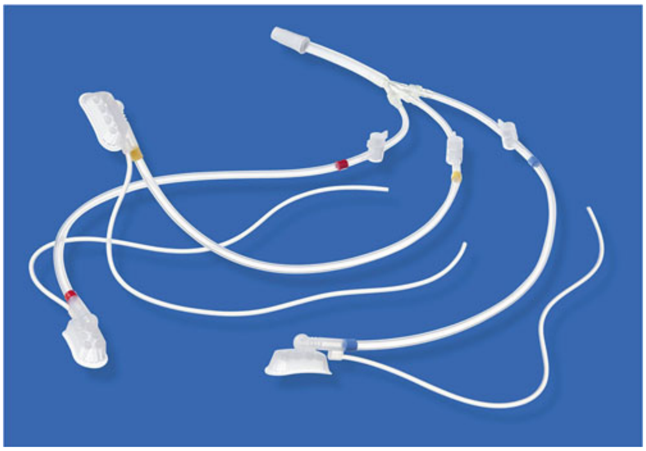

Fig. 9.2 A multi-suction heart positioner: TENTACLES™ (Sumitomo Bakelite Co., Ltd, Tokyo, Japan)

200 and 250 mmHg. The apex of the heart is slightly moved to the midline for exposure of the LAD. The apex is lifted to the ceiling and rotated to the cranial side for exposure of the inferior territory and lifted and rotated to the right lower side for exposure of lateral and posterior territories. To facilitate the exposure, the operating table is tilted in the Trendelenburg position and rotated to the right side in the same manner as mentioned above. Opening the right pleura also helps to rotate the heart. Inadvertent traction using any suction-type heart positioner can possibly cause tear at the epicardium and fat tissue around the apex, causing bleeding. Serious bleeding is rare; however, it is necessary to finish bypass procedure as quickly as possible and neutralize heparin and compress the bleeding site to stop bleeding.

We developed a multi-suction cardiac positioner, TENTACLES™ (Sumitomo Bakelite Co., Ltd, Tokyo, Japan) (Fig. 9.2) [8]. This device has three independent small suction cups and arms with elastic silicone strings. Due to the high tissue affinity of the suction cup, the suction cups can be applied on any surface of the heart and pulled in any desired three different directions using traction string, which is fixed to the surgical drape using clamp. To visualize the LAD, we typically apply one suction cup on the anterior wall of the RV and pull the RV rightward. To secure the heart position, we usually apply another additional suction cup at the LV anterior wall and fix it loosely to the left side (Fig. 9.3a). But anastomosis to the LAD can be performed even with only one or two suction cups applied on the RV, owing to the powerful suctioning capacity of this device. In case of unstable heart such as acute anterior wall myocardial infarction or low ejection fraction, this LV non-touch maneuver is especially useful to avoid suction-induced injury to the weakened infarcted myocardium, hypotension, or life-threatening arrhythmia induced by touching the LV wall. To visualize the inferior wall, we usually apply one suction cup on the RV anterior wall and pull it cranially and another cup on the inferior wall near the apex and slightly lift the apex under the sternum. In addition, we apply third suction cup on the RV inferior wall near the acute margin and pull it in the right-cranial direction to expand exposure of the inferior wall (Fig. 9.3b). The PD can be easily exposed under stable hemodynamic conditions. To visualize the lateral wall, we apply the first suction cup on the apex and lift the heart to confirm the target coronary artery. The second suction cup is applied on the LV lateral wall to rotate the heart rightward, and the traction string is fixed at the right side drape. The third suction cup is applied deeply near the crux of the heart and pulled in the left-caudal direction, and then fixed at the left side drape. Heart is rotated toward the right chest cavity (Fig. 9.3c). Finally, the first suction cup on the apex is detached. The apex is displaced under the right-sided sternum. Additional application of one suction cup on RV outflow tract may sometimes be helpful to prevent RV outflow kinking.

According to the annual report of Japanese Association for Coronary Artery Surgery 2012, suction heart positioner was utilized in 87 % of overall Japanese coronary surgery units.

9.4 Hemodynamic Change Caused by Heart Displacement

Hemodynamic changes are observed in any heart displacement technique. Although both deep pericardial traction and vacuum-assisted suction are safe and effective maneuvers to expose the coronary artery in OPCAB, vacuum-assisted suction devices appear to produce lesser hemodynamic impairment than the deep pericardial traction technique [9, 10]. Transesophageal echocardiography is very useful for quickly detecting signs of hemodynamic instability [11]. Hemodynamic changes are considered to result from RV kinking and obstruction, regional wall motion abnormalities caused by transient ischemia, or compression of the heart by stabilizers. Mitral annulus distortion by heart displacement can cause mitral regurgitation [12].

Cardiac surgeons must collaborate with anesthesiologists to obtain and maintain acceptable hemodynamic stability during distal anastomosis for successful OPCAB surgery. Fluid redistribution, rotation of the patient's position, perfusion of the target coronary artery, catecholamine infusion (too much catecholamine is detrimental for OPCAB), pacing, etc. are effective in stabilizing the hemodynamic condition; however, transient reposition of the heart to the anatomical position have to be considered when hypotension persists [13]. In case stable hemodynamic condition cannot be obtained, utilization of intra-aortic balloon pumping or conversion to on-pump CABG should be decided without delay. Emergent resuscitation and conversion to on-pump beating CABG should be avoided because of the high morbidity and mortality [14].

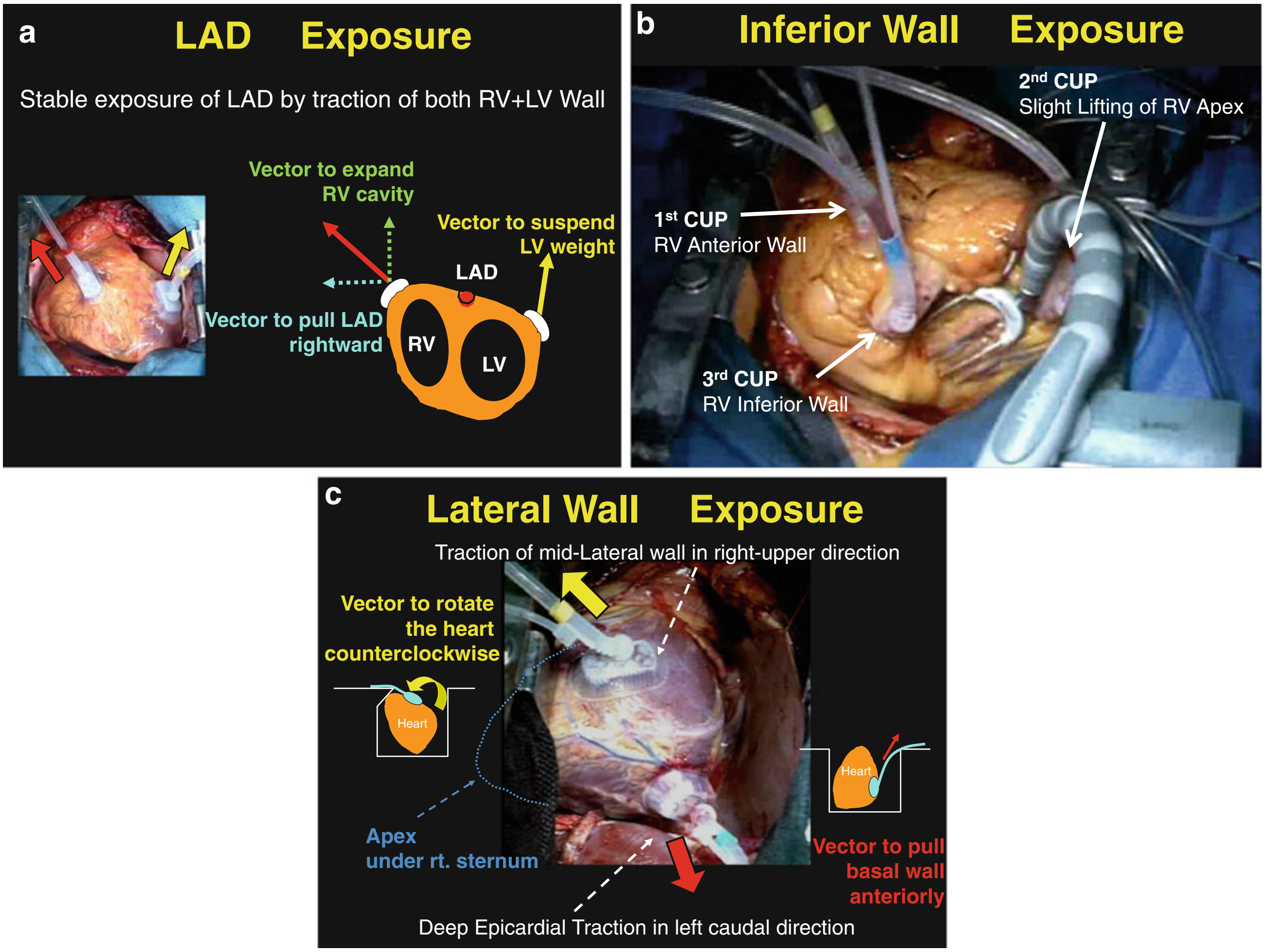

Fig. 9.3 Exposure of coronary arteries using TENTACLES™. (**a**) Exposure of left anterior descending artery. (**b**) Exposure of posterior descending artery. (**c**) Exposure of posterior lateral artery

References

1. Lima RC (2004) Some technical considerations on the prevention of bleeding caused by sutures in the posterior pericardium in off-pump coronary artery bypass operations. Ann Thorac Surg 78:1130
2. Fukui T, Suehiro S, Shibata T, Hattori K, Hirai H (2002) Retropericardial hematoma complicating off-pump coronary artery bypass surgery. Ann Thorac Surg 73:1629–1631
3. Salerno TA (2003) A word of caution on deep pericardial sutures for off-pump coronary bypass procedure. Ann Thorac Surg 76:337
4. Bergsland J, Karamanoukian HL, Soltoski PR, Salerno TA (1999) "Single suture" for circumflex exposure in off-pump coronary artery bypass grafting. Ann Thorac Surg 68:1428–1430
5. Ricci M, Karamanoukian HL, D'Ancona G, Bergsland J, Salerno TA (2000) Exposure and mechanical stabilization in off-pump coronary artery bypass grafting via sternotomy. Ann Thorac Surg 70:1736–1740
6. Mueller XM, Chassot PG, Zhou J, Eisa KM, Chappuis C, Tevaearai HT, von Segesser LK (2002) Hemodynamics optimization during off-pump coronary artery bypass: the 'no compression' technique. Euro J Cardiothorac Surg 22:249–254
7. Mathison M, Edgerton JR, Horsell JL, Akin JJ, Mack MJ (2000) Analysis of hemodynamic changes during beating heart surgical procedures. Ann Thorac Surg 70:1355–1361
8. Arai H, Mizuno T, Yoshizaki T, Itoh F, Oi K, Someya T, Tanaka H, Sunamori M (2006) A new multi-suction cardiac positioner for multivessel off-pump coronary artery bypass grafting. Innovations 1:126–130
9. Abicht JM, Beiras-Fernandez A, Bengel D, Vicol C (2012) Deep pericardial traction suture versus vacuum-assisted apical suction to expose the posterior wall of the heart in off-pump coronary artery bypass: a prospective, randomized study. Heart Surg Forum 15:E224–E231
10. Ustunsoy H, Kazaz H, Celkan MA, Kayiran C, Hayta R, Bayer E (2007) Deep pericardial suture vs apical suction for off-pump bypass grafting. Asian Cardiovasc Thorac Ann 15:123–126
11. Kapoor PM, Chowdhury U, Mandal B, Kiran U, Karnatak R (2009) Trans-esophageal echocardiography in off-pump coronary artery bypass grafting. Ann Card Anaesth 12:167
12. George SJ, Al-Ruzzeh S, Amrani M (2002) Mitral annulus distortion during beating heart surgery: a potential cause for hemodynamic disturbance-a three-dimensional echocardiography reconstruction study. Ann Thorac Surg 73:1424–1430
13. Nierich AP, Diephuis J, Jansen EWL, Borst C, Knape JTA (2000) Heart displacement during off-pump CABG: how well is it tolerated? Ann Thorac Surg 70:466–472
14. Chowdhury R, White D, Kilgo P, Puskas JD, Thourani VH, Chen EP, Lattouf OM, Cooper WA, Myung RJ, Guyton RA, Halkos ME (2012) Risk factors for conversion to cardiopulmonary bypass during off-pump coronary artery bypass surgery. Ann Thorac Surg 93:1936–1942

Stabilization

10

Hitoshi Yokoyama

Abstract

Coronary artery bypass surgery is a microsurgery. Stabilization of the coronary artery on the beating heart is the key concept for successful off-pump coronary artery bypass surgery. Recent progress in 3-dimensional motion capture and reconstruction technology is revealing the quantitative characteristics of coronary artery motion in detail. Various factors such as cardiac contractility, heart rate, mechanical ventilation, and coronary artery anatomy have great influence on the coronary artery motion. The effect of various stabilization or anti-stabilization technique such as suction-type mechanical tissue stabilizer, beta-adrenoreceptor blockers, vasopressors, heart pacing, and ventilation is analyzed and discussed for better understanding of optimizing the stabilization of coronary artery anastomosis site.

Keywords

Suction-type tissue stabilizer • Evaluation for stabilization • Pharmacological stabilization • Landiolol hydrochloride

10.1 Stabilization Is the Key for Successful Off-Pump Coronary Artery Bypass Surgery

10.1.1 Hypothesis: Stabilization-Patency Relationship

Off-pump coronary artery bypass is a microsurgery, in which a surgeon works on small moving object. Error of microstitches on the small vessels may result in graft stenosis and occlusion. Studies of human performance show the range in technical error of surgeon with high-power magnification glasses is between 0.1 and 0.2 mm if he or she has a good hand [1]. Assuming a surgeon is working on a coronary artery of 1–2 mm in diameter, the error of suture could be up to 20 % in maximum.

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There are miscellaneous factors affecting coronary artery motion (Fig. 10.1). Every effort should be paid to avoid or control these factors for better stabilization.

Here is a hypothesis or assumption on the relationship among stabilization, surgeon skill, and graft patency. Intuitively, residual motion of the anastomosis sites under efforts for stabilization affects the graft patency (Fig. 10.2). When the residual motion is acceptable for the surgeon, he or she feels comfortable enough to place precise stitches, making a good anastomosis with excellent graft patency. If the residual motion of anastomosis site were too big to make an acceptable anastomosis, expected graft patency would decease dramatically.

Surgeon's skill is another factor for graft patency. The stabilization-patency relationship can be shifted to left by surgical training. The expert surgeon is able to manage to work on the moving coronary artery somehow, while the surgical resident is not. However, there is a human limit for working on a moving small target even for the expert surgeon. Thus, here is a hypothesis that these 2 factors, stabilization and surgeon skill, may affect the configuration of the

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Factors for stabilization

- Heart
  - Chronotropic state: heart rate
  - Inotropic state: contractility
    - preload / afterload
    - sympathetic / parasympathetic nerve tone
    - serum catecholamine (intrinsic / extrinsic)
  - Coronary artery anatomy
  - Surrounding fat
- Adjacent organ movement
  - Lung ventilation
- Mechanical stabilization
  - Suction-type tissue stabilizer
  - Additional tips
- Pharmacological stabilization
  - Inotropic agents
  - Vasopressors

Fig. 10.1 Factors influencing the stabilization of the coronary artery on a beating heart

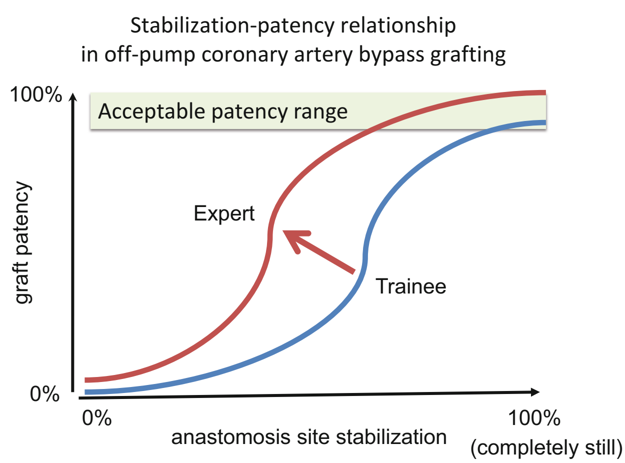


Fig. 10.2 Hypothesis: stabilization-patency relationship in off-pump coronary artery bypass grafting. For trainees with less experience, acceptable graft patency can be achieved only when the anastomosis site stabilization is near perfect (100 %). For expert surgeons, acceptable graft patency can be achieved as long as the anastomosis site stabilization is not poor. This relationship curve can be shifted to the left by surgical skill training

anastomosis and graft patency. Therefore, surgical training (see Chap. 26: Teaching and training) and stabilization is the key for successful off-pump coronary artery surgery. Here comes the next question: regarding the stabilization, how good is good enough for surgeons to provide an acceptable graft patency?

10.1.2 How Good Is Good Enough for Stabilization?

An expert off-pump surgeon can make a good stitch on the moving coronary artery. However, there is a human limit of acceptable motion of the target. Figure 10.3 shows a scheme of suturing the moving coronary artery. The task of a surgeon is to hold the coronary artery adventitia and make a precise stitch without laceration of the wall. The coronary artery wall is soft and flexible and can be held to make immobile point even on the moving floor made with myocardium and fat tissue. Try to hold the coronary artery wall by forceps. If it can be held to be immobile without any tension, a surgeon can make a incision and stitches. If a surgeon feels any traction force on the holding point, delicate procedure around the holding point on the coronary wall without a risk of laceration is not recommended. In summary, a surgeon can confirm if he or she obtains an acceptable stabilization by holding the target coronary artery wall in static position.

10.2 Evaluation of Stabilization

The motion of target anastomosis areas during off-pump coronary artery bypass is an important issue for cardiac surgeons. Several attempts for evaluating the cardiac surface motion in a quantitative fashion have been reported. In 1996, Borst and associates [2] reported that a mechanical stabilizer (Octopus) significantly reduced the area circumscribed by the 2-dimensional reference points on the right coronary artery and obtuse marginal branch in pigs by using an analog video camera. In 2002, Detter and associates [3] measured the deviation of small vessels in the anterior wall by using an orthogonal polarizations spectral imaging device, reporting that the deviation was significantly decreased with mechanical stabilizers. They also showed better stabilization is associated with shorter anastomosis time. In 2003, Koransky and associates [4] 3-dimensionally reconstructed the motion of the left anterior descending artery with digital sonomicrometry. They reported that mechanical stabilization significantly reduced the 3-dimensional excursion, maximum velocity, and average velocity. In 2004, Cattin and associates [5] captured the wall movements of the beating heart by using a high-speed camera coupled with a laser sensor, analyzing the trajectory of the point of interest. In their system, the 2-dimensional lateral motion (*x*-, *y*-axis) was captured with the high-speed camera, and the out-of-plane motion (*z*-axis) was acquired with the laser sensor. In 2005, Lemma and associates [6] captured the coronary artery simultaneously with two digital cameras, reconstructing the wall movements of the heart in 3-dimensional fashion. They quantitatively reported the distance of marker displacement

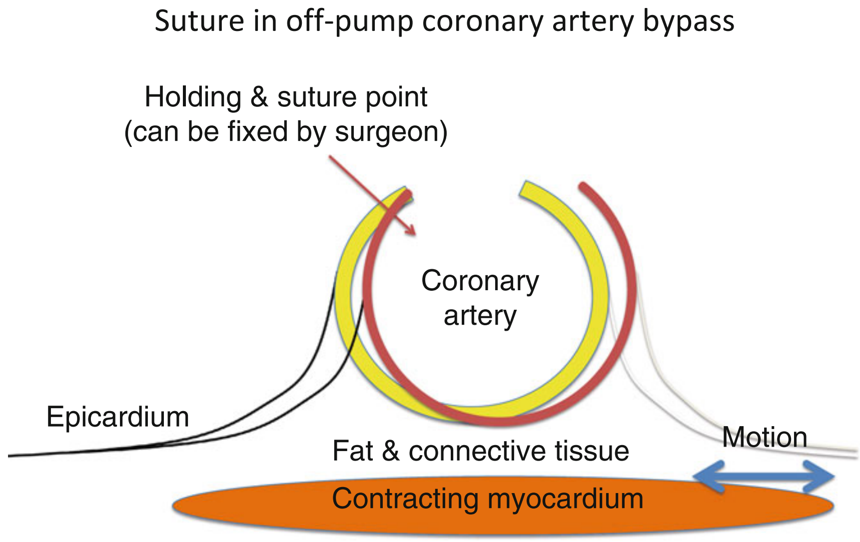


Fig. 10.3 Suture in off-pump coronary artery bypass grafting. The bases of the coronary arteries are fixed to the contracting myocardium. The coronary artery wall can be held immobile, because the wall and surrounding fat are flexible

on the beating heart in the Cartesian coordinate system (*x*-, *y*-, *z*-axis) before and after stabilization.

Most recently, Watanabe and associates developed a 3-dimensional digital motion capture and reconstruction system [7], which is an application of modern robotic technology (Fig. 10.4). The new digital system is able to reconstruct the 3-dimensional motion of any coronary arteries such as distance moved, velocity, acceleration, and deceleration in every region and every axis. By the use of an endoscope with high-speed camera (955 frames per second), accuracy of mean resolution (70 ± 6 μm) and time resolution of 3-dimensional data points (480 xyz position data per second) are improved. The endoscope and the small lightweight markers for tracking can be sterilized and used in any clinical procedure. In the following chapters, several studies using this system are introduced.

10.3 Tissue Stabilizers

10.3.1 Pre-Octopus Era: Tape, Snare, etc

In the previous era before Octopus or other suction-type tissue stabilizer, many efforts to stabilize the coronary anastomosis site were reported [8–12]. These efforts include tape, snare, and stitches around the target coronary artery, which are still useful in addition of the current suction-type tissue stabilizer. Because the effects of tissue stabilization depends on the local factor such as fat deposition around the anastomosis site and the tortuosity of the target coronary artery, few stitches around the coronary anastomosis site with traction, for example, may provide further stabilization. The off-pump surgeon needs to know the history and should apply these inexpensive, simple, and effective techniques when appropriate.

10.3.2 Suction-Type Tissue Stabilizer

In 1996, Borst and colleagues developed Octopus tissue stabilizer, which immobilizes the epicardium using a suction device [2]. Jansen and colleagues used this device for the patients who underwent off-pump coronary artery bypass [13]. With an aid of the Octopus tissue stabilizer, off-pump technique became popular in the late 1990s. Several suction-type tissue stabilizers are now available (Fig. 10.5), becoming the common, simple modality for off-pump coronary artery bypass surgery.

In an animal study, Watanabe and associates [7] found that mechanical stabilization (Octopus) can reduce the distance moved during one cardiac cycle remarkably, while the rapid, sudden movements such as maximal velocity, acceleration, and deceleration are not decreased much (Fig. 10.6). In detail, the distance moved in one cardiac cycle is decreased to 15.9 % of the baseline value (84.1 % reduction below the baseline when the baseline value is assumed as 100 %) in the left anterior descending artery by the Octopus stabilization, while maximum velocity, acceleration, and deceleration is only decreased to 62.5 % (37.5 % reduction), 65.3 % (34.7 % reduction), and 64.1 % (35.9 % reduction), respectively. In other words, "sudden quick motion" remains even under the most recent sophisticated mechanical tissue stabilizer. Several efforts to decrease these sudden quick motions are introduced in the following sections.

10.4 Pharmacological Stabilization: Beta-Blocker

β-adrenergic receptors are mainly located in the heart, blood vessels, and bronchi. β_1-receptor blockers decrease heart rate (negative chronotropic effect) and myocardial

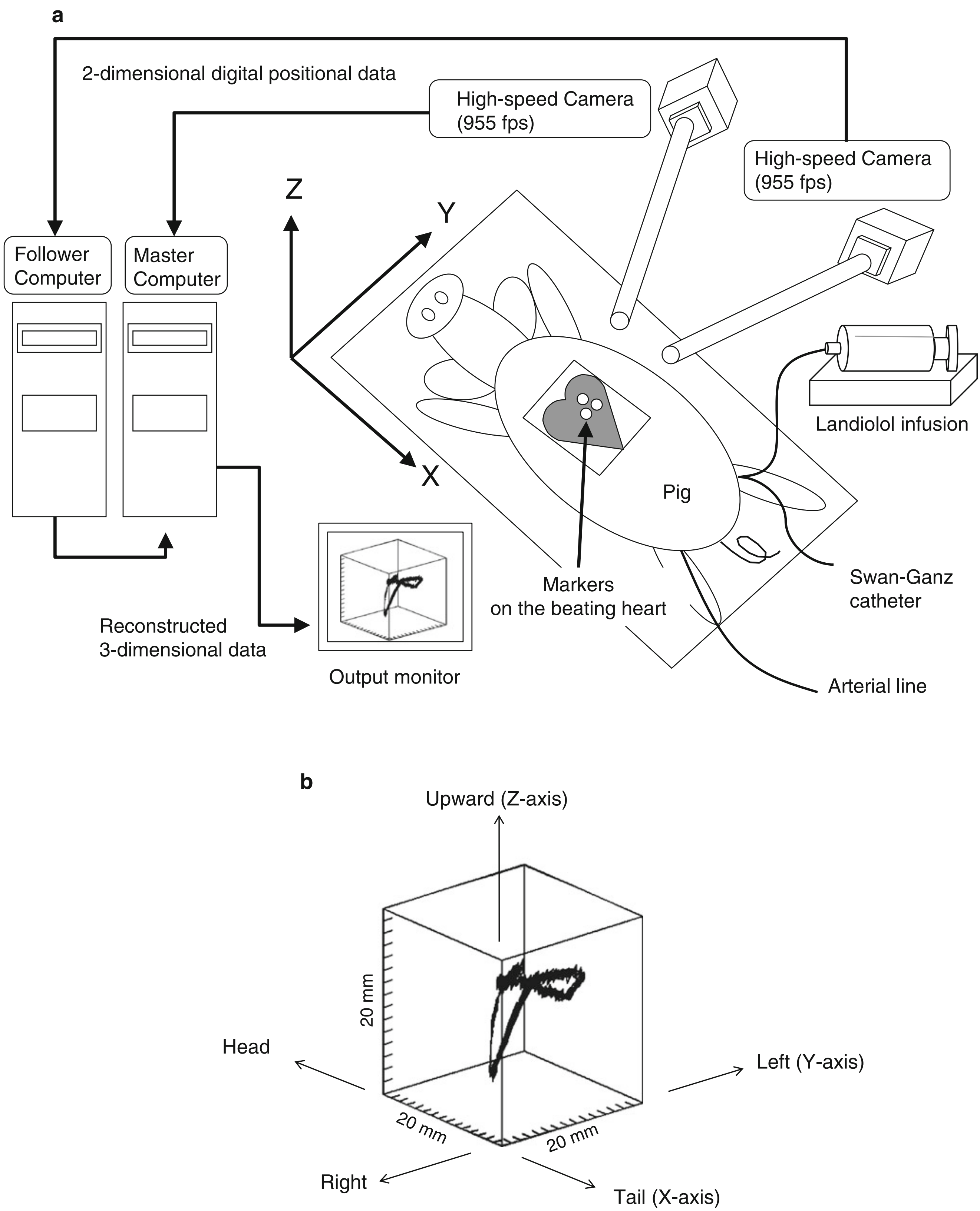


Fig. 10.4 (**a**) Three-dimensional digital motion capture and reconstruction system. Two high-speed cameras lining in a different angle capture the motion of markers on the beating heart. These 2-dimensional position data of the surface of the coronary artery are reconstructed into 3-dimensional data in the master computer. (**b**) An example of 3-dimensional coronary artery motion in one cardiac cycle

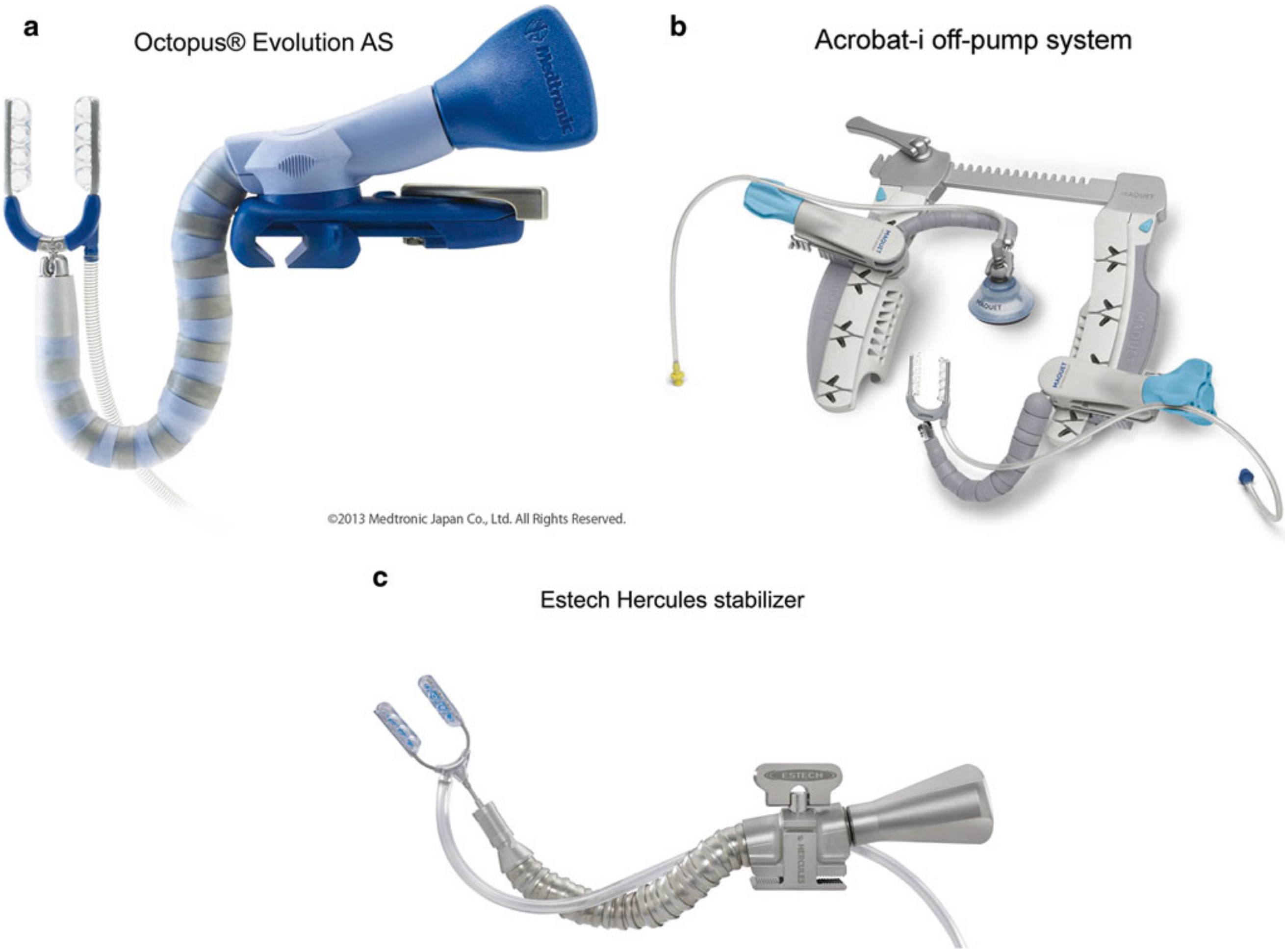


Fig. 10.5 Modern suction-type tissue stabilizers on the market. (**a**) Medtronic Octopus Evolution AS. (**b**) CTS Acrobat-i Off-Pump System. (**c**) Estech Hercules stabilizer

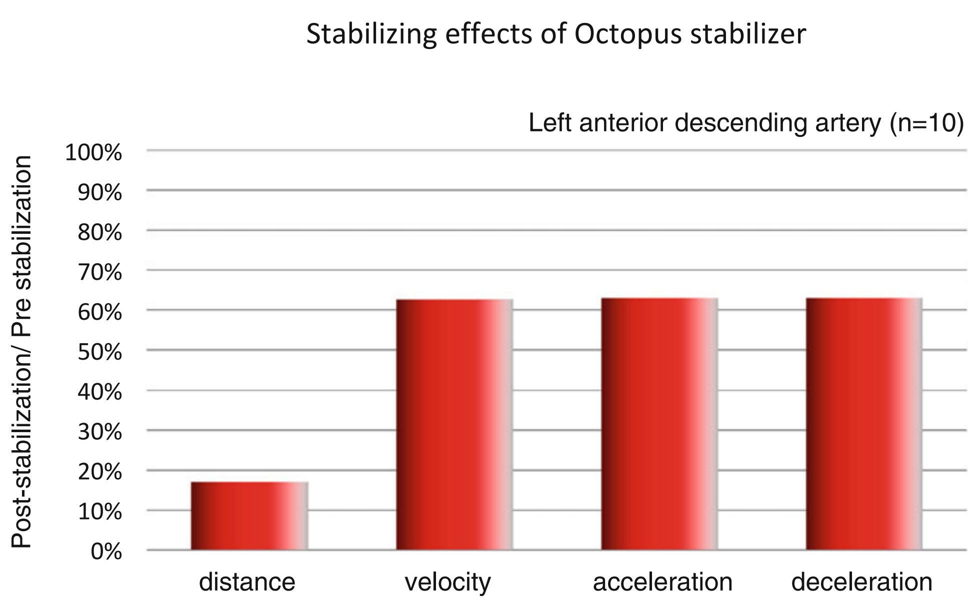
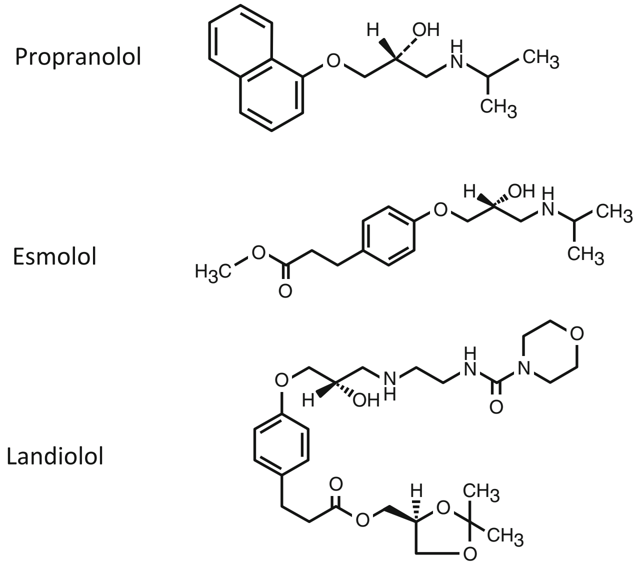


Fig. 10.6 Stabilization effect of Octopus (Modified from Ref. [7])

a



b

Intravenous beta-receptor blocker

	Propranolol	Esmolol	Landiolol
Half life	6 hrs	9 min	4 min
β 1 selectivity	β1 = β2	β1 > β2	β1 >> β2
Effecton Heart rate / Blood pressure	HR↓↓ BP↓	HR↓ BP↓↓	HR↓BP→
For OPCAB surgery	X	△	○

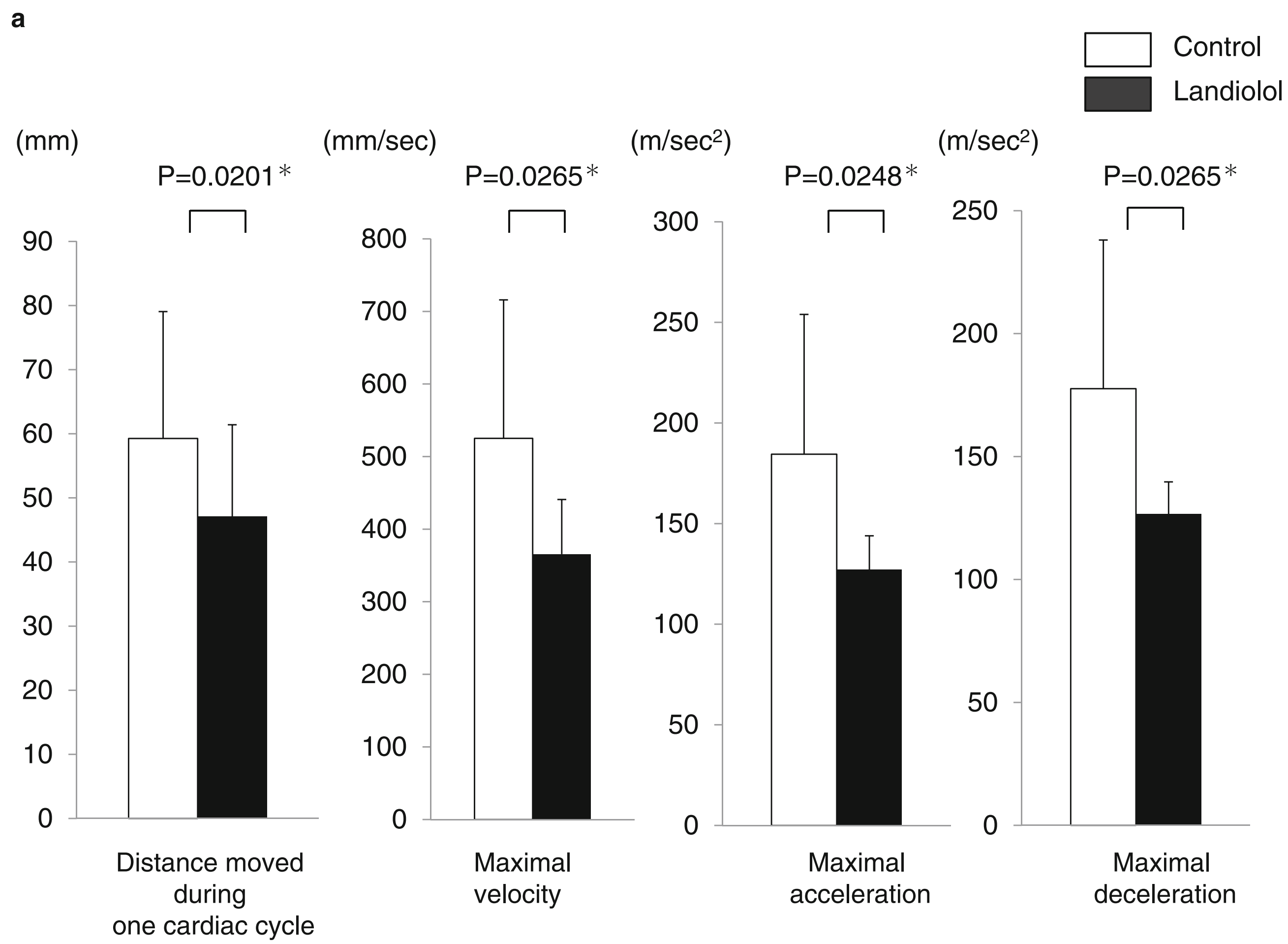
Fig. 10.7 Beta-blockers for intravenous administration. (**a**) Chemical structure. (**b**) Comparison of beta-blockers: propranolol has a long half-life that makes this drug uncontrollable during surgery. While esmolol decreases systemic blood pressure rather than heart rate, landiolol decreases heart rate with sustained systemic blood pressure, which is a characteristic of this drug that makes it suitable for use in off-pump coronary artery bypass (OPCAB)

contraction force (negative inotropic effect), whereas β_2-receptor blockers dilate the smooth muscle of blood vessels in the heart, brain, and other organs and contract the smooth muscle of the trachea. In the clinical settings, β-receptor blockers have been used for the patients with heart disease as antihypertensive, anti-arrhythmic, and antianginal agents. For the patients with ischemic heart disease, β_1-receptor blockers also reduced myocardial damage in acute myocardial ischemia since they reduce myocardial metabolic requirements during ischemia and increase oxygen delivery to the ischemic myocardium during and after ischemia [14–17]. A recent study demonstrated that coronary anastomosis time during off-pump coronary artery bypass was shorter under an infusion of esmolol, a short-acting β_1-blocker, suggesting favorable stabilization during β_1-blocker infusion [17].

Propranolol (Fig. 10.7), a nonselective β_1- and β_2-receptor blocker, was first introduced as an anti-tachycardia and anti-tachyarrhythmia drug during coronary artery bypass surgery. However, propranolol has a long duration of action time (2–14 h) with several side effects such as conduction disturbance, hypotension, and cardiac failure [14, 15]. Propranolol also blocks β_2-receptor with a risk of perioperative asthma attacks. Esmolol (Fig. 10.7), an ultra-short-acting selective β_1-receptor blocker, has been developed recently to avoid these side effects [14, 15]. More recently, landiolol hydrochloride (Fig. 10.7) has been developed by modifying the chemical structure of esmolol, to increase β_1-receptor selectivity and potency without affecting the duration of action. This agent has some unique characteristics. Landiolol hydrochloride has a very rapid onset and offset of action [14–16, 18, 19]. Compared with esmolol, heart rate decreases more rapidly with landiolol [15–18]. Landiolol is rapidly metabolized by serum pseudocholinesterase and liver carboxylesterase to an inactive metabolite in humans within a half-life of 4 min, which is shorter than that of esmolol [14, 16, 18–20]. Renal and hepatic clearance does not contribute to the pharmacokinetics of this agent at clinical concentrations [18–20] which is useful for intraoperative infusion for the patients with renal and/or hepatic dysfunction [20]. Landiolol hydrochloride has higher β_1-selectivity than any other known β-blocker [19]. It also suppresses ventricular and supraventricular arrhythmias in experimental settings [18, 19]. Furthermore, landiolol does not produce the dose-dependent decrease in mean arterial pressure like esmolol [15, 19], which seems to be suitable for off-pump coronary artery bypass surgery.

Landiolol, as a β_1-blocker with negative inotropic effect, decreases the myocardial contractility or, in other words, decreases the developed force and velocity of myocardial contraction [21]. Because coronary artery sits on the contracting myocardium, there is a hypothesis that landiolol has an effect of cardiac motion stabilization during off-pump coronary artery bypass surgery.

Recently, Wakamatsu and associates [22] demonstrated that landiolol infusion achieves better stabilization of the surface coronary artery under the mechanical stabilizer on the beating heart (Fig. 10.8a). Landiolol decreases all motion



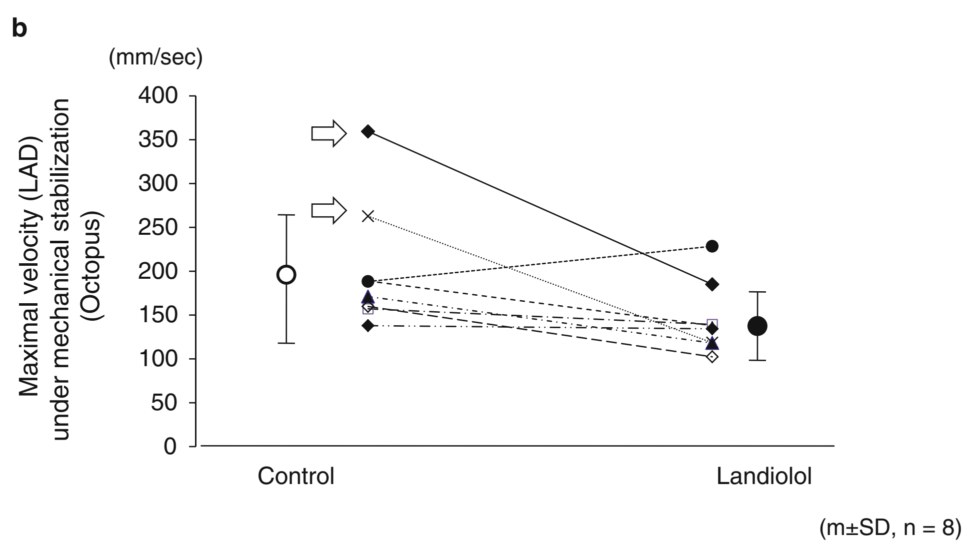


Fig. 10.8 Stabilization by beta-blocker. (**a**) Changes in motion parameters by intravenous infusion of landiolol hydrochloride. (**b**) Changes in maximal velocity by intravenous infusion of landiolol under mechanical stabilization. Note the point of poor stabilization (open arrow) which was stabilized by landiolol infusion

parameters, such as distance moved during one cardiac cycle, velocity, and acceleration/deceleration, at anastomosis site of the left anterior descending artery, left circumflex artery, and distal right coronary artery. These motion parameters were decreased by 20–30 %, in general, below the control level during landiolol infusion in the dose range with 10–15 % reduction in the heart rate and maintained systemic blood pressure.

As pointed out, sudden quick motion of the anastomosis site remains under mechanical stabilization, which obviously increases the surgical difficulty. Mechanical stabilizers also have a considerable deviation of the stabilizing effects depending on the individual variations of the coronary artery anatomy and periarterial fat deposition. For example, each data point under the mechanical stabilization showed considerable variation in maximal velocity (Fig. 10.8b). Landiolol infusion effectively decreased the maximal velocity, especially when this parameter was greater than the mean value or "poor stabilization" (Fig. 10.8b; open arrow). Thus, administration of landiolol hydrochloride can decrease the residual motion that remained after the application of mechanical stabilizer. Because β_1-blockade has a negative inotropic action on the whole heart, landiolol exerts a general stabilization effect on the coronary arteries in any part of the beating heart, in addition to the local immobilization effect by mechanical stabilizer.

In conclusion, landiolol infusion during off-pump coronary artery bypass surgery is recommended to construct precise coronary artery anastomosis on the beating heart. Given a certain dose range of landiolol that decreases the heart rate but not the systemic blood pressure, the motion stabilization effect can be induced during beating heart surgery. Especially, landiolol infusion is recommended when the surgeon encounters unfavorable situations that the conventional mechanical stabilization only achieves a poor local stabilization because of individual anatomy variations in the specific target coronary arteries.

Dose and mode of landiolol administration should be carefully selected, because hypotension caused by cardiac manipulation or dislocation should be avoided during off-pump coronary artery bypass surgery. Yoshida and associates conducted clinical study of landiolol in the intensive care unit and recommended intravenous continuous infusion, not bolus administration, to avoid unexpected severe bradycardia or profound hypotension [23]. Our protocol of intraoperative landiolol infusion is as follows: after intratracheal intubation under general anesthesia, the continuous intravenous infusion of landiolol hydrochloride in very low dose (1 μg/kg/min) is started. During sternotomy and graft harvesting, the dose of landiolol increased gradually as long as systemic blood pressure is maintained as high as the preoperative value. The infusion is continued over night and stopped gradually after the patient starts to take oral beta-blocker. As the result, the dose of landiolol is low (average 3–5 μg/kg/min; range 1–20 μg/kg/min) without serious side effects such as severe hypotension or bradycardia. In addition to the stabilizing effect of the coronary anastomosis site, recent clinical study demonstrates that this protocol prevents postoperative atrial fibrillation [24].

10.5 Other Factors Affecting the Stabilization

10.5.1 Vasopressors

Hemodynamic collapse or systemic hypotension may occur as an adverse event during off-pump coronary artery bypass surgery. Hemodynamic variations can be caused by several factors, including (1) displacement and (2) stabilization of the heart, as well as (3) myocardial ischemia during coronary occlusion [25]. Vertical displacement of the heart to access the lateral and inferior walls decreases the venous return, stroke volume, cardiac index, and mean arterial pressure [26, 27].

Under these circumstances, the hypotension is tentatively treated with intravenous administration of vasopressors such as noradrenaline or phenylephrine by anesthesiologists. Noradrenaline is a potent α_1- and β_1-receptor agonist, with minor effects on β_2-receptors; thus it increases the blood pressure by increasing the cardiac output and systemic vascular resistance [28]. Phenylephrine is a synthetic, selective α_1-adrenergic receptor agonist that increases the blood pressure by increasing the peripheral vascular resistance with either no change or a decrease in the cardiac output [29, 30].

Recently, Kurosawa and associates [31] found that an infusion of noradrenaline significantly increases the target coronary artery motion under mechanical stabilization on a beating heart, whereas phenylephrine does not (Fig. 10.9). The administration of noradrenaline, at the dose required to increase the systolic arterial pressure by 30–50 %, significantly increased all motion parameters at the anastomosis site on the left anterior descending artery. In contrast, the administration of phenylephrine at the dose required to increase the systolic arterial pressure by 30–50 % did not significantly increase the 3-dimensional cardiac motion parameters, except for the distance moved during one cardiac cycle at the anastomosis site on the left anterior descending artery.

In conclusion, the use of a vasopressor with little influence on the coronary artery motion is recommended for the anesthesiologists in the need for maintenance of systemic blood pressure during off-pump coronary artery bypass surgery.

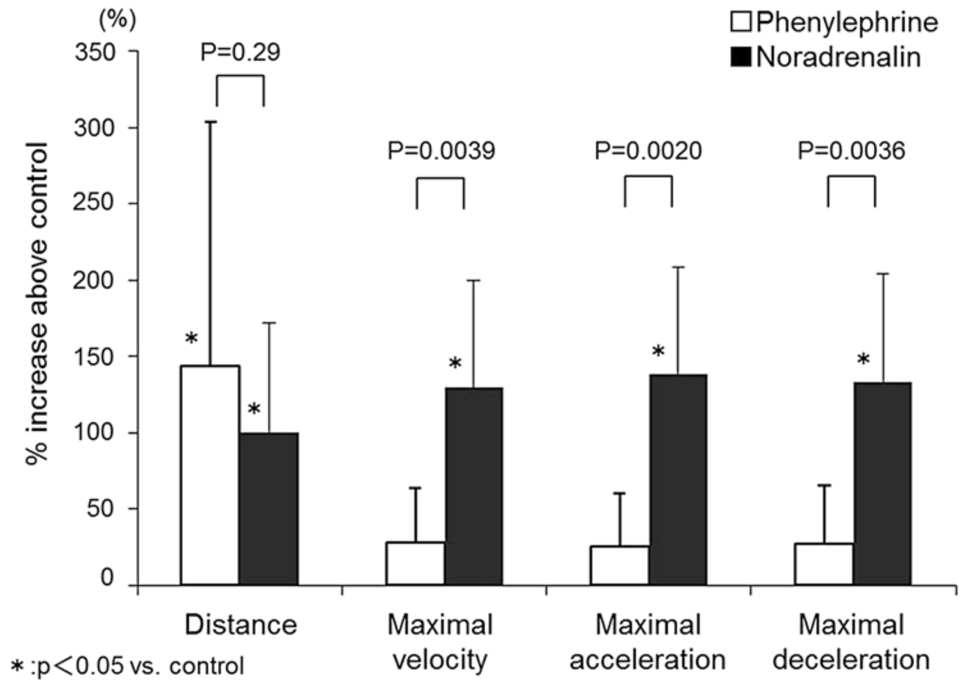


Fig. 10.9 Comparison of noradrenaline and phenylephrine on coronary artery motion

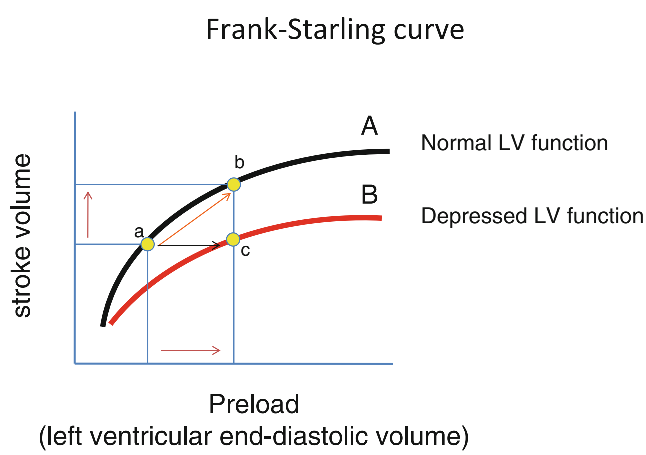


Fig. 10.10 Frank-Starling curve. In the normal functioning heart (*A*), decreased heart rate increases the preload and stroke volume ($a \rightarrow b$). In the heart with depressed contractile function (*B*), decreased heart rate only increases the preload, not the stroke volume ($a \rightarrow c$)

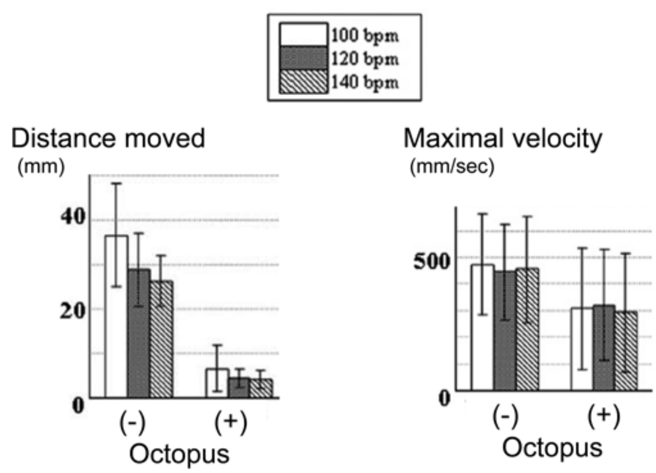


Fig. 10.11 Effect of cardiac pacing on coronary artery motion

10.5.2 Heart Pacing

Heart pacing during off-pump coronary artery is recommended by two reasons: (1) increased cardiac output and (2) decreased coronary artery motion.

Frank-Starling's Law shows that the cardiac preload determines the cardiac output (Fig. 10.10). When the cardiac function is normal (Fig. 10.10; [A]), bradycardia elongates the diastolic phase of the heart, increasing the left ventricular end-diastolic volume (preload) and stroke volume as well, without a decrease in the cardiac output. However, when cardiac function is depressed (Fig. 10.10; [B]), bradycardia only increased the left ventricular end-diastolic volume and pressure, but not the stroke volume, resulting in the failing heart with excessive preload. To avoid these critical conditions of the depressed heart, maintenance of the heart rate by an intraoperative pacing is recommended either by atrial or ventricular lead or Swan-Ganz pacing.

Figure 10.11 shows the stabilizing effect of heart pacing. When the heart rate is increased by pacing, the distance moved during one cardiac cycle is decreased [7]. There is an explanation for this phenomenon. Again by the Frank-Starling's Law, increased heart rate decreases stroke volume by shortening the diastolic phase of the left ventricle. Decreased stroke volume represents a decreased maximal

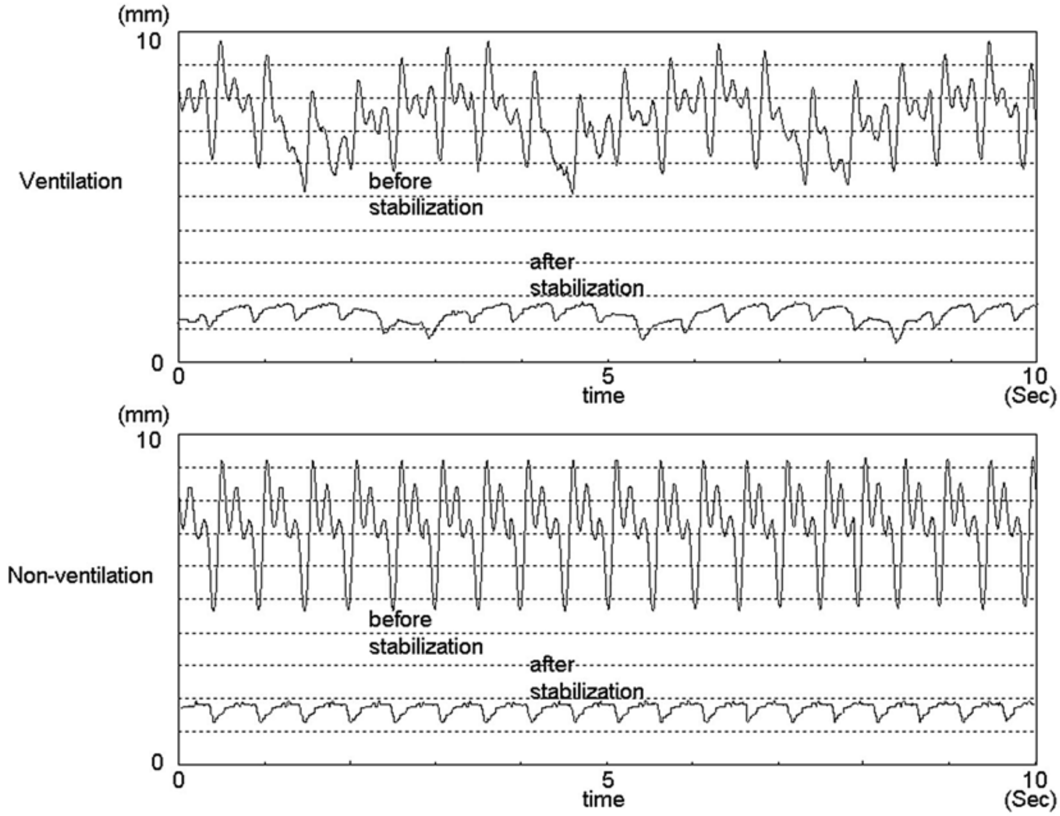


Fig. 10.12 A trace of coronary artery motion on the beating heart with or without mechanical lung ventilation

myocardial contraction, which influences the coronary artery sitting just above the myocardium.

The author recommends pacing the heart to maintain the heart rate above 80 beats /min especially when the surgeon encounters the heart with depressed cardiac function and bradycardia during off-pump surgery.

10.5.3 Mechanical Ventilation

The heart is adjacent to the bilateral lungs. The lung motion or lung ventilation affects the heart position. Cattin [5] demonstrated displacement of the heart by positive-pressure ventilation by high-speed camera. Lemmma [6], by 3-dimensional motion analysis, pointed out that positive-pressure ventilation has an important influence on cardiac surface stabilization. As shown in Fig. 10.12, the coronary artery motion is influenced by mechanical ventilation in low-frequency motion pattern even under the mechanical stabilization [7]. The heart is displaced in a tidal volume-dependent manner [32] (Fig. 10.13).

Here is a tip for mechanical ventilation during coronary artery anastomosis in off-pump coronary artery bypass surgery. A low tidal volume, high-frequency mechanical ventilation is recommended to the anesthesiologist if appropriate. Another tip is a short-time (few seconds) cessation of the mechanical ventilation when the surgeon is just trying a technically demanding stitch on the fine coronary artery wall (Fig. 10.14).

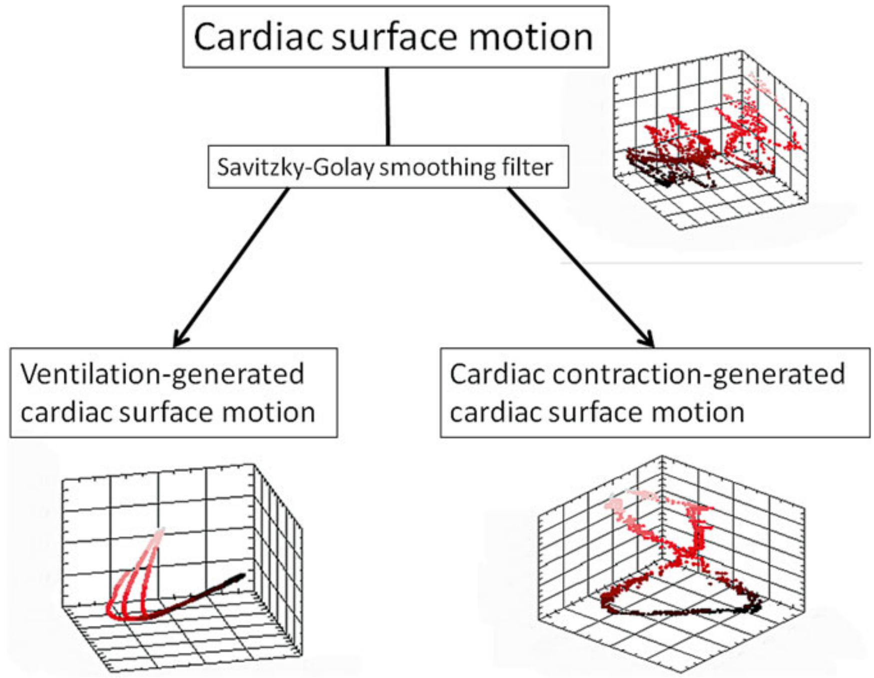


Fig. 10.13 Savitzky-Golay smoothing filter separates the motion of the coronary artery into cardiac contraction-generated motion and ventilation-generated motion

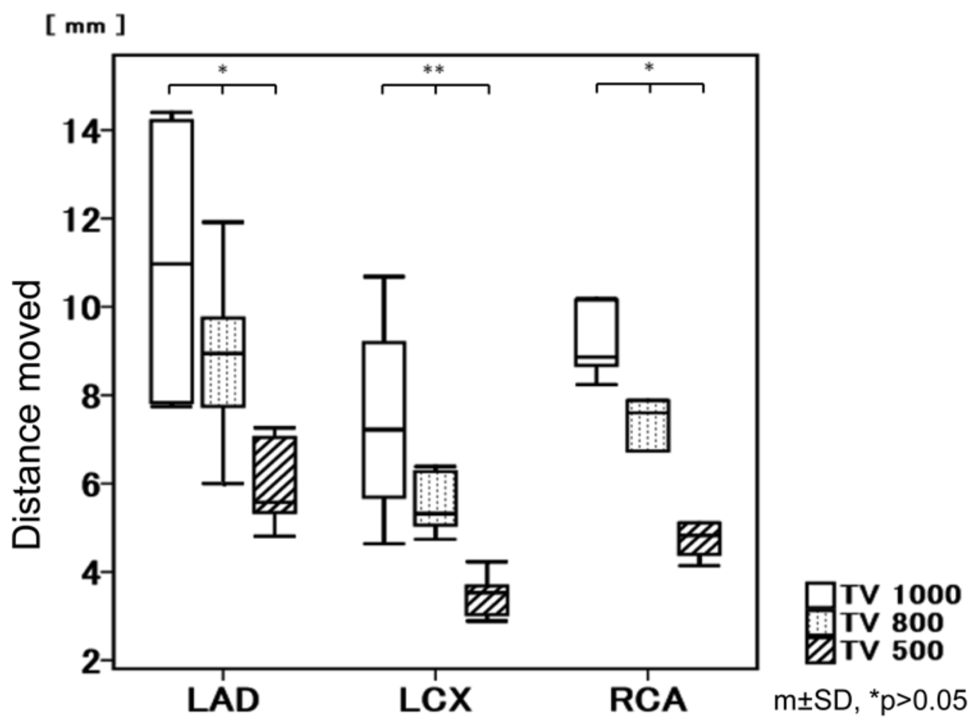


Fig. 10.14 The coronary artery is displaced in a ventilation volume-dependent manner

References

1. Taylor R, Jensen P, Whitcomb L, Barnes A, Kumar R, Stoianovici D, Kavoussi L (1999) A steady-hand robotic system for microsurgical augmentation. Int J Robot Res 18(12):1201–1210
2. Borst C, Jansen EW, Tulleken CA, Grundeman PF, Mansvelt Beck HJ, van Dongen JW, Bredée JJ (1996) Coronary artery bypass grafting without cardiopulmonary bypass and without interruption of native coronary flow using a novel anastomosis site restraining device ("Octopus"). J Am Coll Cardiol 27(6):1356–1364
3. Detter C, Deuse T, Christ F, Boehm DH, Reichenspurner H, Reichart B (2002) Comparison of two stabilizer concepts for off-pump coronary artery bypass grafting. Ann Thorac Surg 74(2):497–501
4. Koransky ML, Tavana ML, Yamaguchi A, Kown MH, Miniati DN, Nowlin W, Robbins RC (2003) Quantification of mechanical stabilization for the performance of off-pump coronary artery surgery. In: The heart surgery forum, vol 6, no. 4. Carden Jennings Publishing Co, Charlottesville, pp 224–231
5. Cattin P, Dave H, Grünenfelder J, Szekely G, Turina M, Zünd G (2004) Trajectory of coronary motion and its significance in robotic motion cancellation. Eur J Cardiothorac Surg 25(5):786–790
6. Lemma M, Mangini A, Redaelli A, Acocella F (2005) Do cardiac stabilizers really stabilize? Experimental quantitative analysis of mechanical stabilization. Interact Cardiovasc Thorac Surg 4(3):222–226
7. Watanabe T, Omata S, Odamura M, Okada M, Nakamura Y, Yokoyama H (2006) Three-dimensional quantification of cardiac surface motion: a newly developed three-dimensional digital motion-capture and reconstruction system for beating heart surgery. J Thorac Cardiovasc Surg 132(5):1162–1171
8. Buffolo EJC, Andrade JCS, Branco JNR, Aguiar LF, Ribeiro EE, Jatene AD (1990) Myocardial revascularization without extracorporeal circulation. Eur J Cardiothorac Surg 4(9):504–508
9. Benetti FJ, Naselli G, Wood M, Geffner L (1991) Direct myocardial revascularization without extracorporeal circulation. Experience in 700 patients. CHEST J 100(2):312–316
10. Pfister AJ, Zaki MS, Garcia JM, Mispireta LA, Corso PJ, Qazi AG, Gurny P (1992) Coronary artery bypass without cardiopulmonary bypass. Ann Thorac Surg 54(6):1085–1092
11. Fanning WJ, Kakos GS, Williams TE (1993) Reoperative coronary artery bypass grafting without cardiopulmonary bypass. Ann Thorac Surg 55(2):486–489
12. Mohr R, Moshkovitz Y, Agranat O (1993) Coronary artery bypass without cardiopulmonary bypass: low-risk surgery for high-risk patients [abstract]. Circulation 88:I-637
13. Jansen EW, Grundeman PF, Borst C, Eefting F, Diephuis J, Nierich A, Cotrufo M (1997) Less invasive off-pump CABG using a suction device for immobilization: the 'Octopus' method. Eur J Cardiothorac Surg 12(3):406–412
14. Ahmet I, Fukushima N, Sawa Y, Masai T, Kadoba K, Kagisaki K et al (1999) The effect of a new ultra-short-acting beta-adrenergic blocker, ONO-1101, on cardiac function during and after cardiopulmonary bypass. Surg Today 29:248–254
15. Sasao J, Tarver SD, Kindscher JD, Taneyama C, Benson KT, Goto H (2001) In rabbits, landiolol, a new ultra-short-acting β-blocker, exerts a more patent negative chronotropic effect and less effect on blood pressure than esmolol. Can J Anesth 48:985–989
16. Bessho R, Chambers DJ (2001) Myocardial protection: the efficacy of an ultra-short-acting β-blocker, esmolol, as a cardioplegic agent. J Thorac Cardiovasc Surg 122(5):993–1003
17. Otaki M, Ogawa T, Inoue T, Oku H (2002) Off-pump coronary bypass grafting to double vessel disease with the pharmacological assist of esmolol: an experimental study. J Cardiovasc Surg 43(3):307–311
18. Atarashi H, Kuruma A, Yashima MA, Saitoh H, Ino T, Endoh Y, Hayakawa H (2000) Pharmacokinetics of landiolol hydrochloride, a new ultra-short-acting β-blocker, in patients with cardiac arrhythmias. Clin Pharm Therap 68(2):143–150
19. Sugiyama A, Takahara A, Hashimoto K (1999) Electrophysiologic, Cardiohemodynamic and [beta]-blocking actions of a new ultra-short-acting [beta]-blocker, ONO-1101, assessed by the in vivo canine model in comparison with esmolol. J Cardiovasc Pharmacol 34(1):70–77
20. Takahata T, Yasui-Furukori N, Sakamoto J, Suto K, Suto T, Tateishi T, Munakata A (2005) Influence of hepatic impairment on the pharmacokinetics and pharmacodynamics of landiolol hydrochloride, an ultra-short-acting β1-blocker. Drugs R & D 6(6):385–394
21. Levy MN, Pappano AJ, Berne RM (2007) Cardiovascular physiology. Mosby Elsevier, Philadelphia
22. Wakamatsu H, Watanabe T, Sato Y, Takase S, Omata S, Yokoyama H (2010) Selective beta-1 receptor blockade further reduces the mechanically stabilized target coronary artery motion during beating heart surgery. Innov Technol Tech Cardiothorac Vasc Surg 5(5):349–354
23. Yoshida Y, Terajima K, Sato C, Akada S, Miyagi Y, Hongo T, … Sakamoto A (2008) Clinical role and efficacy of landiolol in the intensive care unit. J Anesth 22(1):64–69
24. Wakamatsu H, Yokoyama H (2011) Intraoperative infusion of landiolol hydrochloride, an ultra-short acting beta-1 adrenergic receptor blocker, prevents postoperative atrial fibrillation after off-pump coronary artery bypass surgery. CHEST J 140(4_MeetingAbstracts):508A–508A
25. Shroyer AL, Grover FL, Hattler B, Collins JF, McDonald GO, Kozora E, … Novitzky D (2009) Veterans affairs Randomized On/Off Bypass (ROOBY) Study Group. On-pump versus off-pump coronary-artery bypass surgery. N Engl J Med 361(19):1827–1837
26. Couture P, Denault A, Limoges P, Sheridan P, Babin D, Cartier R (2002) Mechanisms of hemodynamic changes during off-pump coronary artery bypass surgery. Can J Anesth 49(8):835–849
27. Mishra M, Malhotra R, Mishra A, Meharwal ZS, Trehan N (2002) Hemodynamic changes during displacement of the beating heart using epicardial stabilization for off-pump coronary artery bypass graft surgery. J Cardiothorac Vasc Anesth 16(6):685–690
28. Schwarz B, Hofstötter H, Salak N, Pajk W, Knotzer H, Mayr A, … Hasibeder W (2001) Effects of norepinephrine and phenylephrine on intestinal ovygen supply and mucosal tissue oxygen tension. Intens Care Med 27(3):593–601
29. Klaus S, James R (1981) Alpha1- and alpha2-adrenoceptors: pharmacology and clinical implications. J Cardiovasc Pharmacol 3(Suppl 1):S14–S23
30. Dunaway S, Yu Q, Larson DF (2007) Effect of acute alpha adrenergic stimulation on cardiac function. Perfusion 22(4):289–292
31. Kurosawa H, Seto Y, Wakamatsu H, Sato Y, Takase S, Omata S, Yokoyama H (2014) Effects of phenylephrine and noradrenaline on coronary artery motion in an open-chest porcine beating heart model. Surg Today 44:1128–1137
32. Sato Y, Yokoyama H Intraoperative mechanical ventilation affects cardiac surface motion during beating heart surgery (in submission)

11 Securing the Distal Anastomosis Site: Coronary Artery Occlusion, Shunt, and Blower

Tomohiro Mizuno and Hirokuni Arai

Abstract

Obtaining an optimal anastomotic site is essential for successful OPCAB. Coronary artery occlusion is a simple and easy anastomotic technique. Regional myocardial ischemia rarely occurs during anastomosis. Intraluminal coronary shunts are safe, easy to handle, and useful for obtaining an optimal operative field and perfusing coronary artery as well. Extraluminal shunts are also useful for coronary perfusion. All three techniques have their own advantages and disadvantages. In the simple occlusion technique, occlusion of a large left anterior descending artery (LAD) with a small posterior descending artery and a LAD with mild stenosis can cause significant ischemic changes. Occlusion of right coronary artery (#2 to #3) sometimes causes life-threatening arrhythmia. In these cases, coronary perfusion is necessary. Although an intraluminal shunt can be used in most cases, insertion into a meandering coronary artery is difficult or even dangerous. The coronary artery might be injured or coronary perfusion may not be secured. An extraluminal shunt can secure adequate blood flow, although the tube might disturb the anastomosis. An extraluminal shunt can be used only for LAD and RCA. Carbon dioxide blower with saline mist is essential for obtaining bloodless operative field for off-pump coronary artery bypass grafting. These techniques should be selected properly for each case and coronary artery.

Keywords

Off-pump coronary artery bypass grafting • Intraluminal shunt • Extraluminal shunt • Coronary occlusion • CO_2 blower

11.1 Coronary Artery Occlusion

Obtaining a stable and bloodless target coronary artery is critical for successful distal anastomosis in off-pump coronary artery bypass grafting (OPCAB). This includes maintaining the systemic circulation during anastomosis and avoiding myocardial ischemic injury and intimal injury of the target coronary artery.

Simple occlusion of the target coronary artery during distal anastomosis is a common surgical technique. Simple occlusion is theoretically harmful to the myocardium; however, this technique can be easily used even in the visually poor operative fields such as posterolateral lesions. We most frequently use simple coronary occlusion, which allows better visualization of the coronary arteriotomy site than coronary shunt technique. The suture needle can be easily passed through the coronary artery without any obstacle, with the shortest distal anastomosis duration.

In our clinical experience, almost all coronary arteries can be anastomosed using the simple occlusion technique. Before the left anterior descending artery (LAD) is incised, it is clamped for a short time (approximately 3–5 min), and the electrocardiographic (ECG) characteristics, blood pressure, pulmonary artery pressure, and the regional myocardial wall motion are estimated. If the short-time LAD clamp test does

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not induce any hemodynamic changes, the LAD is reclamped after a short-time declamping time and anastomosis is initiated. If the clamp test induces the ECG changes or hemodynamic instability, an extraluminal shunt tube is utilized to avoid the regional ischemia during anastomosis. A large LAD with a small posterior descending artery (PDA) and a LAD with mild stenosis seem to be risk factors in our experience. A simple clamp to a right coronary artery (RCA) (#2 to #3) can cause life-threatening arrhythmia. Van Aarnhem EE et al. reported that critical ischemia had been observed only in the RCA and in nonocclusive disease in 365 distal anastomoses of their 200 cases [1]. We always anastomose to the PDA, not the main trunk of the RCA (#2 to #3) if there is no special reason. When we need to include the main RCA, we always use an extraluminal coronary shunt catheter to avoid ischemia and arrhythmia. We do not use any coronary perfusion technique for other coronary arteries except for the LAD and main RCA.

Temporary coronary occlusion in OPCAB is an easy method to obtain an optimal operative field. However, coronary occlusion can cause the clamp lesion injury. To obtain hemostasis at the anastomotic site, various techniques have been introduced including direct coronary clamping with a bulldog clamp, snaring with elastic silicone air cushion sutures, and using an intraluminal shunt tube. Demaria RG et al. reported multifocal stenosis after coronary snaring in OPCAB [2]. We also encountered the same problem in our experience. Hangler HB and colleagues reported that local occlusion of human coronary arteries may cause focal endothelial denudation, local microthrombosis, atherosclerotic plaque, and injury to target vessel side branches [3]. However, Perrault LP et al. showed that snaring the coronary artery for achieving hemostasis did not cause endothelial dysfunction in a porcine study [4]. It was also reported that hemostatic devices (snaring, direct clamps, and intraluminal shunts) did not cause any greater endothelial dysfunction [5]. After all, the main goal of occluding a target coronary artery is to achieve hemostasis with as low a force as possible to not injure the coronary endothelium. Our group developed a coronary occlusion tourniquet with a spring to control the occlusive force (Coronary occluder®, Sumitomo Bakelite, Japan) (Fig. 11.1) [6]. The maximum snaring force is 100 g, which is the same as that of a bulldog clamp. The target coronary artery is encircled proximally and distally with a 4-0 polypropylene suture buttressed with a small felt pledget as a cushion, and the polypropylene suture is passed through the occlusion device. After incising the coronary artery, we slowly snare it with the occlusion device and stop snaring just at the time when hemostasis is obtained. In most cases, hemostasis can be obtained before the maximum snaring force is achieved. This device prevents excessive coronary endothelial injury.

11.2 Coronary Artery Shunt

Temporary coronary occlusion in OPCAB is an easy way to obtain an optimal operative field without any disturbing device. Intraoperative hemodynamic deterioration and/or perioperative myocardial infarction are not encountered in almost all cases in clinical practice. However, transient myocardial ischemia can always affect the hemodynamic condition and cardiac contractile function. Yeatman M and colleagues showed that intraoperative hemodynamic deterioration was transient and recovered soon after the heart was repositioned to its anatomical position when the coronary artery was perfused with a shunt tube, whereas early cardiac functional recovery was impaired by the simple snaring technique [7]. Other group reported that the use of temporary intraluminal shunts resulted in reduced acute ischemia, maintained left ventricular (LV) function, and improved early graft patency compared with the simple coronary occlusion technique in minimally invasive direct coronary artery bypass (MIDCAB) [8].

There are two types of coronary perfusion systems: an intraluminal shunt and an extraluminal shunt. The intraluminal shunt is manufactured by several companies, and each shunt has its own structural features. It contains a shunt tube and a suture that holds the tube. The proximal and distal ends of the shunt tube are expanded slightly to fit the internal lumen of the coronary artery. After the target coronary artery is opened, an intraluminal shunt tube is inserted proximally and distally into the coronary artery. The intraluminal shunt can achieve both hemostasis and coronary perfusion. When the tube is inserted into the proximal side, the bloodstream from the tube should be checked out. The intraluminal shunt can be used in almost all coronary arteries.

Intraluminal shunts are safe, easy to handle, and quite useful (Fig. 11.2). However, if its manipulation is poor, the device can cause some serious problems. When an appropriate intraluminal shunt is used, the intraluminal shunt causes only minor damage of the coronary artery [9]. However, a larger shunt tube can injure the coronary endothelium, causing postoperative coronary stenosis [10], and the tube can tear and even penetrate the target artery. A smaller intraluminal shunt cannot achieve hemostasis. When the shunt is inserted into a meandering coronary artery, the tube can injure the coronary artery, and the shunt might not perfuse the coronary artery because the proximal and/or distal tip of the shunt tube might be closed by the meandering arterial wall. If the coronary artery is opened near a stenotic lesion, an intraluminal shunt cannot be inserted because it cannot pass through the stenotic lesion.

When we use an intraluminal shunt, we always encircle a target coronary artery just proximal and distal to the anastomotic site with a silicone elastic air cushion suture. The

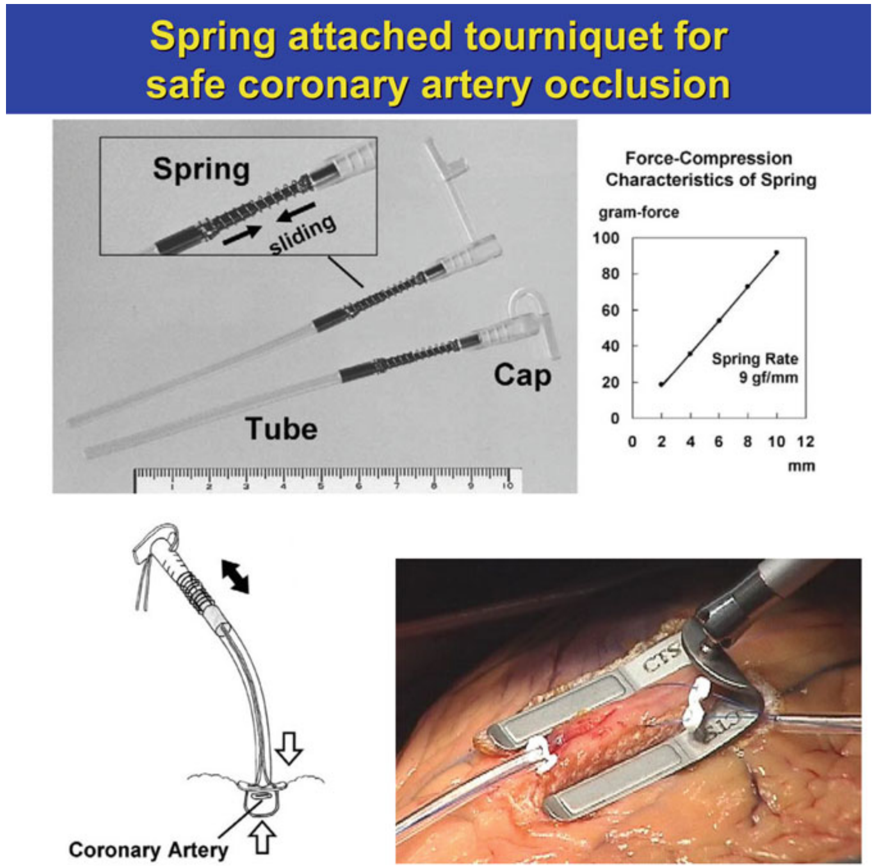

Fig. 11.1 Coronary occluder® (Sumitomo Bakelite Co., Ltd.)

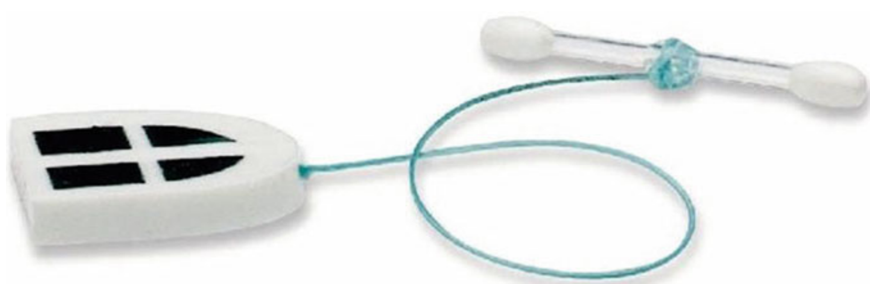

Fig. 11.2 A representative of intraluminal shunt: Anastaflow® (Edwards Lifescience

coronary artery should be incised approximately 5 mm in length as it is easier to insert the tube through the larger incision. When the target coronary artery is incised, the proximal elastic suture is slightly pulled upward to obtain temporary hemostasis, and the shunt tube is inserted in an optimal operative field. Then, the distal part is inserted into the distal coronary artery while the shunt tube is clamped with forceps to stop the bleeding. If hemostasis cannot be obtained, the proximal elastic suture is tightened with hemostat clips one by one toward the coronary artery, and the target artery containing the shunt tube is snared gently to stop bleeding. Just before the anastomotic suture is tied, the graft is de-aired, and the shunt is removed. We always select the appropriately sized or a smaller-sized tube as lesser coronary damage occurs with a smaller shunt than with a larger shunt, and a bigger shunt can tear the graft when it is removed.

External shunts are also safe and easy to use. After the proximal side of the target coronary artery is occluded, an external shunt tube is inserted toward the distal site of the coronary artery. The risk of injuring the coronary endothelium is the same as that for an intraluminal shunt, but external shunt has several features that are better than those of intraluminal shunt. The first advantage is that the inflow bloodstream is stronger than that of an intraluminal shunt. External shunt tubes have not been widely commercialized; thus, our group developed an original external shunt tube (Coronary perfusion catheter®, Sumitomo Bakelite, Japan) (Fig. 11.3) [11]. The blood inflow of an external shunt is

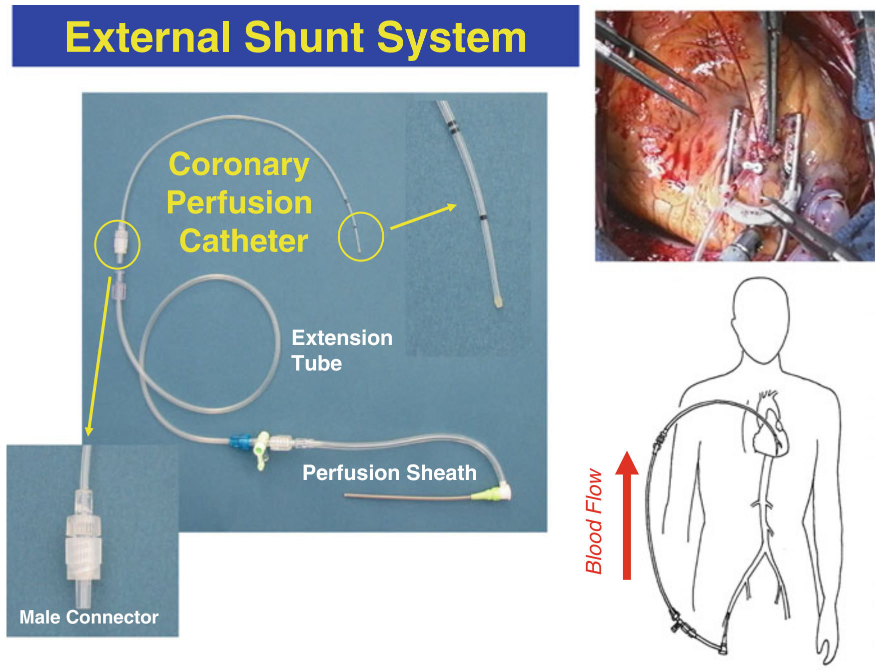

Fig. 11.3 An external shunt: coronary perfusion catheter® (Sumitomo Bakelite Co., Ltd.)

usually obtained from a healthy femoral artery. We sometimes connect the tube to a saphenous vein graft already anastomosed to the ascending aorta and obtain good blood flow [12]. In the intraluminal shunt technique, the blood inflow originates from the diseased coronary artery, which might result in decreased blood flow. In our clinical experience, ischemic problems can be prevented by using an intraluminal shunt under stable circulatory conditions, but ischemia can occur even with an intraluminal shunt if the stenotic lesion is severe. From this viewpoint, the blood flow from the external shunt is always strong and sufficiently reliable to perfuse the target coronary artery. To obtain more reliable coronary perfusion, a coronary active perfusion system was created. The system injects arterial blood into the coronary artery during the diastolic phase of the cardiac cycle [13, 14].

Another advantage is that an external shunt can start perfusion even in the middle of the anastomosis. Even if ischemia causes the hemodynamic deterioration after anastomosis is initiated with the coronary occlusion technique, an external shunt tube is easily inserted into the distal coronary artery with little bleeding, and the ischemic condition can be reversed. Furthermore, an external shunt can be used in a long coronary incision.

Although external shunt can be easily applied to LAD and RCA (#2 to #3), its application to postero-descending artery and posterolateral branch is tricky due to limited surgical field. On the other hand, coronary perfusion is only necessary in case of a large LAD with a small PDA, a LAD with mild stenosis, and RCA (#2 to #3); thus, coronary perfusion to the LAD and RCA is likely sufficient to perform OPCAB.

11.3 Blowers

A certain volume of blood comes from a target coronary artery and its surrounding tissues even if the target coronary artery is appropriately occluded. To obtain an optimal operative field, carbon dioxide (CO_2) blower plays a critical role during anastomosis. The solubility of CO_2 in the blood is known to be about 30 times higher than that of air; thus, it is reasonable to use CO_2 to remove the blood from a bloody operative field. CO_2 is less likely to cause coronary air emboli and brain microemboli than compression air. CO_2 jets can remove the blood, open the incised coronary and graft walls, and provide an effective optimal field for easy anastomosis. However, surgeons should be aware that excessive use of a CO_2 blower might cause some serious problems. High-flow CO_2 jets may injure the endothelium of the coronary artery and occasionally dissect the coronary artery and arterial graft. Excessive use of CO_2 blowers during proximal anastomosis might cause brain emboli to develop [15]. To avoid dry conditions, normal saline mist has to be added to CO_2 jet. Taken together, CO_2 blowers should be applied only for the time needed to properly pass the suture needle through the wall of the coronary artery, graft, and aorta. Appropriate use of CO_2 blowers is essential.

References

1. Van Aamhem EE, Nierich AP, Jansen EW (1999) When and how to shunt the coronary circulation in off-pump coronary artery bypass grafting. Eur J Cardiothorac Surg 16[Suppl II]:S2–S6

2. Demaria RG, Fortier S, Carrier M, Perrault LP (2001) Early multifocal stenosis after 2 coronary artery snaring during off-pump coronary artery bypass in a patient with diabetes. J Thorac Cardiovasc Surg 122:1044–1045
3. Hangler HB, Pfaller K, Antretter H, Dapunt OE, Bonatti JO (2001) Coronary endothelial injury after local occlusion on the human beating heart. Ann Thorac Surg 71:122–127
4. Perrault LP, Menasché P, Bidouard JP, Jacquemin C, Villeneuve N, Vilaine JP, Vanhoutte PM (1997) Snaring of the target vessel in less invasive bypass operations does not cause endothelial dysfunction. Ann Thorac Surg 63:751–755
5. Perrault LP, Desjardins N, Nickner C, Geoffroy P, Tanguay J, Carrier M (2000) Effects of occlusion devices for minimally invasive coronary artery bypass surgery on coronary endothelial function of atherosclerotic arteries. Heart Surg Forum 3:287–292
6. Arai H, Oi K, Tanaka H, Tabuchi N, Sunamori M (2005) Safe coronary artery occlusion with a new tourniquet in off-pump bypass grafting. Ann Thorac Surg 80:1137–1139
7. Yeatman M, Caputo M, Narayan P, Ghosh AK, Ascione R, Ryder I, Angelini GD (2002) Intracoronary shunts reduce transient intraoperative myocardial dysfunction during off-pump coronary operations. Ann Thorac Surg 73:1411–1417
8. Menon AK, Albes JM, Oberhoff M, Karsch KR, Ziemer G (2002) Occlusion versus shunting during MIDCAB: effects on left ventricular function and quality of anastomosis. Ann Thorac Surg 73:1418–1423
9. Wippermann J, Albes JM, Brandes H, Kosmehl H, Bruhin R, Wahlers T (2003) Acute effects of tourniquet occlusion and intraluminal shunts in beating heart surgery. Eur J Cardiothorac Surg 24:757–761
10. Gerosa G, Bottio T, Valente M, Thiene G, Casarotto D (2003) Intracoronary artery shunt: an assessment of possible coronary artery wall damage. J Thorac Cardiovasc Surg 125:1160–1162
11. Arai H, Yoshida T, Izumi H, Sunamori M (2000) External shunt for off-pump coronary artery bypass grafting: distal coronary perfusion catheter. Ann Thorac Surg 70:681–682
12. Arai H, Kozakai A, Manabe S, Kawaguchi S, Shimizu M, Egi K, Tabuchi N, Tanaka H, Sunamori M (2004) Perfusion flow assessment of coronary shunt during off-pump coronary artery bypass grafting. Heart Surg Forum 7:E136–E140
13. Koizumi K, Shin H, Matayoshi T, Yozu R (2008) Comparison of active and passive coronary perfusion in off-pump coronary artery bypass grafting. Interact Cardiovasc Thorac Surg 7:977–980
14. Doi T, Kamiya H, Watanabe G, Misaki T (2008) A coronary perfusion system for off-pump coronary artery bypass grafting in an experimental porcine model: relationship between flow rate and myocardial function. Artif Organ 32:525–530
15. Nollert G, Oberhoffer M, Reichart B, Vicol C (2003) Combination of the HEARTSTRING proximal seal system with a blower mister: a possible source of gas emboli. J Thorac Cardiovasc Surg 126:1192–1194

12 Graft Planning

Tomoaki Suzuki and Tohru Asai

Abstract

With the development of the OPCAB technique, the current trend in CABG is toward in situ arterial reconstruction because of the benefit of the aorta no-touch technique and the better long-term clinical outcomes (Endo M, Nishida H, Tomizawa Y, Kasanuki H, Circulation 104:2164–2170, 2001). An arterial graft produces better late graft patency and better long-term patient outcomes than vein graft. Now we have three reliable in situ arteries (both internal thoracic arteries (ITA) and right gastroepiploic artery (GEA)) and one free graft (radial artery). As we all know, the use of the ITA is associated with low rates of mortality and reintervention. Furthermore, some recent reports demonstrate that bilateral internal thoracic artery grafting to the left anterior descending and circumflex coronary arteries offers the best long-term survival and lowest rates of reintervention (Rizzoli G, Schiavon L, Bellini P, Eur J Cardiathorac Surg 22:781–786, 2002; Taggart DP, D'Amico R, Altman DG, Lancet 358:870–875, 2001; Lytle BW, Blackstone EH, Loop FD et al., J Thorac Cardiovasc Surg 117:855–872. 1999). In the decade since Buxton and coworkers (Buxton BF, Komeda M, Fuller JA, Gordon I, Circulation 98:II-1–II-6, 1998) and Lytle and coworkers (Lytle BW, Blackstone EH, Loop FD et al., J Thorac Cardiovasc Surg 117:855–872. 1999) revealed the long-term efficacy of bilateral ITA grafting, it has been gaining acceptance among surgeons, and there is no doubt that it affords the best long-term outcome. CABG with grafting of the bilateral ITAs to the left coronary system and additionally the GEA to the distal RCA has been reported to provide good long-term outcome (Chavanon O, Durand M, Hacini R et al., Ann Thorac Surg 73:499–504, 2002; Tavilla G, Kappetein AP, Braum J, Gopie J, Tjien ATJ, Dion RAE, Ann Thorac Surg 77:794–799, 2004; Suzuki T, Asai T, Matsubayashi K et al., Ann Thorac Surg 91:1159–1164, 2011).

For high-quality OPCAB, the skeletonization technique is now essential that makes the arterial graft into optimum condition. Skeletonization has many advantages, such as avoidance of early spasm, easy identification of potential bleeding, quality of the vessel, functionally lengthened and larger graft with maximum flow, ease in performing sequential anastomosis, and preservation of sternal blood flow and venous drainage.

In this chapter, I discuss the optimal grafting model using multiple arterial conduits.

Keywords

Aorta no-touch • Composite graft • In situ graft

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12.1 Arterial Graft Planning Using ITA, GEA, and RA

12.1.1 Internal Thoracic Artery

The ITA is the most reliable conduit. Its patency is better than 90 % at 15 years, and its use has been proven to prolong patient survival. The ITA is an elastic artery with a thin intima and a well-formed internal elastic membrane. The media is formed by a combination of elastic lamellae and smooth muscle cells. Vasa vasorum are seen in the adventitia but there are few in the media. The ITAs produced endothelium-derived relaxing factor and prostacyclin which contribute to the high patency and excellent function as grafts. The incidence of atherosclerosis in ITAs is lower than the SVG after used for CABG. The ITA is a very delicate vessel that can be injured easily. Skeletonization has gained acceptance among surgeons for harvesting the ITA because of the advantage of preservation sternal blood flow, creating increased effective length and the free flow of the ITAs in anastomoses. Higami [9] and associates firstly described ultrasonic ITA skeletonization and revealed its technical feasibility and advantage. They showed that the skeletonized ITA averaged 4 cm longer than the pedicled conduit, and the free flow rate is greater than 100 mL/min, which is at least 20 % higher than of the pedicled ITA. In my experience, the ultrasonic scalpel improves technical ease, shortens the harvesting time, and increases the effective length and free flow of the ITAs. Now standard surgeons should master the ultrasonic skeletonization technique for the effective use of ITAs in OPCAB surgery.

12.1.2 How to Use Both ITAs

Some recent reports demonstrate that bilateral internal thoracic artery grafting to the left anterior descending and circumflex coronary arteries offers the best long-term survival and lowest rates of reintervention. The clinical evidence level of long-term effect of using bilateral ITAs has elevated recently. If the patient requires reconstruction of both the LAD and CX area, the left and right ITAs should be used routinely in combination together.

It is unknown what grafting model of both ITAs is the most effective. Cardiovascular surgeons should discuss the best grafting model of both ITAs. Two common combinations of the ITA placement include (1) the right ITA (RITA) to the LAD across the midline with the LITA to the CX and (2) the RITA to the CX through the transverse sinus with the LITA to the LAD. Several reports showed that the early clinical results, graft patency rate, and technical difficulty were similar in both combinations. The LAD reconstruction is most important in CABG that should be anastomosed individually by one ITA. We prefer the RITA to the LAD and the LITA to the CX combination because we often experience a case that requires the CX-CX sequential grafting (Fig. 12.1). It is not difficult to perform CX-CX sequential grafting using skeletonized left ITA. As they say, the RITA is too short to graft to the LAD; however, it occurs mainly in pedicled RITA. The skeletonized RITA with ultrasonic scalpel is long enough to reach to the distal LAD (Fig. 12.2). We have experienced in only 2 % of cases that the skeletonized RITA is too short to achieve the LAD.

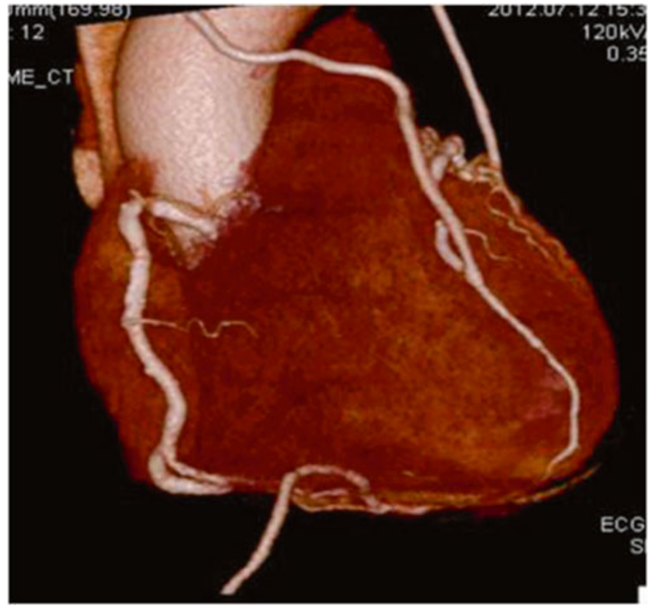

Fig. 12.1 Three in situ arterial grafts: left IMA, right IMA, and right GEA

Some study showed good results of composite Y- or T-graft of the free RITA connected to the in situ LITA. A composite graft can increase the number of anastomoses and may cause damage to the donor artery and undesirable distribution of graft flow to the larger area. Although the results of composite graft are acceptable, almost all reports showed better patency rate and long-term outcomes of the in situ graft than the composite graft. Thus, the ITAs should be used as the in situ graft whenever technically possible.

12.1.3 Right Gastroepiploic Artery

The history of using the right gastroepiploic artery (GEA) in coronary revascularization started in the 1960s, when Bailey reported the Vineberg implantation of the GEA into the posterior area of the heart. Since direct coronary artery bypass procedures became the standard revascularization method, the GEA to coronary artery anastomosis has been reported by Pym [10] and Suma [11] in 1987.

The GEA is the main branch of the gastroduodenal artery which arises from the right hepatic artery. After the GEA gives off branches to the pancreas, duodenum, and the pylorus, it runs along the greater curvature of the stomach. In contrast to the IMA, the GEA has fewer elastic lamellae in its media and is classified as a muscular artery [12].

The GEA provides at least 20 cm of useable length which can reach all areas of the heart. Skeletonization using ultrasonic scalpel makes the GEA longer and wider, so that it can be anastomosed at a more proximal position than the pedicled GEA. In 1998, the use of skeletonized GEA has been reported for coronary bypass conduit [13]. However, the skeletonization technique is cumbersome and time-consuming with ordinary methods using electrocautery, scissors, and hemoclips. In 2001, we developed a simple and safe technique for harvesting skeletonized GEA using an ultrasonic scalpel (Harmonic Scalpel, Ethicon Endo-Surgery, Cincinnati, Ohio) [14]. The size of the skeletonized GEA has surprised us since we have been using the technique described above. It has ranged from 2.5 to 6.5 mm in internal diameter at the site of the distal anastomosis (Fig. 12.3). This is quite different from the size of conventionally prepared GEA with surrounding tissues, which was reported to be 1.25–2.5 mm in earlier work. The difference implies that skeletonization may play an important role in dilating GEA maximally. I believe it is most important that we prepare each GEA conduit at its maximal dilatation prior to anastomosis. What we have found since we started the skeletonization technique is that the first appearance of GEA does not predict the potential size of the artery. The vascular tonus of GEA can vary significantly during an operation. Care should be taken not to underestimate the size of GEA at the beginning of operation. In no case the GEA was too narrow for use after the proper skeletonization technique. The suitable targets of the in situ GEA are the distal right coronary artery or the distal circumflex artery. It is very feasible to perform sequential grafting using skeletonized GEA for its sufficient length and diameter.

The early functional patency rate of the skeletonized GEA is reported to be better than that of the nonskeletonized GEA. Kim and coworkers [15] evaluated the early and 1-year postoperative results of grafting the skeletonized GEA to the

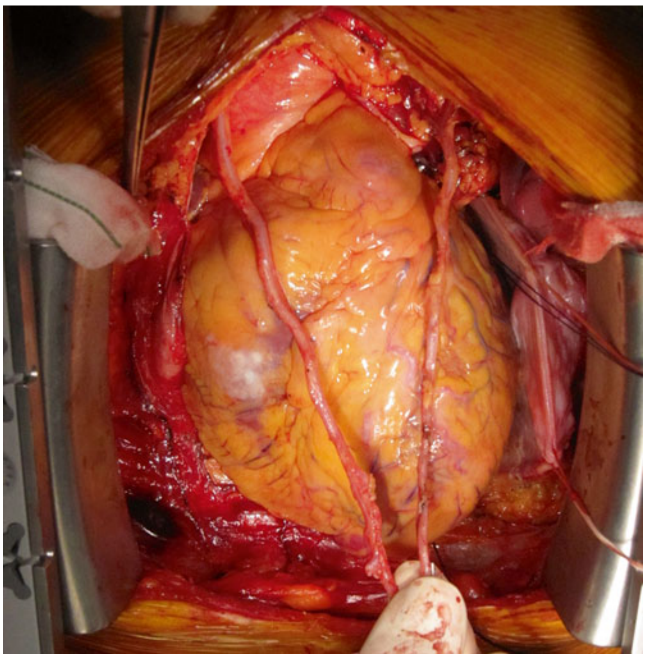

Fig. 12.2 Two mammary arteries: the skeletonized RIMA is long enough to reach the distal LAD

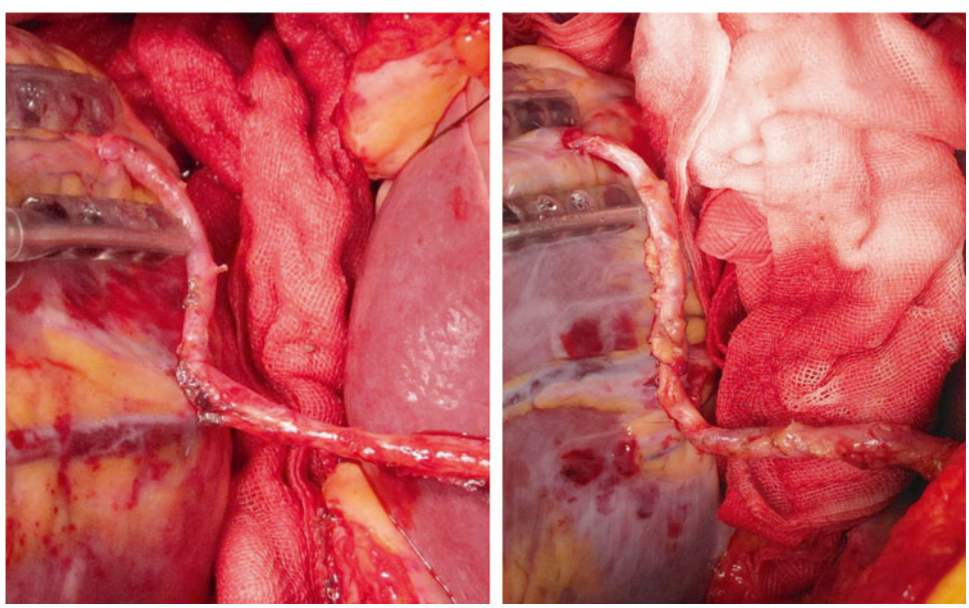

Fig. 12.3 Skeletonized GEA has sufficient length and adequate large diameter that make easy sequential grafting

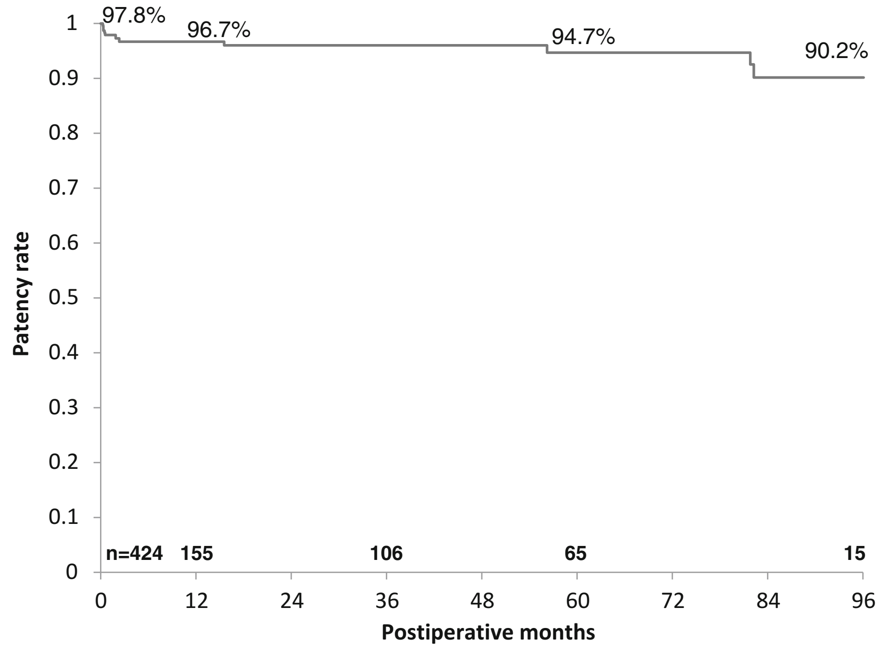

Fig. 12.4 Cumulative patency rate of the GEA graft by the Kaplan-Meier method

RCA and found an excellent early patency rate of 98.3 % and 1-year patency rate of 92.0 %.

There are little in the literature of mid- and long-term patency rate of the GEA. Suma and coworkers [12] reported their 20 years' experience of using GEA graft that the cumulative patency rate of the GEA was 97.1 % at 1 month, 92.3 % at 1 year, 85.5 % at 5 years, and 66.5 % at 10 years, respectively. Of them, in 172 skeletonized GEA graft with 233 distal anastomoses, the patency rate at 1 and 4 years after surgery was 92.9 % and 86.4 %, respectively. Ali and colleague [16] focused and evaluated the skeletonized GEA patency rate collecting the data from 11 clinical papers. Overall patency rates were 97.7 % within three months, 92.4 % at a mean of ~1 year, 91.5 % at a mean of 2 year, and 86.4 % at 4 years. In 2013, we presented our single-center report that the cumulative patency rate of the skeletonized GEA was 97.8 % at 30 days, 96.7 % at one year, 96.0 % at 3 years, 94.7 % at 5 years, and 90.2 % at 8 years after surgery that is superior to that for pedicled GEA or saphenous vein graft [17] (Fig. 12.4). It can be said that skeletonized GEA is a reliable conduit and assumes a large role in all arterial OPCAB strategy. However, the GEA has not necessarily gained acceptance among cardiovascular surgeons worldwide. Reasons for its less frequent use include concerns about insufficient flow capacity and vasospasm, the need to open the abdomen, and competitive flow causing graft failure. We need to open the abdomen when using the GEA; however, the skin incision extends only 3–4 cm. It is well known that flow competition may occur when the GEA is anastomosed to coronary artery with low-grade stenosis. As a general rule, we use the GEA only when the coronary artery stenosis is severe. We think that late graft occlusion may occur in association with flow competition. In our study, we discovered through multivariate analysis that low-grade target vessel stenosis was a strong risk factor for late GEA occlusion. We therefore recommend again that the GEA should in principle be used for more severe stenosis (>75 %).

Surgeons have not necessarily achieved great understanding of the potential ability of the GEA that has been undervalued. We think that the GEA will play a critical role in an area of OPCAB procedure with in situ all arterial grafting and surgeons should discuss and grasp the detail of the potential power of the GEA.

12.1.4 Radial Artery

The radial artery is frequently used as second graft of choice after the ITAs in CABG. Carpentier [18] et al. firstly reported the use of radial artery in CABG; however, it was soon abandoned because of disappointing early angiographic outcomes. After improvement of harvesting technique, management of pharmacologic dilatation, and the use of postoperative calcium channel blocker, the radial artery was reviewed according to encouraging reports in the 1990s.

The radial artery is a very convenient conduit that has several advantages including the ease of harvesting, sufficient length for grafting to almost any coronary artery territory, and suitable caliber for matching coronary artery. The radial artery is the muscular artery and has more spastic character than other arterial conduits. To prevent the spasm of the radial artery, intravenous nitrates or calcium channel blockers should be used intraoperatively as well as postoperatively until the patient can take oral medications. The endothelium of the radial artery plays an important role for preventing vasospasm. To preserve the endothelial function, the surgeon should take caution not to inflict excessive manipulation on the radial artery and not to mechanically dilate it during harvesting.

The radial artery is often used as composite graft connected to the ITA in end-to-side fashion. Effort to achieve aorta no-touch strategy in OPCAB procedure has led to the increased use of the RA as a composite bypass graft. Although the patency rate of radial artery composite graft is acceptable, almost all studies showed the superiority of direct aortocoronary bypass to composite graft. Therefore, when the RA composite grafting is performed, careful consideration of undesirable distribution of the blood flow due to unbalanced vascular area is needed.

The early (~12 months) patency rate of the radial artery is very favorable that is expected more than 90 %. Recently, the long-term (5years~) patency rate has been reported to be between 70 and 98 %. The patency differences of the radial artery are more significantly influenced by target coronary territory and target vessel stenosis than other conduits. It is said that if the proximal stenosis is 90 % or more, radial artery patency between ITA-RA composite graft and direct aortocoronary bypass was similar. Therefore, when the proximal native stenosis is milder, the radial artery should be used as direct aortocoronary anastomosis.

In the current circumstance of aorta no-touch OPCAB, the radial artery is a supplemental conduit used in cases which the bilateral ITAs are not available or complete reconstruction of left side coronary area cannot be achieved with bilateral ITAs alone.

12.1.5 Saphenous Vein Graft

The saphenous vein is the most popular and easily handled for graft to the RCA or the CX, and the relevant long-term clinical outcome, flow capacity, patency, and long-term complications are well known. As the advantage of the arterial conduit has become evident, the use of the SVGs has decreased. Now, in an aorta no-touch arterial OPCAB era, the SVGs are used in limited cases, including nonavailable GEA, RCA target with milder proximal stenosis, hemodialysis or renal failure patient in that the RA should not be used, and emergency with hemodynamic instability. The reasons for less use of the SVGs are as follows: wound complication such as edema, cellulitis, and delayed healing causing patients' discomfort; need for aorta manipulation during proximal anastomosis; and so-called graft disease that worsens long-term outcome. The SVG may developed intimal hyperplasia in early phase within 1 year, furthermore, atherosclerotic change in long term (>5years) that related to graft occlusion more frequently than arterial conduits. The patency rate of the SVG may increasingly deteriorate with time, as we know, that is 50–60 % at 10 years after CABG. Endoscopic vein harvesting technique has been developed for the purpose to reduce the clinical complications including wound infection, leg edema, pain, and prolonged hospital stay. Although the endoscopic vein harvesting technique has been widely spread among surgeon, the clinical result is disappointing. Lopes et al. reported the clinical outcome comparing endoscopic harvesting to open harvesting and concluded that endoscopic vein-graft harvesting is independently associated with vein-graft failure and adverse clinical outcomes. Thus, the endoscopic vein harvesting technique should be used only in selected patient. The damage of the endothelium of the SVGs often leads to platelet aggregation that causes intimal hyperplasia resulting to graft occlusion. Recently, no-touch technique of the SVG harvesting is recommended that provides a pedicled graft. It preserves normal intact adventitia, vasa vasorum, medial blood flow, and endothelial function. The perivascular fat protects the vein against arterial hemodynamics and kinking result in preventing future atherosclerosis. Early SVG failure is associated with distention-induced endothelial denudation. Superior long-term patency rate of pedicled SVG is demonstrated in recent review. In either approach of endoscopic or open harvesting, a careful handling of the SVG during harvesting is important not to damage the endothelium.

12.2 Aorta No-Touch Technique with All Arterial Grafting

12.2.1 An Advantage of Aorta No-Touch Technique

The incidence of stroke in patients undergoing routine CABG is reported to be 1–3 %, most commonly as a result of ascending aortic embolic phenomena. Various studies have proven embolic showers using transcranial Doppler during cannulation, clamping, or declamping maneuvers and especially in association with the release of the aortic cross-clamp. The best strategy to reduce stroke risk appears to be to completely avoid handling the aorta, the so-called aorta no-touch technique. An effort to reduce stroke during CABG has led to widespread use of aorta no-touch strategy with off-pump technique. The main indication for no-touch aorta OPCAB operation is patients who have a severely atherosclerotic or porcelain ascending aorta.

Kapetanakis and associates [19] reported that stroke rate with on-pump CABG was 1.5 times (2.2 % versus 1.6 %) that with off-pump CABG with partial aortic clamping and three times (2.2 % versus 0.8 %) that in the no-touch aorta OPCAB group. Kim and associates [20] reported a lower incidence of perioperative stroke with the no-touch aorta

OPCAB technique, but similar stroke rates between OPCAB with aortic manipulation and conventional on-pump CABG. Misfeld and coworkers [21] presented that 81 of 5,779 (1.4 %) patients in the OPCAB group with aortic manipulation had strokes, compared with 29 of 5,619 (0.5 %) patients in the aortic no-touch group. Lev-Ran and coworkers [22] reported one neurologic event among 429 consecutive patients (0.2 %) in the no-touch OPCAB group, which compared favorably with a stroke rate of 2.2 % observed in the side-clamp OPCAB group. On the other hand, complete avoidance of aortic manipulation preserves the aortic fat pad containing neurogenic tissue and thereby may avoid an autonomic imbalance and further decrease the incidence of atrial fibrillation. Kim and coworkers [23] demonstrated that OPCAB with complete avoidance of aortic manipulation significantly reduced the incidence of postoperative atrial fibrillation compared with conventional CABG (11.4 % versus 21.1 %).

Even though the no-touch technique may be the best clinical practice, it may not always be applicable for every patient and is not routinely applied in many centers. Despite all above evidence in favor of no-touch technique, the real world does still include saphenous vein grafting with proximal anastomosis in patients with multivessel disease.

It is known that the cause of neurologic complication in 3 % of patients undergoing CABG who have strokes is multifactorial and thus may not be avoided by reducing the manipulation of the aorta alone. It needs to be addressed whether there is a relationship between the degree and type of aortic manipulation during OPCAB procedures and subsequent stroke.

At any rate, there is almost no doubt that aorta no-touch technique has several advantages to prevent an embolic complication associated to diseased ascending aorta. Surgeon should keep making an effort to refine their skill and master the aorta no-touch technique to reduce an extra preventable embolic event.

12.2.2 Graft Arrangement for Complete Revascularization with Aortic No-Touch Technique

12.2.2.1. Composite Grafting

Left-sided bilateral ITA grafting can be regarded as the best surgical revascularization technique with respect to survival and freedom from adverse cardiovascular events such as late myocardial infarction, recurrent angina, and reintervention. The use of bilateral ITAs enables the performance of OPCAB operations without manipulation of the ascending aorta, as an in situ or Y-configuration. Several arrangements of bilateral ITA grafting have been proposed to achieve left anterior descending and circumflex arterial grafting. With the advent and increased popularity of the off-pump technique, many surgeons currently use the technique of arterial composite T- or Y-grafting with free right ITA or radial artery attached end to side to the left ITA. A commonly used arrangement is the composite T-graft, whereby free ITA grafts are attached proximally end to side to in situ ITA. Several studies [24–26] reported that the clinical and angiographic results of composite grafting were equivalent to those of individual grafting. Some other studies reported that composite grafting may be susceptible to the detrimental effect of flow competition with native coronary artery when used for a mildly stenosed target vessel. When all target vessels in triple-vessel disease were bypassed with a composite ITA graft, a major concern was that the single attached LITA would not be able to supply enough blood to the revascularized myocardium. Studies using transit-time Doppler techniques indicate that construction of composite arterial grafts results in a significant increase in flow through the left ITA. The amount of flow supplying each region depends on the severity of coronary stenosis and coronary vascular area. Composite arterial grafting causes splitting of internal thoracic artery flow to various myocardial regions. Conduit flow is largely affected by the native coronary flow. Nakajima and coworkers [27] presented angiographic study of 362 patients with composite T-graft in that competitive flow was found in 14.6 % of the composite grafts and occlusion occurred in 3.6 % of the patients. Sabik and colleagues [28] also reported that multivariate analysis identified the degree of preoperative proximal coronary stenosis to be an important predictor of ITA graft occlusion. Manabe et al. [29] showed that the angiographic outcomes of composite grafts were closely related to the severity of stenosis of the target coronary artery. In target vessels with mild stenosis, composite grafting resulted in a higher incidence of graft occlusion or string sign than individual grafting did. They found that composite grafting has been shown to be an independent predictor of graft occlusion or string sign in case of target vessels with mild stenosis; therefore, they do not recommend composite grafting in target vessels with mild stenosis. The precise mechanism of graft failure in composite grafts has not been completely clarified. Failure of ITA graft to LAD as a result of competitive flow deprives the patients of the main benefit they expected to gain from the operation that could have been achieved by using a simple in situ ITA. Lev-Ran and coworkers [24] reported that early results of bilateral ITA grafting with T-graft are comparable with those of in situ grafts; however, increased angina return and decreased midterm survival led them to recommend in situ grafting whenever technically possible. However, composite grafting plays a crucial role in these procedures, because it eliminates the need for proximal anastomosis to the ascending aorta and conserves extra lengths of an arterial graft for additional grafting. We therefore think that composite T- or Y-grafting with two ITAs should be employed for selected patients with severe stenosis in their LAD and marginal branches of the circumflex.

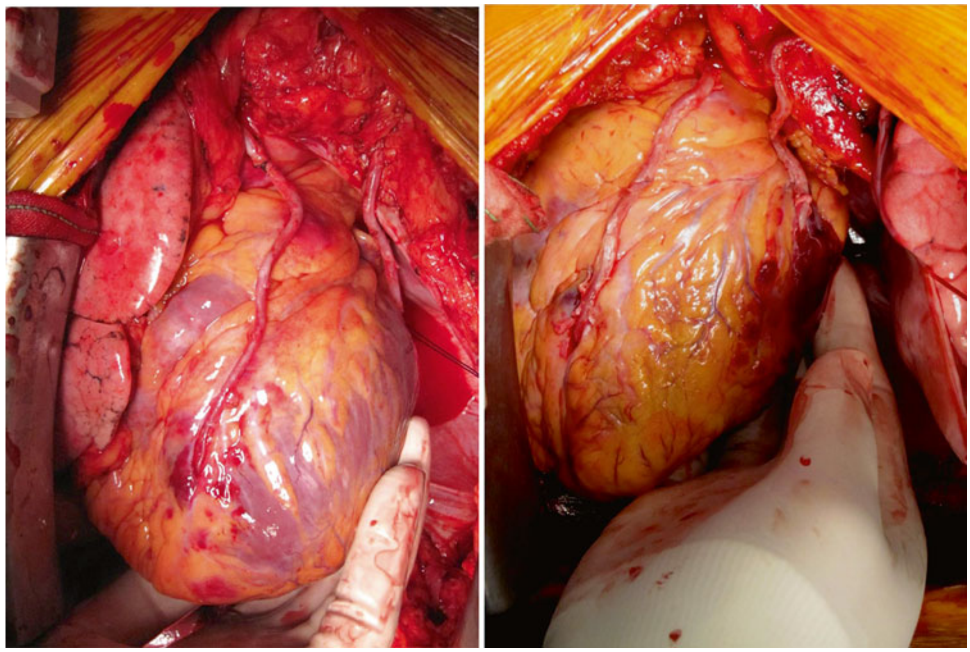

Fig. 12.5 Our favorable graft arrangements: in situ RITA anterior to the aorta to LAD and in situ LITA grafting to CX area

12.2.2.2. In Situ Grafting

Arterial grafts are known to narrow diffusely or occlude when they are used in low-flow condition. However, even in vessels with a stenosis degree as low as 50 %, the patency rate of in situ ITA to LAD was over 90 %. This excellent patency of in situ ITA to LAD was long-lasting and remained high up to 15 years or more after surgery. Although the results of composite graft are acceptable, almost all reports showed better patency rate and long-term outcomes of the in situ graft than the composite graft. We prefer an in situ ITA grafting to composite grafting. Reduced patency rates for free RITA grafts have been demonstrated when these grafts are connected proximally to the aorta. The concerns of in situ right ITA grafting to LAD are insufficient length and proximity of the crossover right ITA to the sternum which could compromise a subsequent repeat sternotomy. Refinement in ITA-skeletonized harvesting technique increased graft length and improved distal free flow and may reduce postoperative sternal wound complication. If the length of the crossover right ITA is not sufficient to comfortably reach the desired anastomotic site on the LAD, we consider the T-graft arrangement. However, in our 225 OPCAB cases of recent 2 years, T-graft technique was implemented in only two cases (0.9 %). Thus, a skilled technique of skeletonization ITA harvesting can resolve the issue of the insufficient length of the RITA graft in almost all cases. The surgeon should master the skeletonization technique of the ITA harvesting with ultrasound scalpel. Grafting an in situ right ITA to the left coronary system can either be performed through the transverse sinus in a retroaortic course [30] or crossing over a route anterior to the aorta. Both techniques have particular disadvantages. Although a retroaortic course of an in situ RITA to the CX coronary artery (through the transverse sinus) has been advocated by some surgeons [30], this technique has several disadvantages such as technical difficulty, compression of the right ITA by the aorta, or the inability to control side-branch bleeding and to detect graft kinks because of out of direct vision. These disadvantages of the retroaortic course have limited its widespread use.

We prefer in situ RITA grafting anterior to the aorta because of technical ease and equivalent patency rate to in situ LITA grafting to the LAD (Fig. 12.5). A major concern over the anterior retrosternal RITA crossover route is the potential risk of damage to the artery during repeat sternotomy. We have made all kinds of efforts to prevent injury of the crossover RITA. The RITA is let into a tunnel of the right pericardium and directed leftward crossing the midline of the ascending aorta toward the LAD. Mediastinal fat was used to cover the RITA. Thus, a space is maintained between the crossover RITA and the posterior table of the sternum for future resternotomy. This maneuver allows free space on the aorta and provides a safety distance between the crossover ITA and sternum. In our previous experience with 7 patients undergoing resternotomy with a patent retrosternal RITA, no RITA was damaged. In all seven cases, the crossover RITA was easily dissected without injury, and the aortic cannulation site and clamping zone were safely maintained.

The use of sequential grafting is essential to achieve complete revascularization with only in situ arterial grafts. The two ITAs in combination with the right gastroepiploic artery provide three sources of blood supply. When OPCAB is planned with the aorta no-touch technique and using BITA grafts, the right coronary artery can be bypassed with an in situ right GEA or an extension of the composite ITA graft. The LAD should be reconstructed individually with one ITA (mainly with the right ITA). We often use the in situ left ITA as sequential graft for CX reconstruction. The left ITA may be allowed to use up to double sequential anastomoses, but difficult for three anastomoses. The skeletonized right GEA is very suitable for sequential grafting with sufficient length and diameter, even up to three or four sequential anastomoses.

In our consecutive 225 elective OPCAB cases of recent 2 years, over 90 % (203 cases) of them were performed using in situ all arterial grafting technique with aorta no-touch policy. We routinely use both ITA and right GEA as in situ graft and never use the radial artery. Thus, in almost all cases, complete revascularization can be achieved with in situ three arterial conduits (both ITAs and right GEA). We use the SVG in a particular case such as previous gastrectomy, RCA target with mild stenosis, or severe calcified right GEA.

References

1. Endo M, Nishida H, Tomizawa Y, Kasanuki H (2001) Benefit of bilateral over single internal mammary artery grafts for multiple coronary artery bypass grafting. Circulation 104:2164–2170
2. Rizzoli G, Schiavon L, Bellini P (2002) Does the use of bilateral internal mammary artery (IMA) grafts provide incremental benefit relative to the use of a single IMA graft? A meta-analysis approach. Eur J Cardiathorac Surg 22:781–786
3. Taggart DP, D'Amico R, Altman DG (2001) Effect of arterial revascularization on survival: a systematic review of studies comparing bilateral and single internal mammary arteries. Lancet 358:870–875
4. Lytle BW, Blackstone EH, Loop FD et al (1999) Two internal thoracic artery grafts are better than one. J Thorac Cardiovasc Surg 117:855–872
5. Buxton BF, Komeda M, Fuller JA, Gordon I (1998) Bilateral internal thoracic artery grafting may improve outcomes of coronary artery surgery, risk-adjusted survival. Circulation 98:II-1–II-6
6. Chavanon O, Durand M, Hacini R et al (2002) Coronary artery bypass grafting with left internal mammary artery and right gastroepiploic artery, with and without bypass. Ann Thorac Surg 73:499–504
7. Tavilla G, Kappetein AP, Braum J, Gopie J, Tjien ATJ, Dion RAE (2004) Long-term follow-up of coronary artery bypass grafting in three-vessel disease using exclusively pedicled bilateral internal thoracic and right gastroepiploic arteries. Ann Thorac Surg 77:794–799
8. Suzuki T, Asai T, Matsubayashi K et al (2011) In off-pump surgery, skeletonized gastroepiploic artery is superior to saphenous vein in patients with bilateral internal thoracic arterial grafts. Ann Thorac Surg 91:1159–1164
9. Higami T, Yamashita T, Nohara H, Iwahashi K, Shida T, Ogawa K (2001) Early results of coronary grafting using ultrasonically skeletonized internal thoracic. Ann Thorac Surg 71:1224–1228
10. Pym J, Brown PM, Charrete EJ, Parker JO, West RO (1987) Gastroepiploic-coronary anastomosis. A viable alternative bypass graft. J Thorac Cardiovasc Surg 94:256–259
11. Suma H, Fukumoto H, Takeuchi A (1987) Coronary artery bypass grafting by utilizing in situ right gastroepiploic artery: basic study and clinical application. Ann Thorac Surg 44:394–397
12. Suma H, Tanabe H, Takahashi A et al (2007) Twenty years experience with the gastroepiploic artery graft for CABG. Circulation 116(1):I-188–I-191
13. Gagliardotto P, Coste P, Lazerg M, Dor V (1998) Skeletonized right gastroepiploic artery used for coronary artery bypass grafting. Ann Thorac Surg 66:240–242
14. Asai T, Tabata S (2000) Skeletonization of the right gastroepiploic artery using an ultrasonic scalpel. Ann Thorac Surg 74:1715–1717
15. Kim KB, Cho KR, Choi JS, Lee HJ (2006) Right gastroepiploic artery for revascularization of right coronary territory in off-pump total arterial revascularization: strategies to improve patency. Ann Thorac Surg 81:2135–2141
16. Ali E, Saso S, Ashrafian H, Athanasiou T (2010) Does a skeletonized or pedicled right gastro-epiploic artery improve patency when used as a conduit in coronary artery bypass graft surgery? Interact CardioVasc Thorac Surg 10:293–298
17. Suzuki T, Asai T, Nota H et al (2013) Early and long-term patency of in situ skeletonized gastroepiploic artery after off-pump coronary artery bypass graft surgery. Ann Thorac Surg 96:90–95
18. Carpentier A, Guemonprez JL, Deloche A, Frechette C, Dubost C (1973) The aorta-to-coronary radial artery bypass graft: a technique to avoid pathological changes in graft. Ann Thorac Surg 16:111–121
19. Kapetanakis EI, Stamou SC, Dullum MKC et al (2004) The impact of aortic manipulation on neurological outcomes after coronary artery bypass surgery: a risk-adjusted study. Ann Thorac Surg 78:1564–1571
20. Kim WS, Lee J, Lee YT, Sung K, Yang JH, Jum TG et al (2008) Total arterial revascularization in triple-vessel disease with off-pump and aortic no-touch technique. Ann Thorac Surg 86:1861–1865
21. Misfeld M, Brereton JL, Sweetman EA, Doig GS (2011) Neurologic complications after off-pump coronary artery bypass grafting with and without aortic manipulation: meta-analysis of 11398 cases from 8 studies. J Thorac Cardiovasc Surg 142:e11–e17
22. Lev-Ran O, Braunstein R, Sharony R, Kramer A, Paz Y, Mohr R et al (2005) No-touch aorta off-pump coronary surgery: the effect on stroke. J Thorac Cardiovasc Surg 129:307–313
23. Kim KB, Kang CH, Chang W-I, Lim C, Kim JH, Ham BM et al (2002) Off-pump coronary artery bypass with complete avoidance of aortic manipulation. Ann Thorac Surg 74:S1377–S1382
24. Lev-Ran O, Paz Y, Penvi D, Kramer A, Shapira I, Locker C, Mohr R (2002) Bilateral internal thoracic artery grafting: midterm results of composite versus in situ crossover graft. Ann Thorac Surg 74:704–711
25. Legare JF, Buth KJ, Sullivan JA, Hirsch GM (2004) Composite arterial grafts versus conventional grafting for coronary artery bypass grafting. J Thorac Cardiovasc Surg 127:160–166
26. Hwang HY, Kim JS, Cho KR, Kim KB (2011) Bilateral internal thoracic artery in situ versus Y-composite graftings: five-year angiographic patency and long-term clinical outcomes. Ann Thorac Surg 92:579–586
27. Nakajima H, Kobayashi J, Tagusari O, Bando K, Niwaya K, Kitamura S (2004) Competitive flow in arterial composite grafts and effect of graft arrangement in off-pump coronary revascularization. Ann Thorac Surg 78:481–486
28. Sabik JF III, Lytle BW, Blackstone EH, Khan M, Houghtailing PL, Cosgrove DM (2003) Does competitive flow reduce internal thoracic artery graft patency? Ann Thorac Surg 76:1490–1497
29. Manabe S, Fukui T, Shimokawa T, Tabat M, Katayama Y, Morita S, Takanashi S (2010) Increased graft occlusion or string sign in composite arterial grafting for mildly stenosed target vessels. Ann Thorac Surg 89:683–688
30. Ura M, Sakata R, Nakayama Y, Aria Y, Oshima S, Noda K (2000) Analysis by early angiography of right internal thoracic artery grafting via the transverse sinus: predictors of graft failure. Circulation 101:640–646

Controversy: Composite Grafts Versus Individual Grafts

13

Toshihiro Fukui

Abstract

Multiple arterial myocardial revascularizations are increasingly being performed off pump using various arterial grafting techniques. The superior patency rate of the internal thoracic artery as an in situ graft makes it the most reliable, and in situ right gastroepiploic artery grafting for a severely stenotic right coronary artery is another established technique. However, it is sometimes necessary to combine these grafts with a free arterial graft in order to achieve complete revascularization. The combination of an in situ left internal thoracic artery with free right internal thoracic and radial arteries is an excellent choice in this situation. These composite grafts have the advantage of preventing postoperative stroke because manipulation of the ascending aorta can be avoided, but they may risk hypoperfusion or jeopardize graft patency. In contrast, an individual free graft with proximal anastomosis to the aorta is still widely used. Its safety is improving with the aid of epiaortic ultrasonography and a clampless anastomotic device. The present chapter addresses the advantages and disadvantages of individual and composite arterial grafts.

Keywords

Composite graft • Individual graft • Arterial graft • Off pump

13.1 Introduction

Coronary artery bypass grafting (CABG) is a well-established method for treating multivessel coronary artery disease. The most important goals of CABG are complete revascularization and long-term graft patency without re-intervention. Saphenous vein (SV) grafts (SVGs) have shown poor patency rates and have failed to improve long-term morbidity [1]. In contrast, the left internal thoracic artery (LITA) has demonstrated superior graft patency and provided excellent clinical results [2]. The use of arterial conduits in CABG has been hypothesized to improve long-term results [3], and the right internal thoracic artery (RITA) [4], radial artery (RA) [5], and right gastroepiploic artery (GEA) [6] have been used as conduits. Various combinations of these arterial grafts have been employed, and many retrospective studies have supported their safety and effectiveness in both individual in situ grafts and composite free grafts.

Composite sequential arterial grafts can increase the number of distal coronary anastomoses with a limited number of grafts and thus avoid proximal aortic anastomoses. Several composite grafting techniques have been proposed, such as Y, T, U, and I composites [7–12]. The LITA is a popular first graft, with the second being either a free RITA or RA [13–15] with no superiority of one over the other as a second graft having been demonstrated. The free GEA graft has rarely been used in a composite graft in this situation because of its inferior patency rate compared with other free arterial grafts [16]. A possible weakness of composite and sequential grafting is that flow is dependent on a single in situ arterial graft.

Individual in situ arterial grafting has the most reliable patency and durability. There are two strategies for using

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bilateral ITAs (BITAs) as in situ grafts to the left coronary system: in situ LITA to left anterior descending artery (LAD) and in situ RITA to left circumflex artery (LCX) or in situ RITA to LAD and in situ LITA to LCX; there is no universal consensus as to which strategy is better. The use of BITAs in situ limits the number of anastomoses per graft.

When free RITA, RA, and SV are used as individual grafts, the proximal anastomosis is usually performed to the aorta, a maneuver that is considered to increase postoperative stroke rate. However, since the introduction of several instruments designed to minimize invasiveness during proximal anastomosis, the stroke rate is reported to be decreasing.

13.2 Arterial Grafting with Off-Pump Coronary Surgery

Off-pump CABG has gained popularity because of the many clinical and economic benefits compared with conventional CABG [17]. However, some concerns remain regarding the quality and completeness of revascularization during off-pump CABG. To overcome these drawbacks, combination composite-sequential arterial bypass grafting performed off pump has been developed, which can achieve multivessel revascularization less invasively, with a limited number of arterial grafts, and without aortic manipulation. In this situation, the SV cannot be used in combination with an ITA as a composite graft because the patency of this combination is suboptimal [18], but multiple arterial conduits have been used for composite and sequential grafting. An observational study and a prospective randomized study have suggested a survival benefit associated with the use of all-arterial grafts [19, 20]. In a meta-analysis by Taggart et al. [19], the BITA group had significantly better survival than the single-ITA group (hazard ratio for death 0.81; 95 % confidence interval 0.70–0.94).

The quality, harvesting technique, and preservation of the grafts as well as the grafting strategy and characteristics of the target coronary artery are important factors in the long-term patency of arterial grafts.

13.3 In Situ BITA

The LITA is the most commonly used in situ arterial graft for revascularization. This graft may be more physiological as an in situ than as a free graft from the standpoint of blood and nerve supplies. Furthermore, because there is no proximal anastomosis, there is no possibility of anastomotic complications. Skeletonization allows an ITA to be completely freed of attachments, which results in extra available length and may obviate the risk of mediastinitis because collateral blood supply to the sternum can be preserved.

A skeletonized in situ LITA can reach any branch in the left coronary system and can be used to create sequential anastomoses to several branches, for example, in situ LITA to diagonal branch and LAD or in situ LITA to obtuse marginal branch and posterolateral branch of the LCX.

The in situ RITA, on the other hand, is of limited length even with skeletonization, making its use for the proximal right coronary artery possible but not popular, because its patency rate is lower there than that of the LITA in the left coronary system. Tatoulis and colleagues [21] reported that the 5-year patency rate of RITA to LAD was 95 % compared with 83 % for RITA to right coronary artery and that angiographic patency rates for in situ RITA to right coronary artery were not better than those of other grafts. In situ RITA is thus usually used for the left coronary artery system, particularly in the mid LAD, the diagonal branch, the proximal part of the obtuse marginal branch, and the posterolateral branch.

Patency rates of in situ ITA grafts have been shown to be excellent and superior to those of free grafts. The long-term patency of in situ RITA to LAD is identical to that of in situ LITA to LAD. That the ITA rarely develops atherosclerosis is thought to be a function of the structure of that vessel and applies even to its use as free graft. A major reason for ITA graft occlusion is competition from a native coronary artery that is without severe stenosis. This tendency of the ITA to become occluded because of competition is similar to that of other arterial grafts.

13.3.1 In Situ LITA to LAD and In Situ RITA to LCX (Fig. 13.1)

We usually use in situ LITA to LAD because of its straight course parallel to the LAD. An in situ LITA has adequate length to reach any part of the LAD. However, because the distal part of the ITA is thin and its media predominantly muscular, use of the distal part of the LITA should be avoided. When the LAD has a long, diffusely diseased lesion, the in situ LITA can be used to perform long-segmental reconstruction of the LAD with onlay patch grafting [22]. The in situ RITA does not, however, have sufficient length to reach the distal LAD for long-segmental reconstruction. Another option for in situ LITA to LAD is that it is possible to perform sequential grafting to the diagonal branch. When the diagonal branch lies adjacent to the LAD, the LITA goes almost straight to the LAD. When the angle between the diagonal branch and the LAD is wide, sequential grafting is not recommended because the LITA may be bent and thus has a risk of kinking.

When the in situ RITA is anastomosed to the LCX territory, it is passed through the transverse sinus. When side branches of the RITA are divided, a metal clip should not be

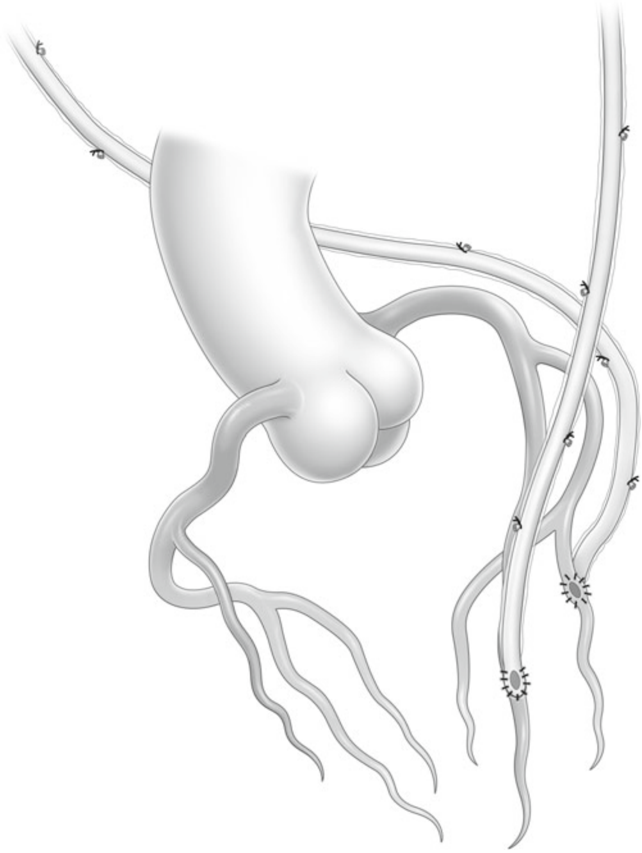

Fig. 13.1 Left internal thoracic artery is grafted to the left anterior descending artery. The right internal thoracic artery is grafted to the circumflex artery

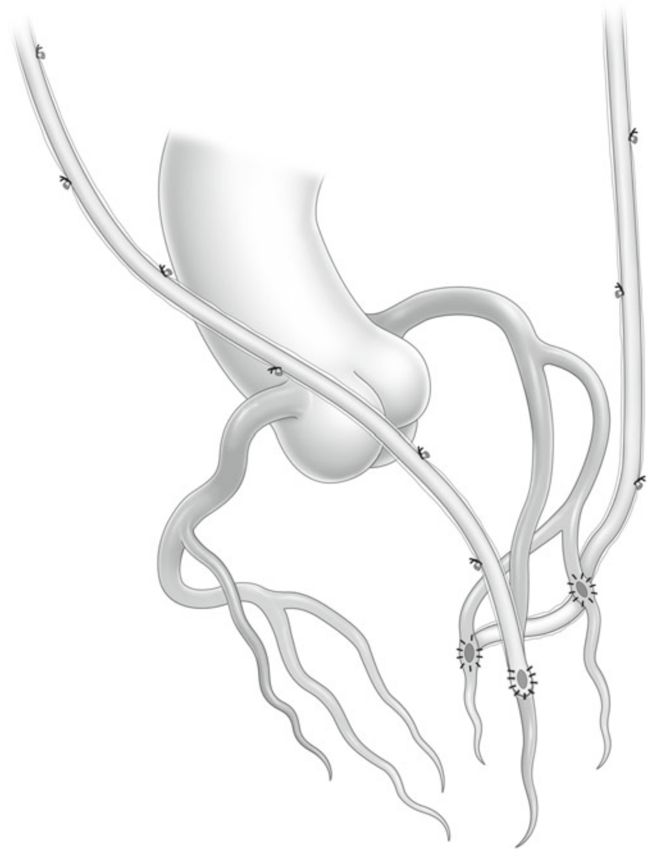

Fig. 13.2 Right internal thoracic artery is grafted to the left anterior descending artery. The left internal thoracic artery is grafted to the circumflex artery

used because the clip may come off when the graft is passed through the transverse sinus and lead to bleeding behind the aorta. It is preferable to harvest the ITA by skeletonizing it with an ultrasonic scalpel. The RITA is completely mobilized from the level of the subclavian vein, and the right internal thoracic vein is divided before its connection to the brachiocephalic vein. The pericardium of the right upper portion is incised anterior to the right phrenic nerve. The distal anastomosis of in situ RITA to the proximal part of the LCX with off-pump technique can be technically demanding. We always apply a commercially available heart positioner and stabilizer to the heart and often widely open the right pleura to avoid right heart compression and obstruction of venous return. Anastomosis is performed with an 8–0 polypropylene running suture using parachute technique. This configuration is much safer than in situ RITA to LAD at reoperation.

The in situ RITA is occasionally used for a high lateral or diagonal branch running in front of the aorta. With this strategy, the in situ RITA should be protected with the thymus at the end of the procedure in order to prevent damage at reoperation.

13.3.2 In Situ RITA to LAD and In Situ LITA to LCX (Fig. 13.2)

When the in situ RITA is anastomosed to the LAD, it is directed anterior to the aorta. With this strategy, the length of the in situ RITA should be checked to ensure that it has sufficient length, which it does in nearly all patients, to reach the LAD. In some cases, however, increased volume of the right heart can increase the distance between the LAD and the root of the RITA. Patients with right heart failure can be improved after complete revascularization. Pevni et al. suggested that in situ RITA to LAD not be performed in patients with a short RITA, a very long ascending aorta, an enlarged right ventricle, or an LAD anastomotic site that is too distal or unpredictable or in patients with high probability of repeat surgery, such as valve operations [23].

This strategy is especially useful in patients with unstable left main or bifurcation disease using off-pump technique [24]. The LAD is first revascularized using the in situ RITA with minimal rotation of the heart. After completing LAD revascularization, the LCX can be revascularized using the in situ LITA for hemodynamic stability. The patency rate of the in situ RITA is comparable to that of the in situ LITA when anastomosed to the LAD [25]. Furthermore, in our analysis, the patency rate of in situ RITA to LAD was superior to that of in situ RITA to LCX [26].

In situ RITA grafts are sometimes at risk of injury at reoperation. The RITA should be wrapped in thymic tissue and covered with mediastinal fat at the end of the surgery to prevent injury upon reopening [27]. If adhesions between the in situ RITA and sternum are severe at reoperation, establishment of cardiopulmonary bypass with femoral or axillary cannulation is recommended to decompress the heart.

When in situ LITA is used for the LCX, multiple sequential anastomoses can be performed. If the LITA is extremely long, it is possible to anastomose it to the posterolateral branch of the RCA. When sequential anastomoses are carried out with the in situ LITA, the first anastomosis should be done between the most proximal branch of the LCX and the LITA in side-to-side fashion because the length and course of the LITA are easily chosen. We prefer creating a perpendicular anastomosis in a diamond shape to a parallel anastomosis. The second or third anastomosis is made sequentially to the distal branches. The terminal anastomosis is done either perpendicularly or parallel at the discretion of the surgeon.

13.4 Composite Grafting with BITAs

When the in situ RITA cannot reach the LAD or LCX, the RITA is frequently used as a free graft. When the LCX has multiple lesions, sequential grafting is performed using a free RITA graft. With this strategy, proximal anastomosis of the free RITA is performed to the in situ LITA, to another graft (RA or SVG), or directly to the aorta. In contrast, the LITA is used as a free graft in a limited number of situations, for example, where there is injury during harvesting, subclavian artery stenosis, or radiation injury.

Free RITA-to-aorta anastomosis is rarely performed because the patency rate of the free RITA proximally anastomosed to the aorta may be inferior to that of the LITA anastomosed to the aorta. The poor graft patency of the free RITA anastomosed to the aorta is considered to be due to mismatch between the aorta and the conduit wall and a difference in the flow pattern [8].

Because BITA for the left coronary system has shown superior long-term survival compared with single ITA, a free ITA should be used for left coronary artery. Making a Y- or T-shaped anastomosis between the free ITA and the in situ ITA is performed either before or after construction of the distal anastomoses. We prefer creating a Y-shaped anastomosis after performing all distal anastomoses because at that point decisions regarding the length and course of the free ITA graft are more easily made. A benefit of this configuration is that fewer grafts are required.

Multiple sequential distal anastomoses between the free ITA and branches of the LCX with off-pump technique are considered to be a more complex procedure because the free ITA is smaller and shorter than other grafts. However, the ITA is rarely atherosclerotic and is easy to handle when taken with skeletonization. Tatoulis et al. demonstrated that the 10-year patency rates of in situ ($n = 450$, 89 %) and free ($n = 541$, 91 %) RITA grafts were similar ($p = 0.44$) [28]. Furthermore, in our previous analysis, follow-up angiographic results of sequential grafts were as good as those of individual grafts [29]. Competitive or reverse flow due to a lack of stenosis in a native coronary artery could be the potential cause of occlusion in composite grafts [30].

13.4.1 In Situ LITA to LAD and Free RITA to LCX (Fig. 13.3)

We typically use the RITA as free graft because multiple sequential grafts to lateral or posterior vessels can be performed with this graft. A metal cannula is inserted into the proximal end of the free RITA and the vessel ligated, and milrinone solution is injected to dilate the graft. One side of the graft is marked with crystal violet to prevent twisting. When sequential distal anastomoses are carried out with the free RITA, the first anastomosis is performed side to side to the most proximal branch in diamond-shaped fashion. The second or third anastomosis is created sequentially to the distal branches. The terminal anastomosis is done either perpendicular or parallel. The free RITA can reach the posterior descending artery when its proximal anastomosis is carried out on the left ITA [31].

The most popular site of proximal anastomosis of the free RITA is the in situ LITA using a T or Y configuration, depending on the length of the free RITA graft. Tector et al. demonstrated excellent results using BITA T grafts [9], reporting that sewing the BITAs at right angles (T shaped) preserves valuable proximal length and prevents kinking. The T anastomosis can be located proximally or distally to accommodate the position of the first distal coronary anastomosis. We prefer a Y-shaped anastomosis because of the smaller angle between the in situ LITA and the free RITA, which may lead to smoother blood flow. The best anastomotic site is at the level of the pulmonary artery. Calafiore et al. showed that Y grafting using BITAs had the same angiographic and clinical results as in situ BITAs [32]. Anastomosis between two ITAs is not as difficult because the wall characteristics are the same. We use an 8–0 polypropylene running suture for this anastomosis.

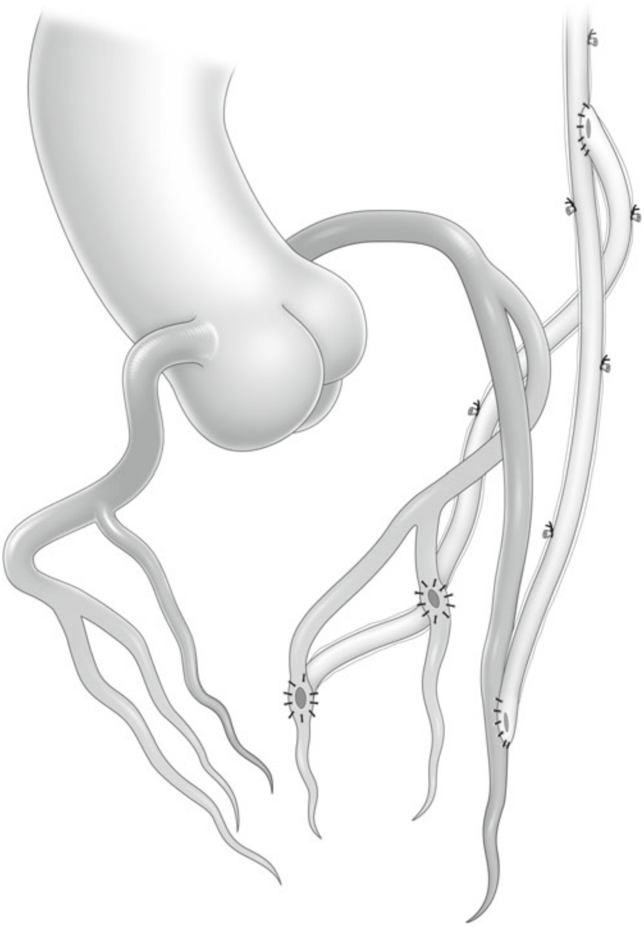

Fig. 13.3 Left internal thoracic artery is grafted to the left anterior descending artery. The free right internal thoracic artery or radial artery is sutured to the in situ left internal thoracic artery as a Y-graft to multiple circumflex branches

13.4.2 In Situ RITA to LAD and Free LITA to LCX

Based on the same anatomical characterization of the BITAs, composite grafting with in situ RITA and free LITA may be possible [23]. However, this configuration is extremely rare and is limited to occasions when the LITA is not available for in situ grafting because of injury during harvesting, subclavian artery stenosis, or radiation injury due to a mediastinal tumor or breast cancer. Making a T or Y anastomosis between the in situ RITA and the free LITA is performed at the anterior surface of the heart and near to the distal anastomosis of the in situ RITA. Care should be taken not to kink or bend the in situ RITA if the free LITA is short.

13.5 ITA and RA Composite Grafting

The RA is the second or third most frequently used arterial graft. It is a muscular artery and usually has a thick media comprising mostly smooth muscle cells. Thus, it sometimes has an atherosclerotic intima and macroscopic calcification. Because it always needs antispasmodic preparation, we inject milrinone solution directly into the RA and administer diltiazem systemically. Recently, the distal side of the RA has sometimes been used for catheterization in patients undergoing coronary angiography or coronary intervention, so care must be taken not to use distal part aspect for revascularization in these patients.

The RA is easily handled, and when it is skeletonized for harvest, sequential anastomoses for two or three distal coronary arteries can easily be performed. Various sites of proximal anastomosis of the RA have been debated. Some prefer anastomosing the RA directly to the aorta, and others prefer a T or Y ITA composite. In some cases, a straight graft (I-composite graft) with the in situ RITA is possible. If multiple distal anastomoses using the RA are necessary, composite grafting should be considered because it may not reach the aorta. Several authors have demonstrated favorable clinical and angiographic results using the RA [33]. Distal runoff, competitive flow, and proximal anastomosis site are considered to influence the patency of the RA. In our analysis, non-ITA graft, mild target stenosis, and multiple grafts from a single inflow source were independent predictors of graft deterioration [30]. In other words, the RA graft, when it is used in composite and multiple grafts from a single inflow source, tends to deteriorate in targets in which stenosis is not severe. We have recently begun to limit the use of RA to LCX with severe stenosis in non-elderly patients.

13.5.1 In Situ LITA to LAD and RA to Circumflex Artery (Fig. 13.3)

Kobayashi and Nakajima have had extraordinary experiences of in situ LITA and RA composite grafting [34, 35]. The RA is skeletonized and harvested. The length of the RA is almost always greater than 20 cm and is as easily handled as a skeletonized SVG, making the creation of multiple RA grafts easier than free RITA grafting.

When the RA used as a T- or Y-composite graft with the in situ LITA, distal anastomosis is performed first. When sequential anastomoses are carried out with the RA, the first anastomosis should be done to the most proximal branch in side-to-side, diamond-shaped fashion, followed by a second or third anastomosis to the distal branches created sequentially. The terminal anastomosis is created either perpendicular or parallel. Because the wall of the RA is thicker than that of other vessels, care should be taken to pass the needle from intima to adventitia, especially in side-to-side anastomosis. The RA is long enough to reach the posterior descending artery when its proximal anastomosis is to the LITA. Although proximal anastomosis of the RA to the in situ LITA is not difficult, it should be performed carefully because there is a size discrepancy between the ITA and RA. The length of the

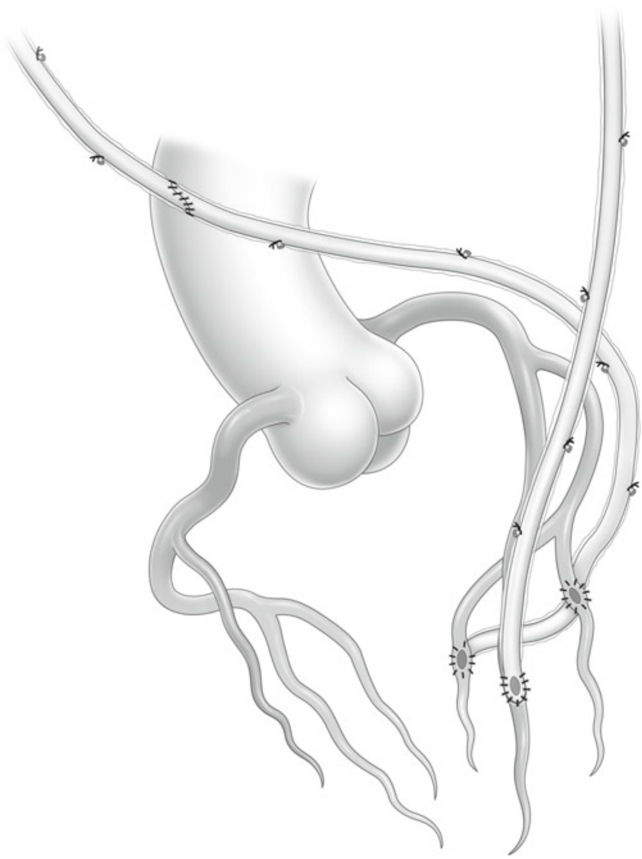

Fig. 13.4 Left internal thoracic artery is grafted to the left anterior descending artery. The in situ right internal thoracic artery and radial artery are anastomosed as an I-graft to multiple circumflex branches

ITA incision should be sufficiently matched to the RA (sometimes requiring greater than 5 mm) so as not to create stenosis of the ITA just distal to the RA-ITA anastomosis. The site of the T or Y anastomosis should be located according to the position of the first distal coronary anastomosis.

13.5.2 In Situ RITA Combined with RA to Circumflex Artery (Fig. 13.4)

Some surgeons prefer an I-composite to a Y-composite in situ RITA-to-RA graft [36]. This configuration has several advantages. First, in situ LITA to LAD is secured and not traumatized by any other grafts that may cause kinking or twisting. In addition, I-composite grafts are long enough to reach all coronary territories. Only the upper one-third of the entire length of the RITA is used; the rest of the RITA is maintained to preserve the blood supply to the body of the sternum on the right side. The RITA and RA are anastomosed in end-to-end or end-to-side fashion. An end-to-side anastomosis consisting of the distal end of the RITA and the side of the RA can prevent a purse-string effect at the anastomosis and is thus our preference. The I-composite graft can reach posterolateral and inferior branches simultaneously; however, the route of the graft (clockwise or counterclockwise orientation) must be determined. According to Kobayashi et al. [37], the route of the I-composite graft should be determined on the basis of the degree of stenosis of the terminal coronary artery anastomosed to the end of the conduit; the terminal coronary artery should have severe stenosis to avoid competitive reverse flow. The angiographic patency rate of I-composite grafts has been shown to be 99.2 % early postoperatively [37]. When an I-composite graft runs anterior to the heart, it should be wrapped in thymic tissue and covered with mediastinal fat at the end of the surgery to prevent injury in the event of reopening.

13.6 Proximal Anastomosis to the Aorta

Because aortic manipulation is considered to be a cause of postoperative stroke, aortic *no-touch* technique with off-pump CABG has been developed to reduce this risk. Edelman et al. conducted a meta-analysis comparing neurologic injury after various degrees of aortic manipulation during CABG (aortic no-touch off-pump CABG, off-pump CABG with a side clamp, and conventional CABG) [38]. Their results demonstrated a significant decrease in neurologic injury when manipulation of the ascending aorta was avoided. Stroke rate in aortic no-touch off-pump CABG was 0.41 % compared with 1.98 % in conventional CABG. However, the risk of neurologic complications cannot be completely eliminated, even with aortic no-touch and total arterial off-pump techniques are used. It is suggested that other factors may affect postoperative stroke, including microembolism of atheromatous plaque, hypoperfusion, carotid stenosis, and systemic inflammation. Epiaortic ultrasonography can detect atheromatous plaque of the ascending aorta and reduce microembolism, and its efficacy in reducing postoperative neurological complication has been demonstrated in a large observational study [39]. With the aid of epiaortic ultrasonography, proximal anastomosis of free grafts to the aorta can be safely performed using a clampless anastomotic device and achieve stroke rates similar to those achieved with aortic no-touch technique and all-arterial grafting [40]. We routinely scan the ascending aorta with preoperative computed tomography and intraoperative epiaortic ultrasonography. When SVG is used for revascularization, we use a side-biting clamp or clampless anastomotic device depending on the results of the scan.

We sometimes use composite grafting with SV and free RITA (Fig. 13.5). With this configuration, in situ LITA to LAD is secured and not traumatized by any other grafts, and the free RITA is not directly anastomosed to the aorta. The discrepancy between the thicknesses of the SV and the free

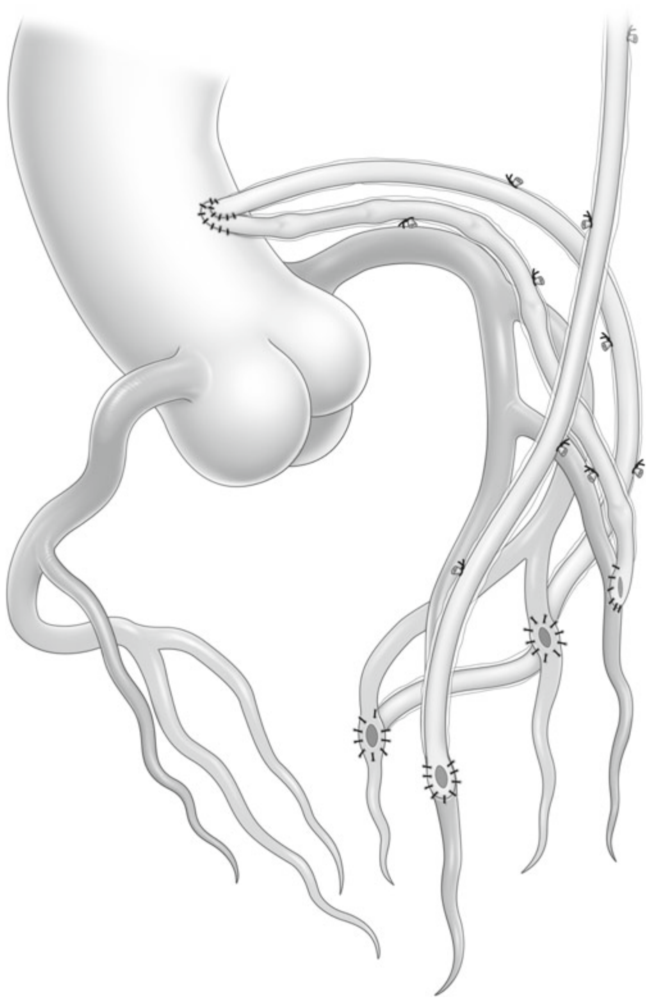

Fig. 13.5 Left internal thoracic artery is grafted to the left anterior descending artery. Aortocoronary bypass is performed with a saphenous vein graft. The free right internal thoracic artery is sutured to the head of the saphenous vein graft to multiple circumflex branches

RITA is less than that between SV and the aorta. However, care must be taken to ensure that the anastomosis is created as close as possible to the aorta because if the SVG becomes occluded, the RITA will do so simultaneously.

13.7 Composite Grafts Versus Individual Grafts

Composite arterial grafting with off-pump technique is an established method to obtain complete revascularization. Several studies have demonstrated the benefits of this strategy and recommended its routine use. The major advantage of this strategy is avoiding manipulation of the aorta and thus reducing stroke rate. Another advantage is achieving multivessel revascularizations less invasively with a limited number of arterial grafts. Moreover, complete revascularization with arterial grafts yields favorable long-term patency compared with SVG, which in turn leads to favorable life expectancy.

The use of composite and sequential arterial grafting techniques has enabled the development of further procedures, such as minimally invasive CABG through a limited-access approach with off-pump aortic *no-touch* technique and total arterial revascularization [41]. This technique is performed at the fourth or fifth intercostal space. The LITA is harvested with a harmonic scalpel with or without endoscopic guidance, and the right RA is harvested simultaneously. Specialized, commercially available heart-positioning and heart-stabilization devices are applied for distal coronary anastomoses. The RA can reach the posterior descending artery using composite T- or Y-grafting technique. The indications for this approach are limited because of the use of off-pump CABG, right-arm RA harvest, T- or Y-composite grafting, and limited visualization with a small thoracotomy.

A possible weakness of composite grafting is that the flow is dependent on a single in situ arterial graft. Preoperative assessment of the left subclavian artery is mandatory if it is to be used as inflow of a composite graft. Measurement of blood pressure in both arms as well as computed tomography and angiography should be performed preoperatively to detect atherosclerotic stenosis. Multiple grafts from a single inflow source may limit the inflow volume and result in decreased graft flow. Another potential weakness is the increased risk of competitive flow compared with individual grafts. When the degree of stenosis of the target native coronary artery is not severe, the composite arterial graft tends to demonstrate *string sign* (luminal narrowing throughout the entire conduit). In that case, individual grafting should be considered in lieu of composite grafting to a target coronary artery with only mild to moderate stenosis. The incidence of arterial graft deterioration has been shown to be particularly high when composite or multiple grafts from a single inflow source are performed to a target coronary artery with mild stenosis [30].

We believe that combinations of composite, sequential, and individual grafting techniques should be used at each institution to reduce the postoperative stroke rate while achieving complete revascularization with good-quality anastomoses and long-term clinical benefit to patients.

13.8 Conclusions

In conclusion, composite arterial grafting using off-pump technique can be routinely performed with favorable clinical and angiographic outcomes. Individual grafting with epiaortic ultrasonography and a clampless anastomotic device can be performed safely and reduce postoperative stroke rate.

When performing multiple arterial grafts, careful attention to the selection of graft material and design is important to gain the full advantages of arterial grafts.

References

1. Fitzgibbon GM, Kafka HP, Leach AJ, Keon WJ, Hooper GD, Burton JR (1996) Coronary bypass graft fate and patient outcome: angiographic follow-up of 5,065 grafts related to survival and reoperation in 1,388 patients during 25 years. J Am Coll Cardiol 28:616–626
2. Cameron A, Davis KB, Green G, Schaff HV (1996) Coronary bypass surgery with internal-thoracic-artery grafts–effects on survival over a 15-year period. N Engl J Med 334:216–219
3. Loop FD, Lytle BW, Cosgrove DM et al (1986) Influence of the internal-mammary-artery graft on 10-year survival and other cardiac events. N Engl J Med 314:1–6
4. Lytle BW, Blackstone EH, Loop FD et al (1999) Two internal thoracic artery grafts are better than one. J Thorac Cardiovasc Surg 117:855–872
5. Acar C, Ramsheyi A, Pagny JY et al (1998) The radial artery for coronary artery bypass grafting: clinical and angiographic results at five years. J Thorac Cardiovasc Surg 116:981–989
6. Suma H, Isomura T, Horii T, Sato T (2000) Late angiographic result of using the right gastroepiploic artery as a graft. J Thorac Cardiovasc Surg 120:496–498
7. Tatoulis J, Buxton BF, Fuller JA, Royse AG (1999) Total arterial coronary revascularization: techniques and results in 3,220 patients. Ann Thorac Surg 68:2093–2099
8. Calafiore AM, Di Giammarco G, Luciani N, Maddestra N, Di Nardo E, Angelini R (1994) Composite arterial conduits for a wider arterial myocardial revascularization. Ann Thorac Surg 58:185–190
9. Tector AJ, Amundsen S, Schmahl TM, Kress DC, Peter M (1994) Total revascularization with T grafts. Ann Thorac Surg 57:33–38
10. Barra JA, Bezon E, Mansourati J, Rukbi I, Mondine P, Youssef Y (1995) Reimplantation of the right internal thoracic artery as a free graft into the left in situ internal thoracic artery (Y procedure). One-year angiographic results. J Thorac Cardiovasc Surg 109:1042–1047
11. Weinschelbaum EE, Gabe ED, Macchia A, Smimmo R, Suarez LD (1997) Total myocardial revascularization with arterial conduits: radial artery combined with internal thoracic arteries. J Thorac Cardiovasc Surg 114:911–916
12. Quigley RL, Weiss SJ, Highbloom RY, Pym J (2001) Creative arterial bypass grafting can be performed on the beating heart. Ann Thorac Surg 72:793–797
13. Lemma M, Gelpi G, Mangini A et al (2001) Myocardial revascularization with multiple arterial grafts: comparison between the radial artery and the right internal thoracic artery. Ann Thorac Surg 71:1969–1973
14. Calafiore AM, Di Mauro M, D'Alessandro S et al (2002) Revascularization of the lateral wall: long-term angiographic and clinical results of radial artery versus right internal thoracic artery grafting. J Thorac Cardiovasc Surg 123:225–231
15. Caputo M, Reeves B, Marchetto G, Mahesh B, Lim K, Angelini GD (2003) Radial versus right internal thoracic artery as a second arterial conduit for coronary surgery: early and midterm outcomes. J Thorac Cardiovasc Surg 126:39–47
16. Cate CM, Gitter R, Jett K (1996) Spasm of the gastroepiploic artery used for coronary artery bypass grafting. Am J Cardiol 77:1022–1023
17. Puskas JD, Williams WH, Mahoney EM et al (2004) Off-pump vs conventional coronary artery bypass grafting: early and 1-year graft patency, cost, and quality-of-life outcomes: a randomized trial. JAMA 291:1841–1849
18. Gaudino M, Alessandrini F, Pragliola C et al (2004) Composite Y internal thoracic artery-saphenous vein grafts: short-term angiographic results and vasoreactive profile. J Thorac Cardiovasc Surg 127:1139–1944
19. Taggart DP, D'Amico R, Altman DG (2001) Effect of arterial revascularisation on survival: a systematic review of studies comparing bilateral and single internal mammary arteries. Lancet 358:870–875
20. Muneretto C, Bisleri G, Negri A et al (2003) Total arterial myocardial revascularization with composite grafts improves results of coronary surgery in elderly: a prospective randomized comparison with conventional coronary artery bypass surgery. Circulation 108(Suppl 1):II29–II33
21. Tatoulis J, Buxton BF, Fuller JA (2004) Patencies of 2127 arterial to coronary conduits over 15 years. Ann Thorac Surg 77:93–101
22. Fukui T, Tabata M, Taguri M, Manabe S, Morita S, Takanashi S (2011) Extensive reconstruction of the left anterior descending coronary artery with an internal thoracic artery graft. Ann Thorac Surg 91:445–451
23. Pevni D, Mohr R, Lev-Ran O et al (2003) Technical aspects of composite arterial grafting with double skeletonized internal thoracic arteries. Chest 123:1348–1354
24. Fukui T, Tabata M, Manabe S et al (2010) Off-pump bilateral internal thoracic artery grafting in patients with left main disease. J Thorac Cardiovasc Surg 140:1040–1045
25. Barner HB, Barnett MG (1994) Fifteen- to twenty-one-year angiographic assessment of internal thoracic artery as a bypass conduit. Ann Thorac Surg 57:1526–1528
26. Fukui T, Tabata M, Manabe S, Shimokawa T, Morita S, Takanashi S (2010) Angiographic outcomes of right internal thoracic artery grafts in situ or as free grafts in coronary artery bypass grafting. J Thorac Cardiovasc Surg 139:868–873
27. Endo M, Nishida H, Tomizawa Y, Kasanuki H (2001) Benefit of bilateral over single internal mammary artery grafts for multiple coronary artery bypass grafting. Circulation 104:2164–2170
28. Tatoulis J, Buxton BF, Fuller JA (2011) The right internal thoracic artery: the forgotten conduit–5,766 patients and 991 angiograms. Ann Thorac Surg 92:9–15
29. Fukui T, Tabata M, Morita S, Takanashi S (2012) Sequential free right internal thoracic artery grafting for multivessel coronary artery bypass grafting. J Thorac Cardiovasc Surg 144:824–829
30. Manabe S, Fukui T, Tabata M, Shimokawa T, Morita S, Takanashi S (2010) Arterial graft deterioration one year after coronary artery bypass grafting. J Thorac Cardiovasc Surg 140:1306–1311
31. Navia D, Vrancic M, Vaccarino G et al (2008) Total arterial off-pump coronary revascularization using bilateral internal thoracic arteries in triple-vessel disease: surgical technique and clinical outcomes. Ann Thorac Surg 86:524–530
32. Calafiore AM, Contini M, Vitolla G, Di Mauro M, Mazzei V, Teodori G et al (2000) Bilateral internal thoracic artery grafting: long-term clinical and angiographic results of in situ versus Y grafts. J Thorac Cardiovasc Surg 120:990–996
33. Possati G, Gaudino M, Prati F, Alessandrini F, Trani C, Glieca F, Mazzari MA, Luciani N, Schiavoni G (2003) Long-term results of the radial artery used for myocardial revascularization. Circulation 108:1350–1354
34. Nakajima H, Kobayashi J, Toda K et al (2012) Angiographic evaluation of flow distribution in sequential and composite arterial grafts for three vessel disease. Eur J Cardiothorac Surg 41:763–769
35. Kobayashi J (2009) Radial artery as a graft for coronary artery bypass grafting. Circ J 73:1178–1183

36. Sajja LR, Mannam G (2002) Right internal mammary artery and radial artery composite in situ pedicle graft in coronary artery bypass grafting. Ann Thorac Surg 73:1856–1859
37. Nakajima H, Kobayashi J, Tagusari O et al (2007) Graft design strategies with optimum antegrade bypass flow in total arterial off-pump coronary artery bypass. Eur J Cardiothorac Surg 31:276–282
38. Edelman JJ, Sherrah AG, Wilson MK, Bannon PG, Brereton RJ, Ross DE, Vallely MP (2013) Anaortic, total-arterial, off-pump coronary artery bypass surgery: why bother? Heart Lung Circ 22:161–170
39. Rosenberger P, Shernan SK, Löffler M et al (2008) The influence of epiaortic ultrasonography on intraoperative surgical management in 6051 cardiac surgical patients. Ann Thorac Surg 85:548–553
40. Emmert MY, Seifert B, Wilhelm M, Grünenfelder J, Falk V, Salzberg SP (2011) Aortic no-touch technique makes the difference in off-pump coronary artery bypass grafting. J Thorac Cardiovasc Surg 142:1499–1506
41. Lemma M, Atanasiou T, Contino M (2013) Minimally invasive cardiac surgery-coronary artery bypass graft. Multimed Man Cardiothorac Surg 2013: mmt007. doi: 10.1093/mmcts/mmt007

Harvesting: Tip and Pitfalls

14

Tetsuya Higami and Kazutoshi Tachibana

Abstract

Currently, the main graft materials used for coronary artery bypass grafting are the internal thoracic artery, radial artery, gastroepiploic artery, and saphenous vein. In this section, the characteristics of each graft and its harvesting, as well as essence of ultrasonic complete skeletonization, are described.

Keywords

Graft • Internal thoracic artery • Skeletonization

14.1 Internal Thoracic Artery

14.1.1 Characteristics of Internal Thoracic Artery

Each internal thoracic artery (ITA) is an elastic vessel (vessel with elastic tissues in the tunica media) with a lower frequency of arteriosclerosis and 2–3 mm vascular diameter which diverges from the subclavian artery and travels downward on the dorsal edges of the sternum. The vascular diameter is equivalent to the coronary diameter. Obviously, the advantages of the ITA are long-term graft patency and improved life prognosis. Among currently available grafts, the ITA is by far the best material. Furthermore, harvesting of the ITA by ultrasonic complete skeletonization (UCS) has the advantages regarding handling during surgery. The effective graft length is approximately 5 cm (30 %) longer than the ITA from pedicle harvesting. In addition, free flow of more than 100 mL/min can be obtained in many cases. The free flow increases by approximately 40 % in comparison to the ITA from pedicle harvesting. In terms of length, enough length for grafting of in situ anastomosis can be provided with UCS. With the left skeletonized ITA, all regions of the left anterior descending artery and circumflex branch can be available.

The expanded use of the right ITA with UCS has surpassed the application of pedicle harvesting. With right skeletonized ITA, most regions of the anterior descending artery and the circumflex branch, except for the end branch of the circumflex artery, can be used for in situ anastomosis. Furthermore, the bilateral ITA with UCS is not only adequately feasible for left main coronary artery disease in terms of blood flow, but it is capable of frequent use for sequential bypass, as well. In addition, the diameter of the skeletonized ITA allows easy anastomosis that leads to its feasibility in an off-pump coronary artery anastomosis in particular.

It is difficult to identify the disadvantages of the ITA. However, pedicle harvesting of the right ITA limits the coronary artery region during in situ anastomosis, which indicates less efficiency than the left ITA. Furthermore, since there are strong concerns about the development of mediastinitis caused by the use of bilateral ITA in high-risk groups including diabetic patients, the disadvantages on the use of the right ITA have been widely recognized. Consequently, the use of which is limited to special cases. However, the limited region for anastomosis and the risk of development of mediastinitis, which are indicated as disadvantages of the right

ITA, are almost solved by the application of UCS. Currently, the right ITA can be safely and easily used as long as harvested by UCS.

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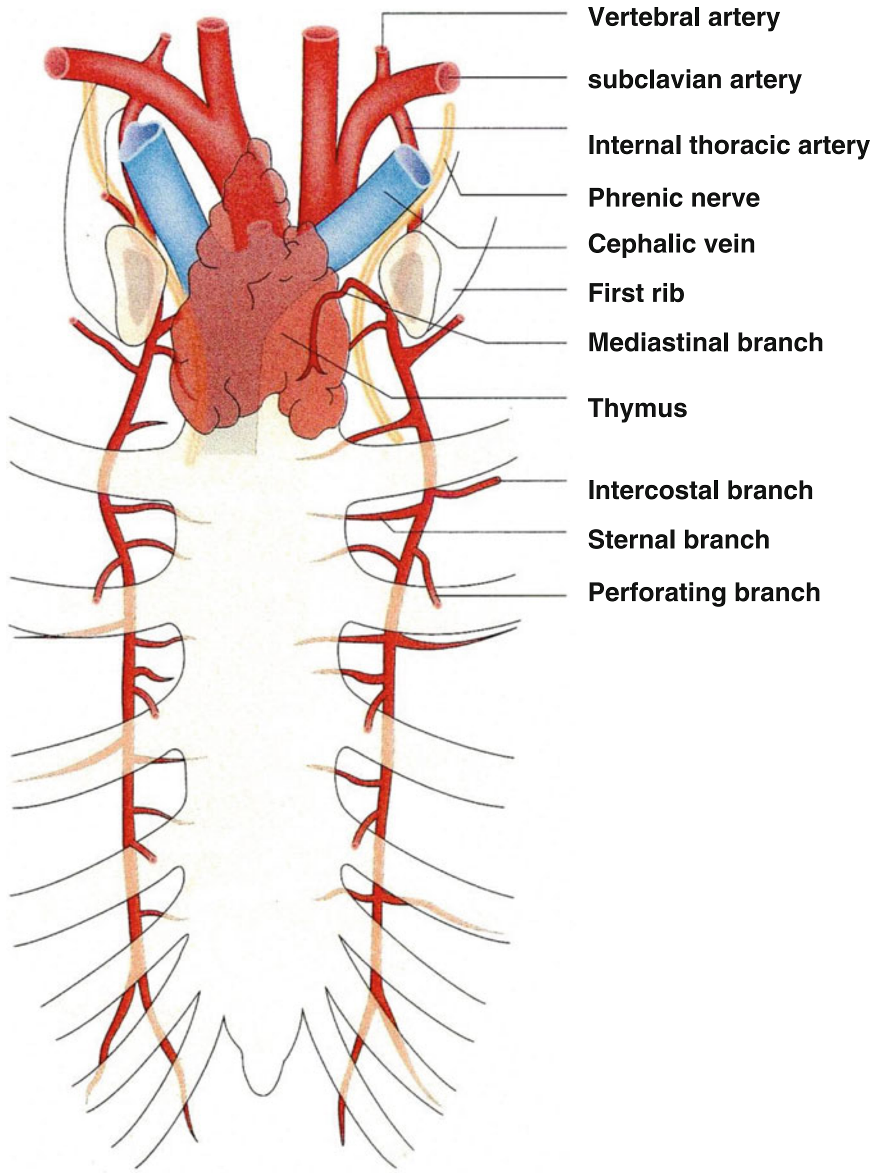

Fig. 14.1 Anatomy of internal thoracic artery

14.1.2 Anatomy of Internal Thoracic Artery (Fig. 14.1)

The ITA, opposite to the origin of the vertebral artery from the subclavian artery, diverges in almost a straight line vertically downward. The ITA courses with the phrenic nerve and then reaches the upper edge of the first rib. At this level, the ITA crosses the phrenic nerve and descends along with two accompanying veins in the space between the intercostal muscle and endothoracic fascia and rib in the posterior surface of the anterior chest wall approximately 1 cm distal to the sternal edge. However, the two accompanying veins merge at the cephalic site from the first intercostal space, and the single vein usually runs distally from the ITA. The brachiocephalic vein extends to the cephalic and lateral sites from the upper edge of the first rib. This vein is located between the medial side (laterally) and the anterior side (frontally) of the ITA. On the other side, since the transversus thoracis muscle often develops in the caudal site from the level of the fourth intercostal space and the fifth rib, the continuity of the transversus thoracis muscle makes the endothoracic fascia unclear. The ITA divides into the superior epigastric artery and musculophrenic artery at the level of the sixth rib and intercostal space.

There are three main branches of the ITA, which diverge into three different directions: (1) the sternal branch which courses to the median side (dorsum of the sternum), (2) the perforating branch which penetrates through the sternal edge, and (3) the anterior intercostal branch which courses laterally. They exit according to the number of the rib. These are the ones which must be dissected in branch trimming. Additionally, one or two branches (thymic branch and rami mediastinales) which course to the mediastinum at the upper ITA (near the first rib and first intercostal space), except the branches which supply the thoracic wall, should be dissected carefully. A relatively thick branch, which is divided superiorly and laterally from the first rib, can sometimes be seen. Trimming this branch allows the course of the ITA to be more linear, and this contributes to the extension of the effective length.

14.1.3 Internal Thoracic Artery Conventional Harvest Technique

A median sternotomy was performed. After dissecting the reflection of the mediastinal pleura from the endothoracic fascia, the ITA and both satellite veins were visualized. The endothoracic fascia was longitudinally incised several millimeters medial to one of the satellite veins using electrocautery. The incision extended along the most of the length of the vessel down to the sixth intercostal space. Retraction of the pedicle visualizes the accompanying vessels and the ITA itself. With the pedicle gently retracted downward and with gentle blunt dissection, the perforating and anterior intercostal arteries are occluded with small metal clips and divided with electrocautery close to the chest wall to avoid damaging the ITA. The pedicle is dissected up to the level of the second or first rib. With variable relation of phrenic nerve with ITA, careful dissection is needed on either side to avoid phrenic nerve injury causing paralysis of the diaphragm which results in delayed postoperative recovery. All the branches of ITA must be clipped to ensure a long-term patency. Inadequate harvest of ITA can result in steal of blood.

14.1.4 Skeletonization of the Internal Thoracic Artery with an Ultrasonic Scalpel

The right and left internal thoracic arteries possess suitable properties (quality and diameter) for grafting. Long-term graft patency of the bilateral ITA is also better. However, the conventional pedicle harvesting of bilateral ITA is now applied less commonly because of concerns about not only the length and blood flow but also the development of mediastinitis caused by a decline in blood flow to the sternum.

In contrast, ultrasonic complete skeletonization (UCS), the procedure invented by the author in 1998, [1–3] is a useful and safe graft harvest technique which alters our view on the use of ITA. The UCS can make in situ grafting using bilateral ITA easier (Fig. 14.2). In this section, the essence on ITA harvesting by UCS is described in detail.

Prior to harvesting, the endothoracic fascia is exposed by dissecting the pleura from the dorsum of the sternum. The endothoracic fascia around the third rib, approximately one centimeter near the median from the course of the ITA, is incised. An endothoracic fascia incision must be made near the median (in an upside visual field) from the internal thoracic vein, which travels with the ITA. It prevents not only unnecessary venous injury but also the knack of effective ITA dissection (Fig. 14.3). The internal thoracic vein can be visualized by a quick touch of the loose adipose and connective tissues with an ultrasonic scalpel (Harmonic Scalpel DH105; Ethicon). “Quick touch” is named for the safe and quick removal procedure of the tissues surrounding the ITA by using a cavitation phenomenon that an ultrasonic scalpel creates. The key points to use the “Quick touch” are as follows: within 0.2 s. of ITA contact time and no several contacts of the same area. When the internal thoracic vein can be clearly and proximally visualized, it should be pulled away to the superior visual field by using the Quick touch. In harvesting of the ITA, it is important for the UCS to separate the vein from the beginning of the procedure and not to cause bleeding.

The basics of ITA exposure are as follows. First is to use the “Quick touch” technique only to the superior region of the visualized ITA. Next is to leave untouched the area inferior to the ITA, that is, the margin connected to the endothoracic fascia. Final point is to rotate the ITA toward and inferiorly by pulling down the fascia. In branch dissection, start with the “Melting cut” of the sternal branch, which is visualized frontally, by grasping the endothoracic fascia with forceps using the left hand and pulling it toward and inferiorly. “Melting cut” is named for the procedure of protein coagulation of the branches by the Harmonic Scalpel. First, it is crucial to keep the probe tip of the Harmonic Scalpel 1 mm away from the main trunk and make a three-dimensional right angle, that is, to square up the main trunk, branch, and probe. Next, rotate the ITA proximally at an angle of 90° by pulling the endothoracic fascia inferior distally. Use the “Melting cut” procedure to the perforating branch visualized in front. Furthermore, rotate the artery at an angle of 90° to use the “Melting cut” procedure to the “anterior-coastal branch” in the frontal visual field. Finally, detach the ITA from the endothoracic fascia. Complete skeletonization of the region is done. In many cases, it is adequate that the distal end of the ITA is stripped up to the bifurcation of the superior epigastric artery and musculophrenic artery. The ITA of distal bifurcation has clearly different macroscopical and histological characteristics. Thus, it is not suitable as a regular graft.

In the proximal side, particularly in the proximal part of first to second intercostal spaces where the endothoracic fascia becomes unclear, harvesting is slightly different. First, the ITA is stripped bluntly using Tuppels by pushing it up from the pleural side to the sternal side, and then the course of the ITA is confirmed. After trimming the branches toward the mediastinal side, the branches toward the thoracic wall

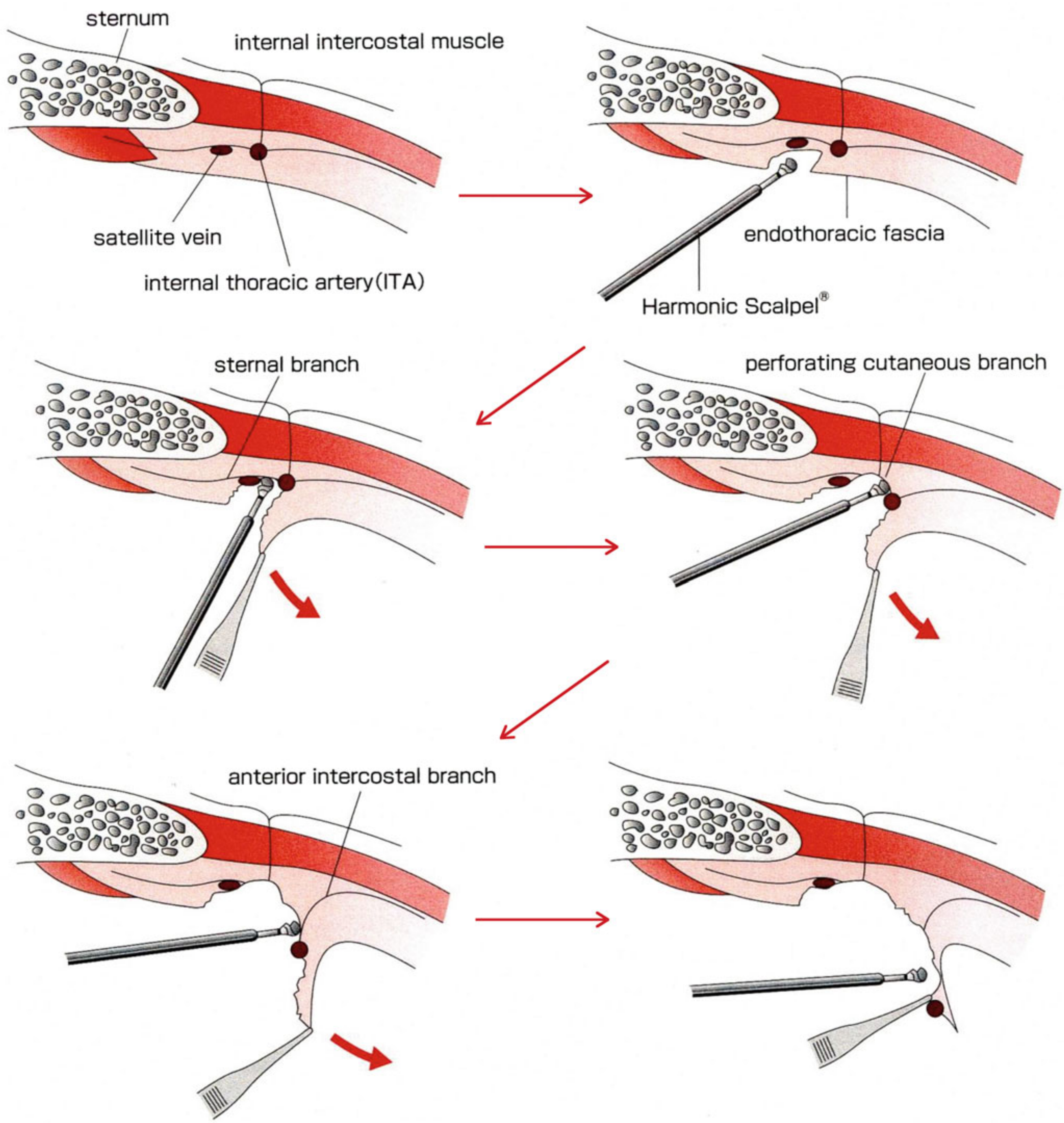

Fig. 14.2 Ultrasonic complete skeletonization of the internal thoracic artery

are trimmed with the Melting cut by rotating the ITA from the proximal visual field to the mediastinal side. Finally, the phrenic nerve is confirmed and stripped up to the site of the intersection with the ITA. At this time, it is crucial to use an ultrasonic scalpel from the viewpoint of avoiding injury to the phrenic nerve after visualizing the courses of the ITA and phrenic nerve.

After dissection of the ITA, a gauze soaked in warm papaverine hydrochloride 10 % is applied on the stripped ITA. This can solve adequately the spasm caused by irritation from the pull or rotation with forceps during ITA harvesting. After systemic heparinization, the bifurcation of the last peripheral branch is dissected, and then free flow is confirmed. The final free flow of ITA is usually more than

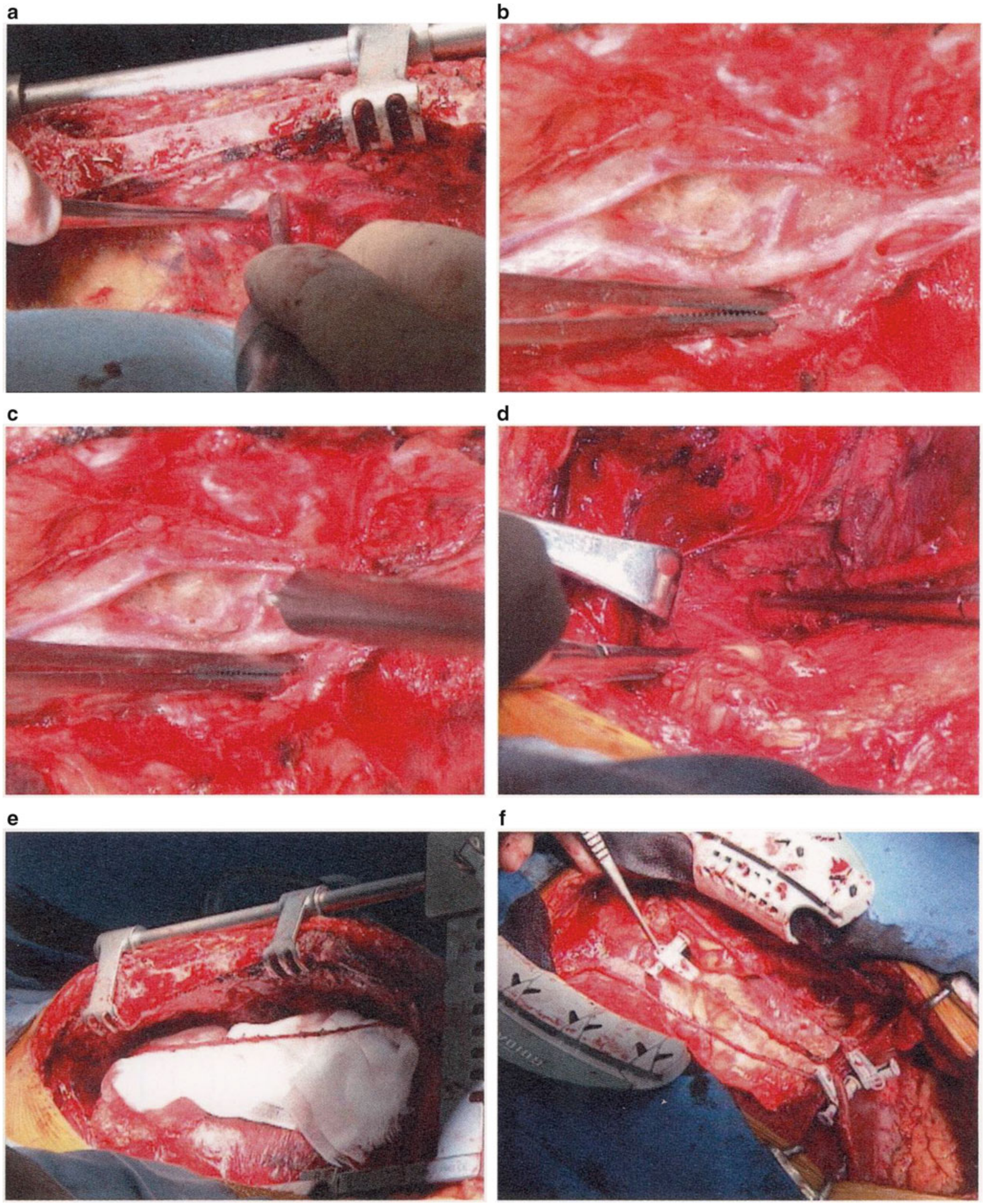

Fig. 14.3 Intraoperative view of ultrasonic complete skeletonization of the internal thoracic artery

100 ml/min. In the event that the free flow is less than 50 mL/min, ITA damage should be considered. The main causes of ITA damage are local hematoma because of branch-out, lumen pressure because of intimal dissection, and thermal damage to the media and adventitia from defect or failure of the Quick touch.

The left ITA harvested in such a way enables in situ anastomosis for the anterior descending artery region and the entire course of the circumflex branch, while the right ITA enables in situ anastomosis for most regions of the left anterior descending artery and circumflex branch.

14.2 Radial Artery

14.2.1 Characteristics of Radial Artery

The radial artery (RA) is relatively a muscular artery which lies in the forearm. Its vascular diameter is 3–4 mm which is slightly thicker than that of the ITA. The use of RA graft has been inadequate because of the occurrence of spasm. In 1992, it was reported that the use of calcium channel blocker prevented spasm. Since then, attention has been drawn to the RA as a friendly conduit for coronary grafting. When Allen's test (test to confirm discontinuity with the ulnar artery) reveals a patent RA, bilateral RA is available. Usually, the nondominant forearm is selected. Currently, the RA is often harvested by the skeletonization technique with an ultrasonic scalpel. An adequate graft length (approximately 20 cm) can be obtained. For long-term graft patency, the RA is said to be better but not superior to the ITA.

14.2.2 Preoperative Evaluation for RA Harvesting

A patient's dominant arm during interview is confirmed. Currently, transradial artery catheterization is often performed. Consequently, it is essential to confirm history of catheterization and the site. RA postharvest complication is the development of symptoms of hand ischemia because of incomplete arch and low formation of the ulnar artery. The reported frequency of low formation of the arch is 6–34 %. No reduction in blood flow from the ulnar artery to the hand is confirmed with the Allen's test. Also, a modified Allen's test for confirmation of blood flow from the arcade to the thumb is routinely conducted by suppression of the peripheral adjacent artery with the use of Doppler blood flowmetry. RA graft has a higher frequency of arteriosclerosis than that of ITA. Thus, tomography and Doppler ultrasonography are useful for evaluation of the RA aspects, such as arterial calcification and coarctation. When skeletonization is performed during surgery, evaluation with Doppler ultrasonography is not required.

The contraindications of RA harvesting are as follows: positive Allen's test results, patients with over 1.5 mg/dL of serum creatinine who are candidates for future dialysis, cases of connective tissue disease presenting with Raynaud phenomenon, and vascular trauma on the antebrachial region or vasculitis.

14.2.3 Anatomy of Radial Artery

The radial artery is the continuation of the brachial artery. It runs between the brachioradialis muscle and flexor carpi radialis in the lateral two-thirds of the forearm. In the distal one-third region of the forearm, the radial artery travels to the wrist, which is surrounded by the fascia sheath. In the proximal two-thirds of the forearm, the lateral cutaneous nerve of the forearm lies above the brachioradialis muscle. The radial nerve divides into the superficial branch and posterior interosseous nerve. The latter passes deeper and laterally than that of the RA, while the superficial branch passes along the lateral site of the RA and travels to the wrist. It is reported that sensory nerve damage can develop because of injury and edema of the lateral cutaneous nerve of the forearm and superficial branch of the radial nerve in 2.6–15.2 %. Thus, care should be taken during skin incision and dissection.

14.2.4 RA Harvest Technique (Fig. 14.4)

For skin incision, two landmark points are plotted parallel to the arterial pulsation at 1–2 cm proximal to the wrist and at 2–3 cm distal to the elbow joint. Incision is done directly above the RA slightly or proximal to the ulnar site in order to avoid edema and sensory damage to the lateral cutaneous nerve of the forearm. Next, the RA beneath the fascia sheath, 3 cm proximal to the wrist, is exposed. The fatty tissues and fascia that course along with the right and left accompanying veins are proximally dissected with an electrocautery. Then, after proximal exposure of the RA, it is adequately visualized with a retractor as it enters the muscles, and the fascial sheath overlying the RA is dissected with an electrosurgical generator. The entire course of the RA and the accompanying veins are exposed with surgical scissors. In order to separate the artery and veins, the fibrous capsule overlying the artery is dissected with surgical scissors and then incised. Since more branches of the veins lie near the elbow joint, the veins are ligated if needed to adequately expose the artery. After adequate exposure of the area directly above the artery, incision of the RA is started with the use of Harmonic Scalpel. A hook-type Harmonic Scalpel is used with output level set at 2. Basically, this maneuver is the same as that of the ITA. Dissection of each branch is sequentially performed with gentle rotation of the RA. Each branch is incised more

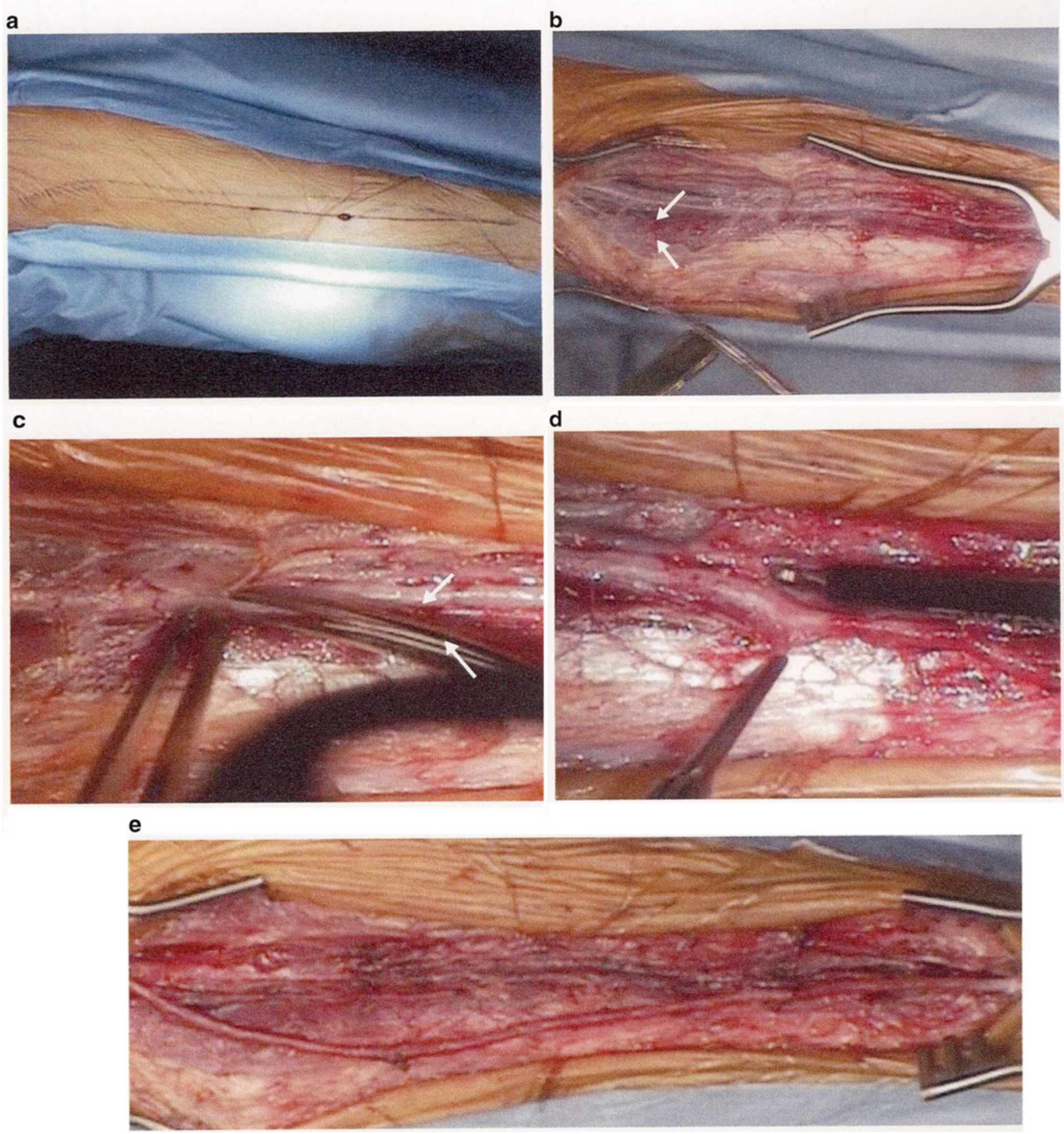

Fig. 14.4 Intraoperative view of ultrasonic complete skeletonization of the radial artery

than 1 mm distal to the main trunk, and the procedure is accomplished with the Melting cut in order not to pull the branches out. The length of the RA harvested by UCS is approximately 20–23 cm in male adults. The blood flow from the proximal site is secured. It is necessary to finally confirm if the ulnar artery and arcade are patent. A blunt needle, such as a vessel cannula, is inserted from the proximal site of the harvested RA, and the RA is hydrostatically dilated by VG solution to remove spasm. Until the time that the harvested RA will be used, it is soaked in the warm VG solution. An in vitro test revealed that "VG solution," which contains verapamil and nitroglycerin, has a superior vasorelaxant property and protective effect on the intimal layer. It demonstrates the most effective result among various vasoconstrictors (Table 14.1). After hemostasis is confirmed, only the deep fascia and skin are closed after sump drain is placed.

14.3 Gastroepiploic Artery

14.3.1 Characteristics of Gastroepiploic Artery

The gastroepiploic artery (GEA) originates from the gastroduodenal branch of the celiac artery. The GEA courses with the gastroepiploic vein 1–2 cm away from the greater curvature of the stomach (Fig. 14.5). The vascular diameter of the GEA is about the same as that of the ITA. The GEA, however, is a muscular artery which is composed of smooth muscle cells within the tunica media different from the ITA. The use of the GEA for coronary artery bypass grafting was reported to be beneficial in 1987. Since then, it has been often used as an in situ graft. However, there are concerns that long-term graft patency rate is inferior to that of the ITA, and there is competition to the blood flow with the coronary artery when stenosis rate is poor. Since the development of the skeletonization technique with the Harmonic Scalpel in order to overcome these disadvantages, the width, length, and blood flow of the GEA graft have been significantly improved. Although the GEA as an in situ graft is valuable second to the bilateral ITA graft, long-term graft patency and blood flow competition remain as its disadvantages. Basically, it is wise not to use the GEA for grafting of the left anterior descending coronary artery (LAD, Cx).

Table 14.1

VG solution	
Verapamil	5 mg
Nitroglycerin	1 mg
Heparin	500 units
8.4 % NaHCO3	1 mL
Saline	100 mL (pH 7.4)

14.3.2 GEA Harvest Technique (Fig. 14.6)

The skeletonization of the GEA is different from that of the ITA. The GEA is located in the free peritoneal cavity, and the trimming of the side branches is not suitable for the hook-type Harmonic Scalpel. Good use of the scissors-type Harmonic Scalpel for GEA skeletonization allows satisfactory results. First, pinpoint exposure of the right GEA is made from the attachment site of the greater omentum at the greater curvature of the stomach. Vessel tape is looped. Similarly, the GEA is dissected and exposed every 3–4 cm. Vessel tape is looped at each dissection site. A total of 6–7 sites are taped. Two neighboring vessel loops are lifted up. First, the fatty tissue above the GEA is completely incised with the Harmonic Scalpel without causing any damage to the GEA. This procedure is performed between vessel loops to completely expose the upper portion of the GEA. The side branches of the GEA together with the lateral fatty tissues are allowed to hang as a bundle below the GEA. Then, they are clipped and dissected with the Harmonic Scalpel 1 mm

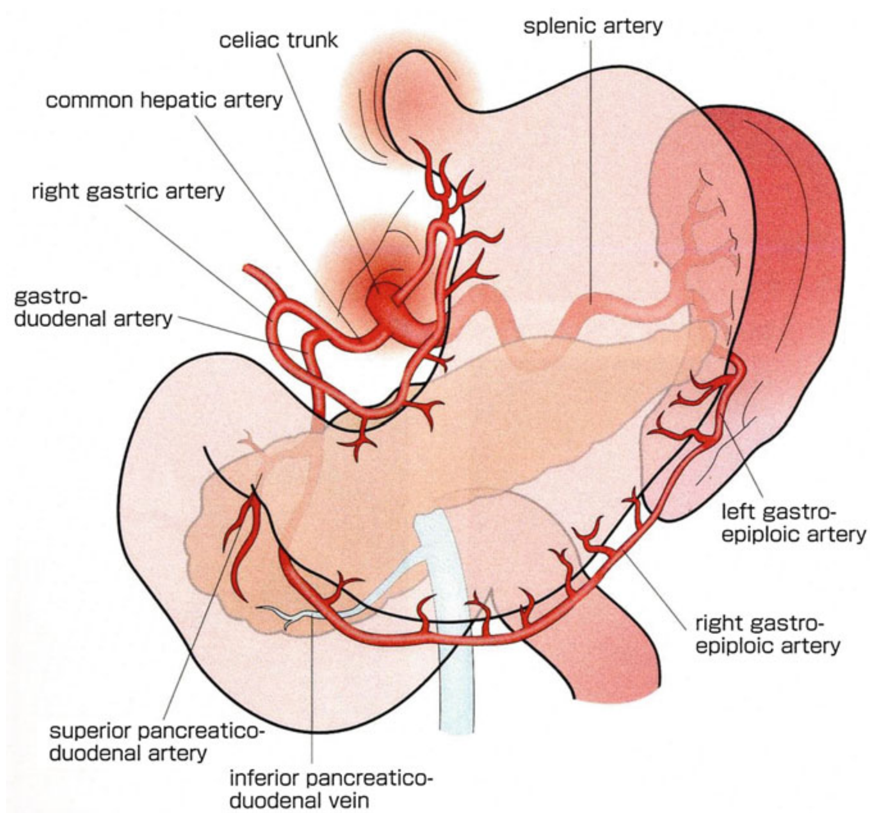

Fig. 14.5 Anatomy of gastro-epiploic artery

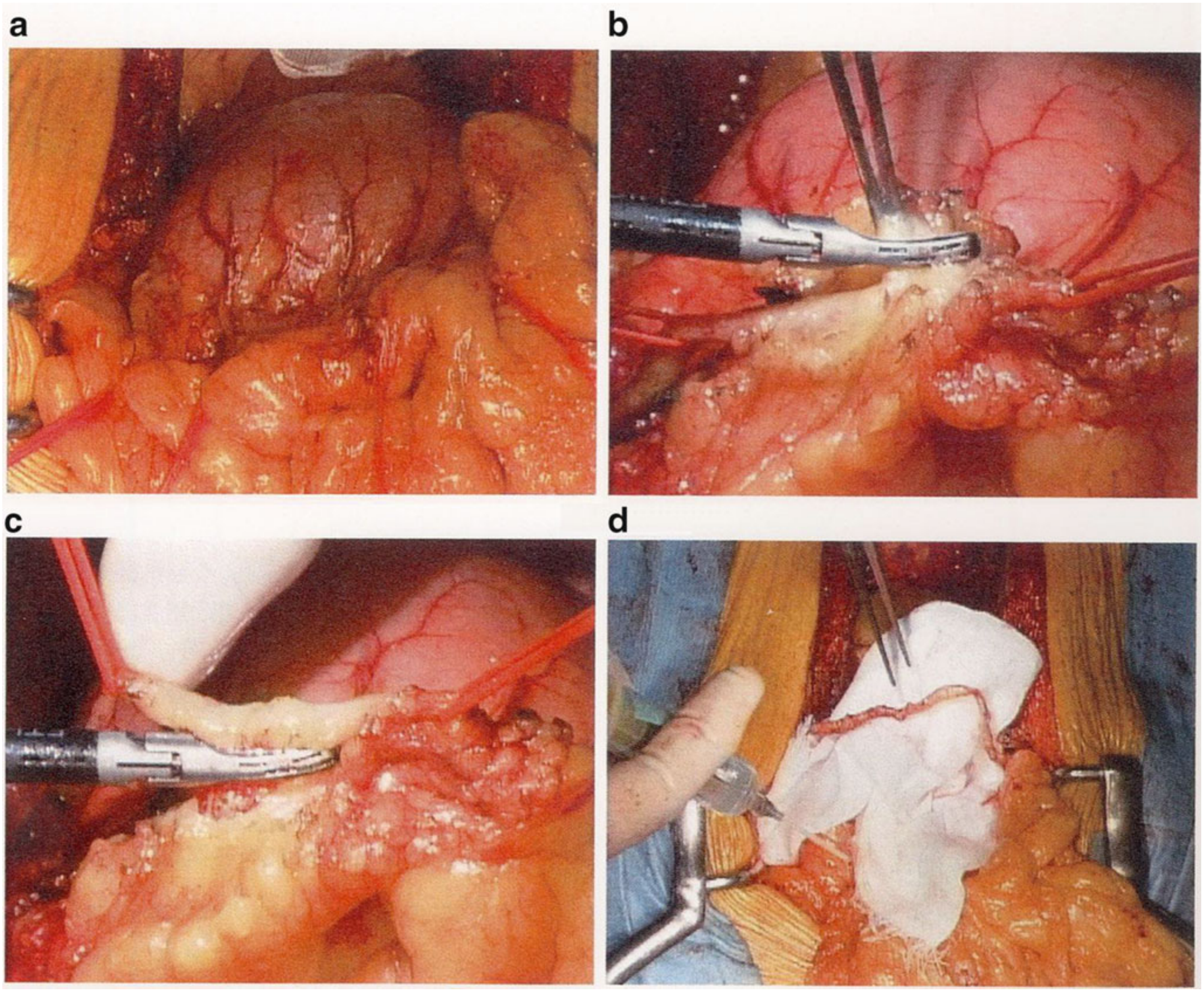

Fig. 14.6 Intraoperative view of ultrasonic complete skeletonization of the right gatro-epiploic artery

distal to the main trunk. In this case, it is important to dissect the branches by gently and slowly rotating the Harmonic Scalpel with the active side of the scissors-type Harmonic Scalpel distally from the main trunk in order to avoid thermal damage to the main trunk. This maneuver is repeated at each vessel loop to complete the skeletonization. At this time, the output level of the Harmonic Scalpel is set at 5. Bleeding due to inadequate coagulation is sometimes observed. As long as skeletonization is performed with the scissors-type Harmonic Scalpel, a longer period of time for coagulation with a lower output level can cause thermal damage to the GEA. This is why the scissors-type Harmonic Scalpel usually causes thermal damage within 2–3 cm laterally. Consequently, a shorter period of time for incision is desirable. After dissection of the GEA, it is covered with gauze soaked in warm papaverine hydrochloride 10 % solution. This solution can adequately relieve spasm caused by irritation from the traction of vessel loop during GEA harvesting.

14.4 Saphenous Vein

14.4.1 Characteristics of Saphenous Vein Graft

The saphenous vein graft (SVG) has had the longest history since Favaloro reported its use in 1968. Currently, the dependent use of SVG decreased sharply because the aorta no-touch technique for off-pump CABG is inevitable, in addition to poor long-term graft patency of SVG compared with arterial grafts. It is an indisputable fact that the SVG is useful in cases with short duration of operation, such as in an emergency surgery, and that the use of arterial graft is deficient under limited circumstances. In addition, current introduction of surgical instruments and appliances, including heart strings and vein enclosure in the aortic anastomosis, allows proximal anastomosis of the SVG, which can avoid partial occlusion of the aorta. They are easy to use in off-pump CABG.

14.4.2 Pre-evaluation for Saphenous Vein Harvesting

Past varix of the lower extremities, vein inflammation, deep thrombophlebitis, and lower extremity trauma and thermal burns are inquired during patient interview. The presence of any previous illness aforementioned is a contraindication to the use of the SVG. Unilateral varix of the lower extremity allows the use of the contralateral SVG. Consequently, preoperative inspection and palpation of the SVG are essential. If necessary, availability and patency of the SVG should be evaluated with an echography. If a vein graft after extension is less than 3 mm graft, the occurrence of early occlusion is likely high. Thus, it is recommended that the SVG should be harvested from the proximal thigh, not from the distal thigh. The following are the advantages of harvesting from the distal thigh: (1) less mismatch with the coronary artery, (2) thin subcutaneous tissue and less branching, and (3) better wound healing and less postoperative edema. On the other hand, the advantages of harvesting from the proximal thigh are as follows: (1) more elastic SVG and (2) larger caliber and better patency in cases when the proximal anastomotic devices are used.

14.4.3 SVG Harvest Technique

Currently, the endoscopic SVG harvest technique has been developed. In this section, the conventional harvest – skin incision – technique is described. The SVG in the distal thigh is harvested from the medial malleolar artery. The SVG in the proximal thigh is harvested from the groin one fingerbreadth medial and distal from the pulsation of the femoral artery. Both parts of the SVG are harvested toward the knee. It is recommended that skin incision should be performed in several batches in order to confirm the vein. If subcutaneous tissue is obliquely dissected due to misperception of the course of the SVG, this can lead to difficult harvesting, poor wound healing, and longer hospitalization. Parallel dissection of the connective tissue capsule above the SVG with surgical scissors will allow adequate length of the SVG to be exposed. During skin incision, it is essential not to touch the SVG by gripping the surrounding tissues with forceps. In the distal thigh, meticulous attention should be applied in order not to damage the saphenous nerve, which runs along the SVG. The side branches are trimmed. They are ligated with 4–0 silk suture. At this time, it is essential to gently and carefully dissect the adventitia of the branch sites in advance to avoid dissection of the surrounding tissues. Since ligation proximal to the branch site can cause SVG stenosis, more than 1 mm length of the branches should be ligated. The SVG is proximally and peripherally ligated and dissected to accomplish the harvesting. When hemostasis is confirmed particularly in the thigh, leakage of clear lymphatic fluid must be confirmed to prevent postoperative lymphatic fluid leakage. When the incision site is closed, a dead space is prevented.

References

1. Higami T et al (2000) Skeletonization and harvest of the internal thoracic artery with an ultrasonic scalpel. Ann Thorac Surg 70:307–8
2. Higami T et al (2000) Histologic and physiologic evaluation of skeletonized internal thoracic artery harvesting with an ultrasonic scalpel. J Thorac Cardiovasc Surg 120:1142–7
3. Higami T et al (2001) Early results of coronary grafting using ultrasonically skeletonized internal thoracic arteries. Ann Thorac Surg 71:1224–8

Graft–Coronary Anastomosis in Off-Pump CABG

15

Masami Ochi

Abstract

Coronary artery bypass grafting (CABG) is a surgical procedure whereby an anastomosis is formed between a graft and the coronary artery. The graft patency rate is one of the most important factors affecting long-term postoperative prognosis.

Among the many factors affecting graft patency, the most important is reliable skill in performing an anastomosis. The basic points requiring caution in performing a graft–coronary artery anastomosis are the same whether it is performed on-pump or off-pump. Surgeons must be aware, however, that there are a number of intrinsic differences when forming the anastomosis. These differences are the reason for the high degree of difficulty of off-pump anastomosis. However, by performing a large number of on-pump anastomoses, as well as accumulating experience in off-pump anastomoses, surgeons may acquire the ability to perform anastomoses of any region of the coronary artery off-pump as accurately as they would on-pump.

Keywords

Graft–coronary anastomosis • Needle handling • End-to-side anastomosis • Side-to-side anastomosis

15.1 Differences Between Off-Pump and On-Pump Anastomosis

The features of off-pump needle handling are as follows:

1. Handling the needle at a location distant from the graft and the coronary artery

   Off-pump, it is not possible to place the graft on the surface of the heart near the anastomosis site, and the first few stitches must therefore be placed at a site distant from both the graft and the coronary artery. It is important to acquire both the skill required to insert the needle accurately into the graft and the ability to handle the needle without tangling the suture.

2. The skill to secure the anastomosis field of view

   Despite the fact that the coronary artery is secured with a stabilizer, this does not suppress small movements. Spraying blood and the presence of the shunt tube may affect needle-handling operations. When a CO_2 blower is used to secure the field of view, this requires the help of an assistant with a good understanding of anastomosis skills.

3. The skill to use a needle holder to hold the needle

   On-pump, the anastomosis can be performed in an easy position and the heart can be moved to a position at which the anastomosis can be performed easily. Off-pump, however, the coronary artery to which the graft is to be anastomosed is secured with a stabilizer, which may make it difficult to puncture the vascular wall within the anastomosis with the needle. Holding the needle with a needle holder requires a different adjustment than that needed for its use on-pump.

4. Anastomosis skills in the circumflex branch region

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Ensuring the anastomosis field of view under stable circulatory dynamics in the circumflex branch region of the coronary artery, the most difficult site of anastomosis in off-pump CABG (OPCAB), requires both skill and experience. An inadequate anastomosis field of view risks the anastomosis becoming inaccurate.

5. Difficulty of dealing with a mistaken coronary artery incision

   Even on-pump, it is difficult to repair the coronary artery posterior wall if this is damaged, but this is even more difficult in OPCAB than on-pump. If the coronary artery incision to form the anastomosis is made at an angle, this makes it even more difficult to form the anastomosis than when on-pump.

6. Potential for damage to the coronary artery intima

   Intimal damage (injury) may be caused by the insertion of an intracoronary shunt or a silastic tube for the purpose of blocking localized blood flow.

7. Significant psychological burden

   The psychological pressure involved in performing an anastomosis while communicating with the anesthetist and paying attention to circulatory dynamics is greater than that required for an on-pump anastomosis. Both the skill to ensure an accurate anastomosis under difficult conditions and the concentration to maintain this are essential.

15.2 Important Points for Ensuring the Success of Off-Pump Surgery

Bearing in mind the specialist nature of OPCAB described above, a number of important points can be described:

1. The principle for puncturing the vascular wall with the needle: the "right-angle principle" (Fig. 15.1)

   When puncturing the vascular wall (especially that of the graft) with a curved suturing needle, minimizing the distance that it runs inside the vascular wall both minimizes tissue damage and prevents distortion of the anastomotic line. Because the suturing needle forms a partially circular arc, every effort must be made to make the penetration into the vascular wall at a right angle to the straight line from its tip. If this is done, the tip of the needle will penetrate the vascular wall at a straight right angle, meaning that less pressure is needed to pass it through the wall (Fig. 15.2). Surgeons will experience for themselves the sensation of the sharp needle tip precisely penetrating the tissue.

2. Adjusting the way of holding the needle with a needle holder

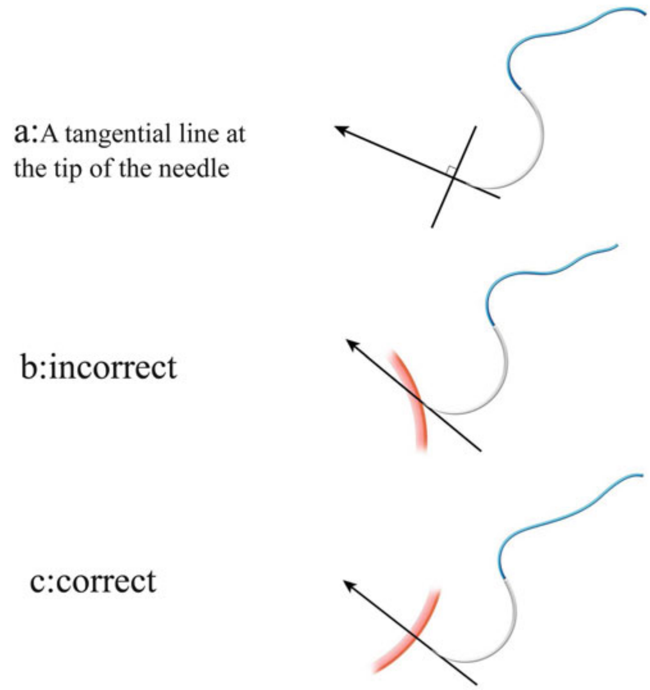

Fig. 15.1 (**a**) The tangential line at the tip of the needle must be right angled. (**b**) Oblique penetration of the needle. (**c**) Right-angled penetration of the needle

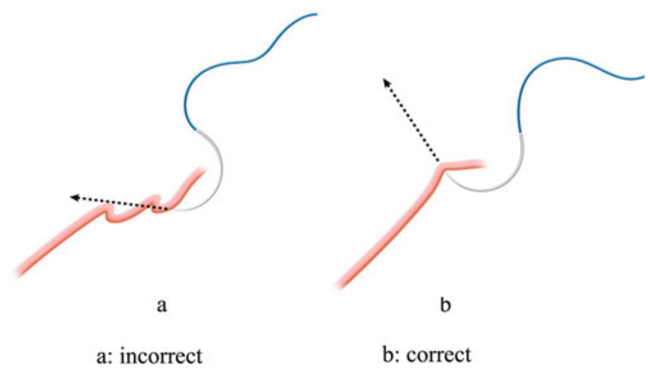

Fig. 15.2 (**a**) Oblique penetration of the needle. (**b**) Right-angled penetration of the needle

In OPCAB, the anastomosis site cannot easily be moved once the coronary artery has been secured with a stabilizer. Particularly in the circumflex branch region or in the peripheral region of the right coronary artery, an anastomosis site is deeper than it would be on-pump, and needle handling is restricted. To ensure accurate needle handling in restricted anastomosis conditions, it is important to adjust the way that the needle is held. In order to handle each needle at the optimum puncture angle for that particular needle, surgeons must know about a range of different methods of grasping needles (Figs. 15.3, 15.4,

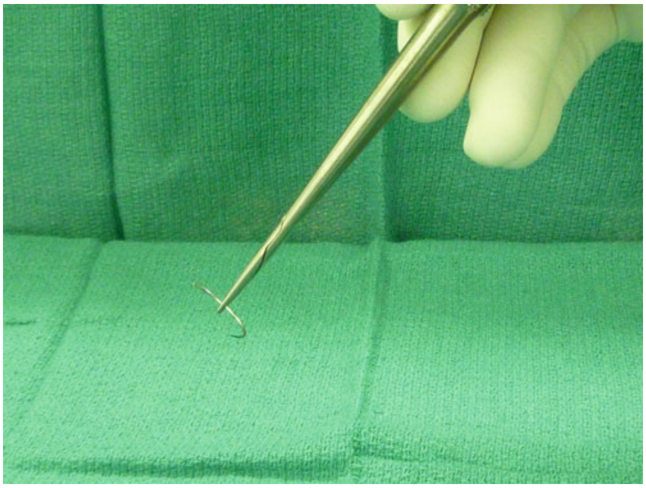

Fig. 15.3 Right-angle needle holding

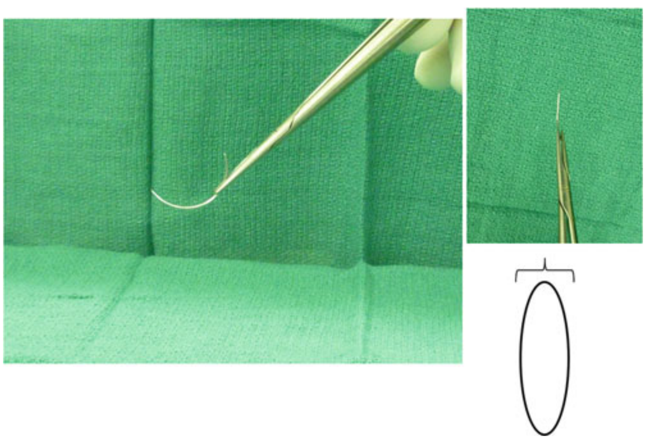

Fig. 15.4 Straight-angle needle holding for the distant toe or the heel: curly bracket

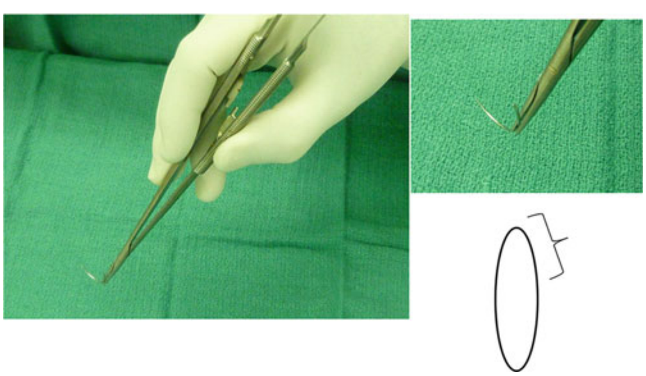

Fig. 15.5 Oblique-angle backhand needle holding for the distant far side: curly bracket

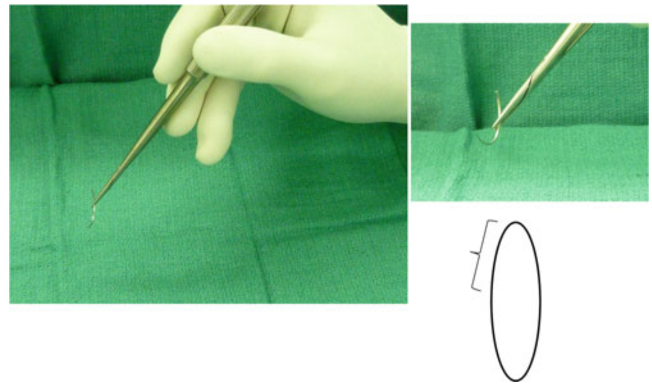

Fig. 15.6 Oblique-angle forehand needle holding for the distant near side: curly bracket

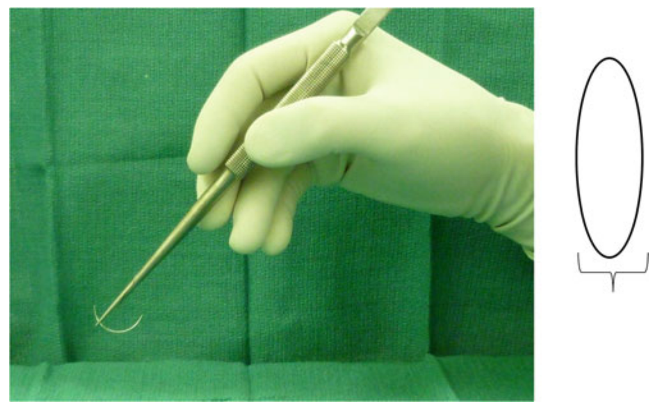

Fig. 15.7 Reversed straight-angle needle holding for the toe or the heel of this side: curly bracket

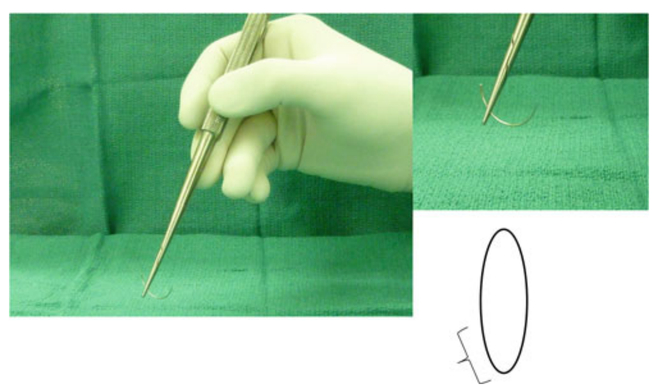

Fig. 15.8 Reversed oblique-angle forehand needle holding for the near of this side: curly bracket

15.5, 15.6, 15.7, and 15.8). By doing so, they can perform anastomoses with almost no shifts in posture or hand position.

3. Fixing the gaze on the anastomosis

As soon as a needle has been removed with forceps or a needle holder after puncture, another needle must be grasped in readiness for the next insertion. If needles are placed in readiness next to the hand, the surgeon must shift his or her gaze away from the anastomosis site. If surgeons can acquire the skill to handle needles

Fig. 15.9 Posture 1: grafting to LAD

Fig. 15.10 Posture 2: grafting to proximal circumflex

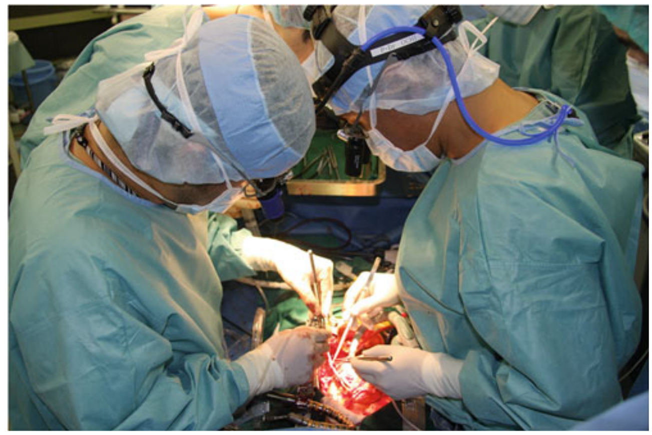

Fig. 15.11 Posture 3: grafting to distal circumflex

Fig. 15.12 Posture 4: grafting to distal RCA

appropriately with forceps and needle holders, as well as the capacity to make an instantaneous judgment on how to pick up the most appropriate needle for the next insertion, this will enable him or her to handle needles without looking away from the anastomosis site. This sort of needle handling both shortens the time required to perform the anastomosis and helps to prevent sutures from becoming tangled.

4. Always perform anastomoses in the same posture (Figs. 15.9, 15.10, 15.11, and 15.12)

   Always face the operating table straight on, and do not move the upper arms away from the body. This posture is important in order to puncture extremely fine vessels with needles at the optimum locations during OPCAB. The same posture should be maintained during all the operations involved in the anastomosis. Holding the various different needles in ways appropriate to the anastomosis aspect for each needle, while controlling the fine movements of the fingertips, will help ensure accurate needle handling.

5. Needle handling should be checked by both the operator and the assistant

   It is a basic principle of anastomosis that the operator should only start to make a puncture with a needle when he or she is confident, but the only way of preventing mistakes is to begin needle puncture under circumstances in which both the operator and the assistant are capable of checking the anastomosis aspect. Should any anxiety or doubt be felt during needle handling, the needle should be let go and left where it is. It can then be determined whether the optimum needle puncture point and direction are being used. Most mistakes can be recognized at this stage.

6. Decide on a single method of needle handling as basic

   Although there are a number of different variations on needle-handling methods during anastomosis, deciding on one basic method makes it easier for this to be understood by the assistant, meaning that mistakes will be less likely to occur.

We basically use the needle-handling method shown in the figure for all anastomoses.

15.2.1 End-to-Side Anastomosis (Fig. 15.13a–e)

– With the heel of the graft at 6 o'clock, starting from the 5 o' clock position, the graft and the coronary artery are joined by advancing 3–4 needles from the outside to the inside of the graft and from the inside to the outside of the coronary artery and pulling on the sutures (a–c).
– This is continued to the toe on the near side of the anastomosis (d).
– The opposite-side needles are handled on the far side, and the toe is ligated with two sutures (e).

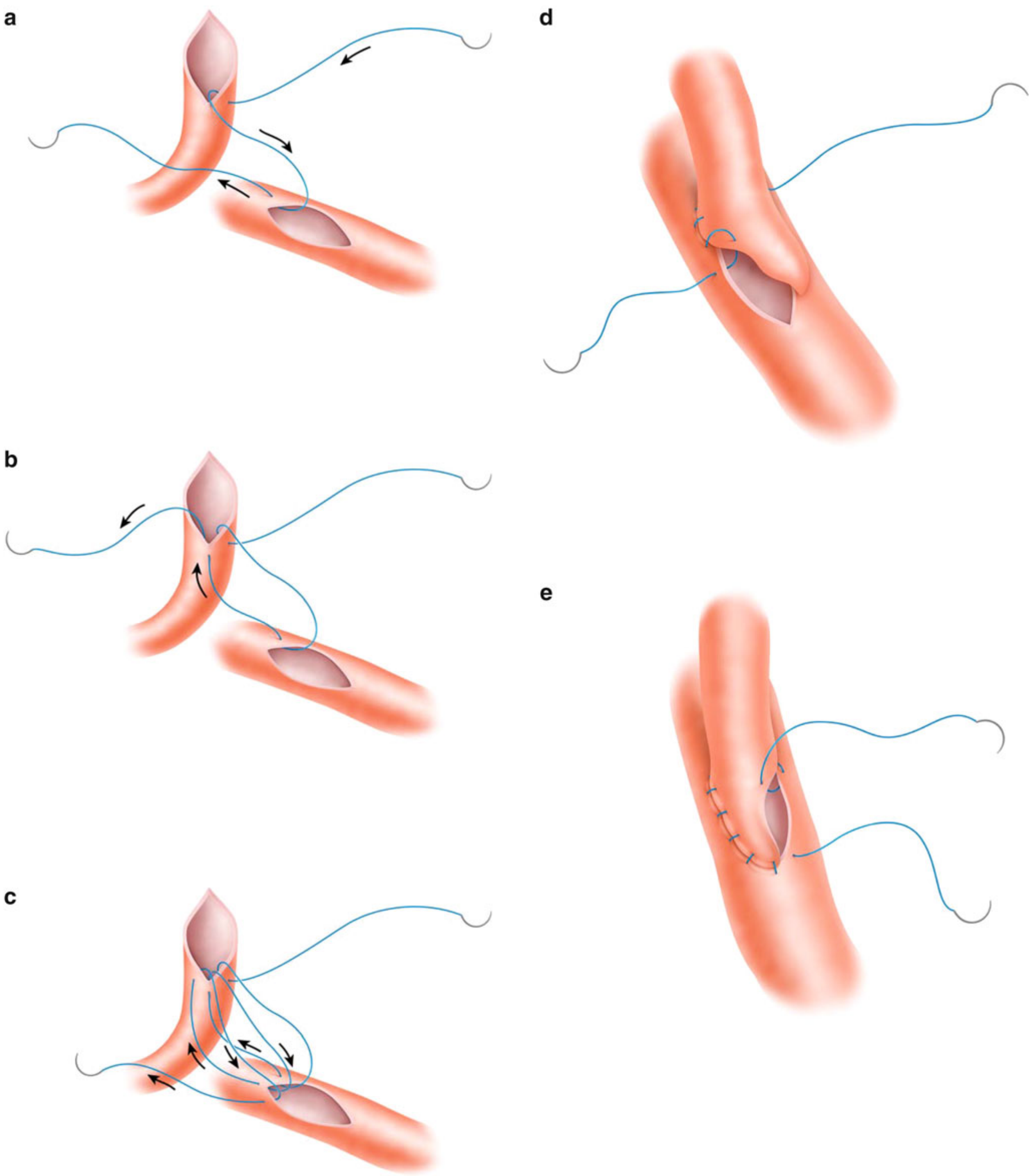

Fig. 15.13 End-to-side anastomosis

The advantages of this needle-handling method are that all needles are handled via a forehand stroke and that both the heel and toe of the coronary artery can be handled from the inside to the outside. A further advantage is that the state of the sutures on the near side can be checked from the inside while performing needle handling on the far side toward the toe.

15.2.2 Diamond Side-to-Side Anastomosis (Fig. 15.14)

In this anastomosis method, the graft and the coronary artery intersect orthogonally. It is important not to make the entrance of the anastomosis too large.

- The graft is positioned on the side opposite the opening of the incision in the coronary artery.
- One needle each is used at the heel and toe and three on each side, for a total of eight.
- A needle is punctured from the outside to the inside at number 1 on the graft in the figure and advanced from the inside to the outside of the coronary artery at number 1*, with the suture pulled tight once it has advanced a half circumference to 5* on the coronary artery.
- The remaining three needles are either advanced as they are, or another needle is inserted, whichever method is easier.

15.2.3 Parallel Side-to-Side Anastomosis (Fig. 15.15)

The needle-handling method is similar to that of the end-to-side anastomosis described above.

- If the heel is positioned at 6 o'clock of the opening of the graft incision, a needle is inserted from outside to inside at the 5-o'clock position, and 3–4 needles are then inserted toward the operator's near side to join the graft to the coronary artery.
- This is continued to the toe on the near side; another needle is inserted on the far side from the outside to the inside of the coronary artery and the inside to the outside of the graft, and ligation proceeds as far as the toe.

This anastomosis method enables a large anastomosis opening to be made with little hemorrhage. This method of performing end-to-side anastomoses between the graft and the coronary artery is used by a number of surgeons.

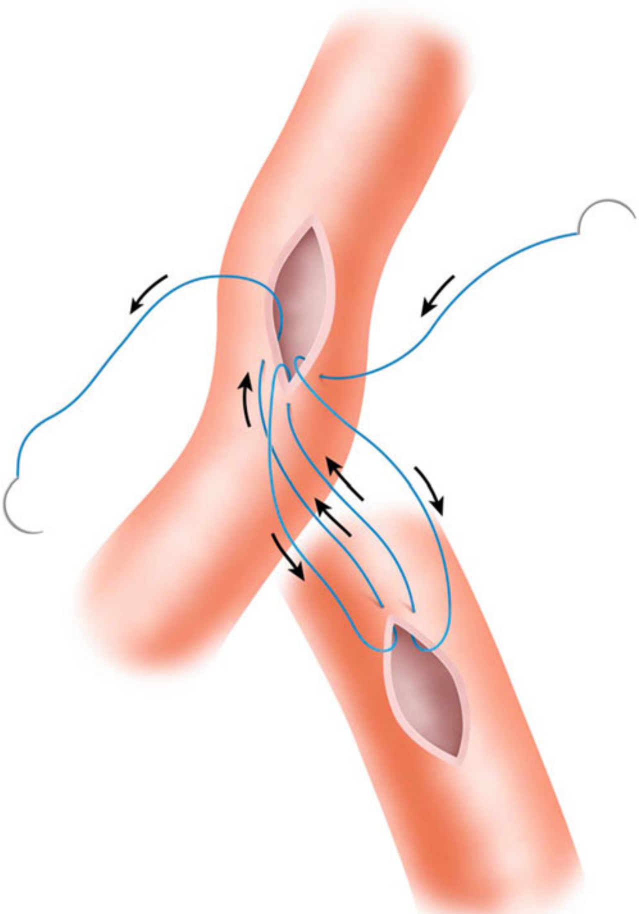

Fig. 15.14 Diamond side-to-side anastomosis

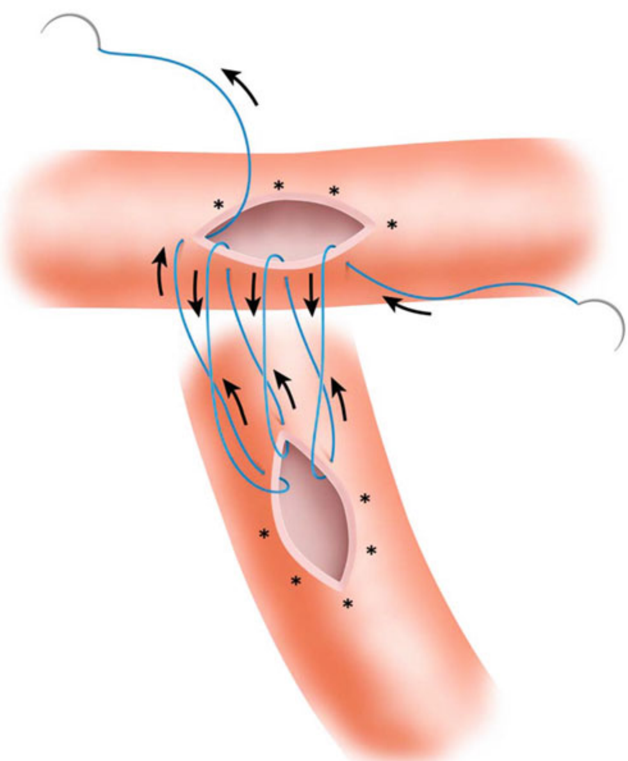

Fig. 15.15 Parallel side-to-side anastomosis

Coronary Endarterectomy and Long Onlay-Patch Grafting

16

Kosaku Nishigawa and Shuichiro Takanashi

Abstract

With the progressive application of percutaneous coronary intervention, many patients referred for surgical revascularization have complex or diffuse coronary artery disease. Such a coronary artery is a surgical challenge, since distal anastomosis is frequently difficult to perform because of diffuse atheromatous plaques. Moreover, conventional distal anastomosis to the distal diffusely diseased left anterior descending artery (LAD) cannot achieve complete revascularization of the myocardium supplied by the side branches (septal perforators and diagonal branches) affected by diffuse atheromatous lesions. For these cases, long onlay-patch grafting (with or without coronary endarterectomy) is an effective surgical option to relieve the ischemia of the myocardium supplied by the side branches affected by diffuse atheromatous lesions. In this chapter, we describe a long onlay-patch grafting with or without endarterectomy and introduce our surgical procedures for a diffusely diseased LAD with an off-pump technique.

Keywords

Diffusely diseased coronary artery • Coronary endarterectomy • Long onlay-patch grafting

16.1 Surgical Treatment for Diffusely Diseased Coronary Artery

The increasing application of percutaneous coronary intervention (PCI) has led to more patients with complex coronary artery disease or a diffusely diseased coronary artery being referred for surgical revascularization. In the Coronary Artery Surgery Study (CASS), extensive and calcified lesions could not be treated surgically in 4.9 % of diseased coronary arteries [1]. Revascularization of a diffusely diseased coronary artery is challenging not only for interventional cardiologists but also for cardiac surgeons, since diffuse atheromatous lesions frequently render themselves unsuitable for conventional distal grafting.

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Coronary endarterectomy was first introduced as a treatment option for diffusely diseased coronary artery in 1957 by Bailey et al. [2]. Although initially reported its operative mortality and morbidity led to many cardiac surgeons being reluctant to perform this procedure, recent advances in surgical techniques and perioperative management have led to reports of improved surgical outcomes of coronary endarterectomy [3]. There are two different methods for coronary endarterectomy: the closed method (traction endarterectomy) and the open method (direct-vision endarterectomy). Traction endarterectomy has risks of incomplete removal of the atheromatous plaque in the distal vessel and shearing off the plaques in the side branches. In contrast, open endarterectomy facilitates complete removal of the plaques from the main vessel and the side branches under direct vision. The main concern associated with the treatment for diffusely diseased coronary arteries is revascularization of the diffusely diseased LAD. The LAD has many side branches (septal perforators and diagonal branches) that come off at two different planes: therefore, endarterectomy

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of the LAD should be performed under direct vision through a long arteriotomy to provide adequate exposure for complete removal of the atheromatous core.

On the other hand, when the calcification of the plaques is not so severe, coronary artery reconstruction with exclusion of the atheromatous plaques from the LAD lumen, which was first reported by Barra and colleagues [4], is a surgical alternative to coronary endarterectomy.

To date, we have performed long onlay-patch grafting with or without coronary endarterectomy for diffusely diseased LAD with an off-pump technique whenever feasible [5]. In the next section, we introduce our surgical techniques of these procedures.

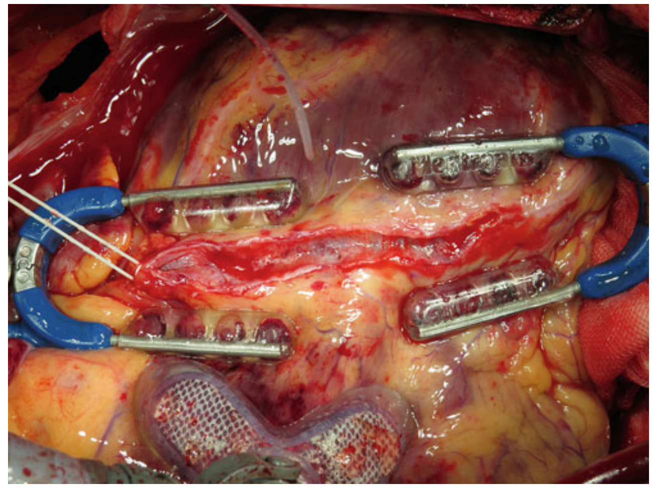

Fig. 16.1 Two sets of tissue stabilizers applied to the proximal and distal end of the long arteriotomy

16.2 Surgical Techniques for a Diffusely Diseased Coronary Artery

16.2.1 Long Onlay-Patch Grafting Without Endarterectomy (Plaque Exclusion Technique)

We perform long onlay-patch grafting when a simple distal anastomosis to the distal LAD cannot relieve the myocardium supplied by the side branches affected by diffuse atheromatous lesions. When the atheromatous plaques are not so severely calcified, long onlay-patch grafting with plaque exclusion can be performed instead of coronary endarterectomy to revascularize the diffusely diseased LAD.

After a median sternotomy, the left internal thoracic artery (LITA) is harvested in a skeletonized fashion using an ultrasonic scalpel. A commercially available heart positioner and stabilizer are routinely used. To obtain a steady operative field for the long arteriotomy and anastomosis on the diffusely diseased LAD, two sets of tissue stabilizers are placed in the distal and proximal parts of the LAD (double-Octopus technique) (Fig. 16.1) [6]. A bloodless field is obtained using a proximal silicone elastic snare suture and a carbon dioxide blower.

A longitudinal arteriotomy is made on the midportion of the diseased LAD, and the incision is extended proximally and distally. The LAD at the level of the most proximal stenotic lesion should not be opened in order to avoid competitive flow, and the distal incision is extended to the non-diseased segment of the LAD. The LITA is longitudinally incised to match the length of the arteriotomy on the LAD. The LITA is then anastomosed to the LAD with several 7-0 or 8-0 polypropylene running sutures to avoid a purse-string effect. The suture lines are placed on the insides of the plaques so as to exclude atheromatous plaques from the lumen of the coronary artery. Care should be taken not to occlude the ostia of the septal perforators and diagonal branches. The majority of the reconstructed lumen finally consists of intact intima of the LITA.

16.2.2 Long Onlay-Patch Grafting with Endarterectomy

Coronary endarterectomy is indicated when the needle cannot pass through severely calcified plaques or there are soft plaques which can be a cause of distal embolism due to plaque rupture. In addition, the techniques of coronary endarterectomy can be applied to long segmental in-stent restenosis after PCI [7]. We perform coronary endarterectomy under direct vision through a long arteriotomy with onlay-patch grafting using the LITA; we do not perform traction endarterectomy for the LAD [8].

The diseased LAD is incised in its midportion, and the incision is extended proximally and distally. The atheromatous core is carefully dissected from the adventitia using a fine spatula and forceps. All the side branches are directly observed, and their intima is carefully dissected and removed with the atheromatous core (Fig. 16.2). To avoid flow competition between the LITA and the native coronary artery, the most proximal stenotic lesion should not be removed. The distal end of the atheromatous core is sharply divided at the level of intact intima, and the divided intima is then tacked with an 8-0 polypropylene running suture. The surface of the endarterectomized LAD is flushed with saline solution, and the residual intimal flaps or fragments of plaques are completely removed. Thereafter, the skeletonized LITA is incised longitudinally and anastomosed to the LAD with several 8-0 polypropylene running sutures. As in the plaque exclusion technique, care should be taken not to occlude the ostia of the septal perforators and diagonal branches, and the majority of the reconstructed lumen consists of intact intima of the LITA (Fig. 16.3).

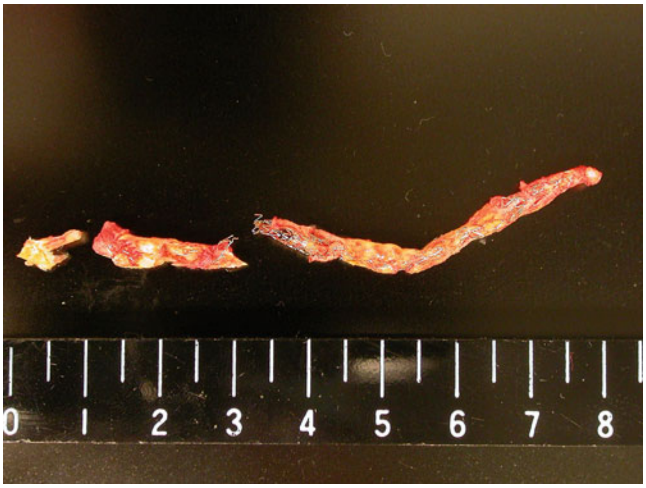

Fig. 16.2 Endarterectomized core (with restenosed coronary stents) demonstrating proper tapering of side branches

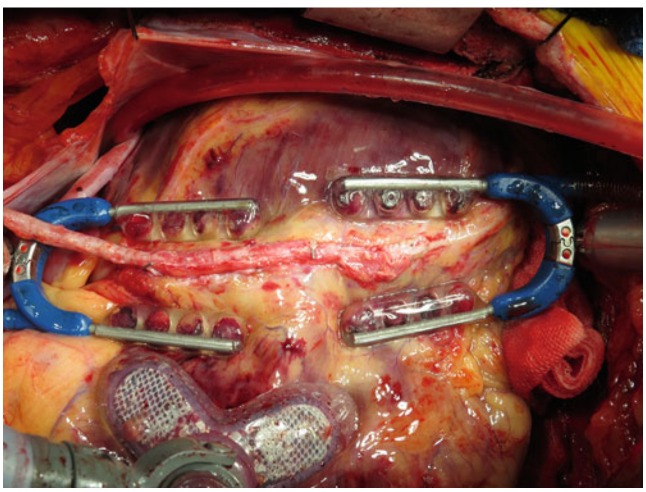

Fig. 16.3 Endarterectomized left anterior descending artery reconstructed using skeletonized left internal thoracic artery graft with an onlay-patch fashion

16.3 Postoperative Management of Coronary Endarterectomy

Unlike conventional distal grafting to the non-diseased segment, long onlay-patch grafting with or without endarterectomy for a diffusely diseased coronary artery requires a direct manipulation of a diseased coronary artery: therefore, there are several pitfalls specific to these procedures. Of those, acute thrombotic occlusion of the endarterectomized vessel is the most disastrous complication after coronary endarterectomy [9]. The lack of endothelium in the endarterectomized vessel leads to the exposure of subendothelial tissue to the bloodstream, which results in the triggering of the coagulation cascade and thrombus formation in the endarterectomized vessel. In order to prevent acute thrombosis after endarterectomy, aggressive anticoagulation treatment in combination with antiplatelet therapy is mandatory. However, to date, there have been no published guidelines or protocols describing optimal antiplatelet or anticoagulation therapy for patients undergoing coronary endarterectomy. In our institute, postoperative anticoagulant and antiplatelet treatment is performed with the following protocol: intravenous infusion of low-molecular-weight heparin (5,000 units/day) is initiated after chest tube output has decreased and continued until warfarin is effective. Low-dose aspirin (100 mg/day), clopidogrel (75 mg/day), and warfarin (maintained with a target international normalized ratio of 2.0) are started after the initiation of oral intake. Warfarin and clopidogrel are discontinued after 3 months and 1 year after surgery, respectively, but aspirin is continued indefinitely.

Here is one of our recent cases. An early postoperative angiography revealed rough surface of the endarterectomized LAD. However, follow-up coronary angiography performed 1 year after surgery demonstrated that the lumen of the reconstructed LAD had become smooth and the diameter of the reconstructed LAD had decreased to match the diameter of the LITA (Fig. 16.4).

16.4 Conclusion

The principal goal of CABG is to achieve complete myocardial revascularization. However, in diffusely diseased coronary arteries, conventional distal grafting is often difficult to perform because of diffuse atheromatous plaques. In particular, simple anastomosis to the non-diseased segment in the LAD cannot relieve the ischemia of myocardium supplied by side branches affected by diffuse atheromatous lesions. With the increasing incidence of complex or diffuse coronary artery disease, long onlay-patch grafting with or without endarterectomy may be the only surgical option to achieve complete revascularization in the diffusely diseased LAD which cannot be treated by PCI or conventional bypass grafting.

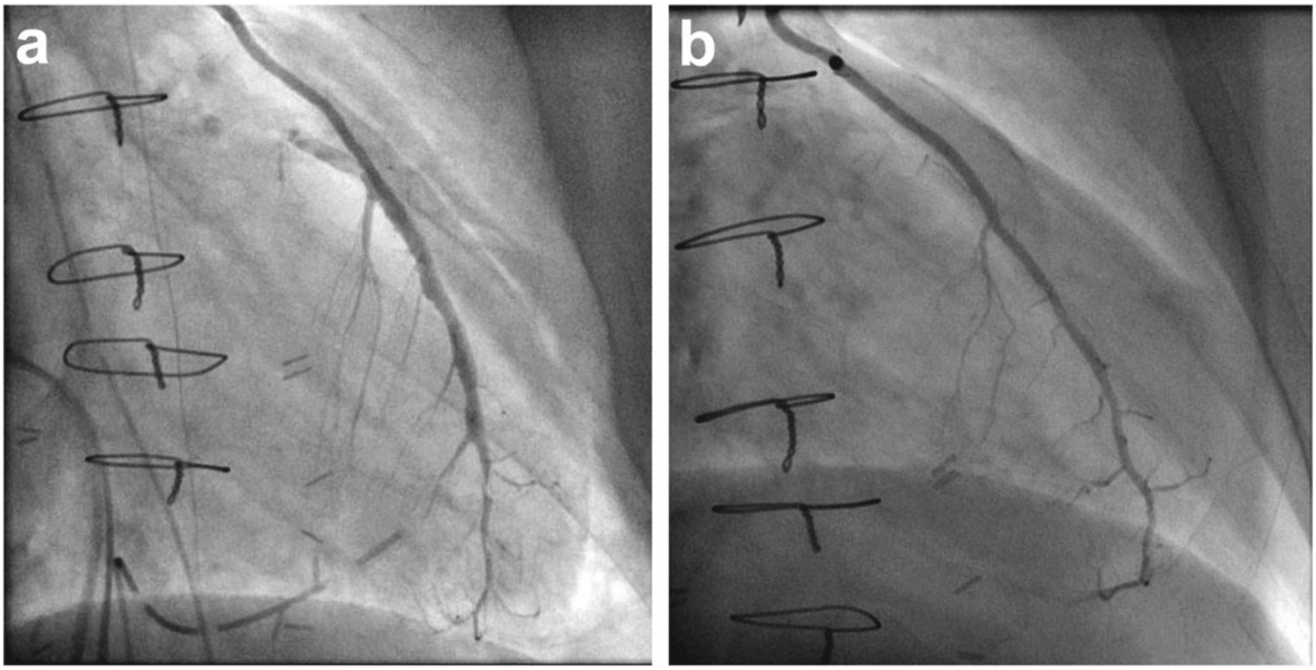

Fig. 16.4 Example of early (**a**) and 1-year (**b**) postoperative angiographic images after coronary endarterectomy for diffusely diseased left anterior descending artery

References

1. Principal CASS, Investigators and their Associates (1983) Coronary Artery Surgery Study (CASS): a randomized trial of coronary artery bypass surgery. Survival data. Circulation 68:939–950
2. Bailey CP, May A, Lewman WM (1957) Survival after coronary endarterectomy in man. JAMA 164:641–646
3. Shapira OM, Akopian G, Hussain A, Adelstein M, Lazar HL, Aldea GS et al (1999) Improved clinical outcomes in patients undergoing coronary artery bypass grafting with coronary endarterectomy. Ann Thorac Surg 68:2273–2278
4. Barra JA, Bezon E, Mondine P, Resk A, Gilard M, Mansourati J et al (2000) Surgical angioplasty with exclusion of atheromatous plaques in case of diffuse disease of the left anterior descending artery: 2 years' follow-up. Eur J Cardiothorac Surg 17:509–514
5. Fukui T, Takanashi S, Hosoda Y (2005) Long segmental reconstruction of diffusely diseased left anterior descending coronary artery with left internal thoracic artery with or without endarterectomy. Ann Thorac Surg 80:2098–2105
6. Takanashi S, Fukui T, Hosoda Y, Shimizu Y (2003) Off-pump long onlay bypass grafting using left internal mammary artery for diffusely diseased coronary artery. Ann Thorac Surg 76:635–637
7. Fukui T, Takanashi S, Hosoda Y (2005) Coronary endarterectomy and stent removal in patients with in-stent restenosis. Ann Thorac Surg 79:558–563
8. Takanashi S, Fukui T, Miyamoto Y (2008) Coronary endarterectomy in the left anterior descending artery. J Cardiol 52:261–268
9. Uchimuro T, Fukui T, Mihara W, Takanashi S (2009) Acute thrombosis after endarterectomy of stented left anterior descending artery. Interact Cardiovasc Thorac Surg 8:663–665

OPCAB Proximal

17

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Abstract

Internal thoracic artery graft (ITA) in CABG contributes for excellent long-term survival, and moreover bilateral ITA grafts improved long-term survival than single usage of ITA especially in young people. Furthermore, the use of in situ gastroepiploic artery makes it possible to achieve aorta no-touch technique in OPCAB. However, the really optimal graft selection differs according to the patient's condition such as patient's age, comorbidity, hemodialysis, frailty, and so on. Aorta manipulation is one of the biggest risk factor after CABG. In Japan, the saphenous vein graft is still used in many patients. It means that the ascending aorta is often used for the proximal blood supply sauce. We should know the significant effect of the epiaortic echo scanning for the ascending aorta and should select the proximal anastomosis technique and anastomosis devices to obtain good result and to avoid stroke after CABG.

Keywords

Proximal anastomosis • Aortic side clamp • Aortic anastomosis device • Aorta non-touch technique

17.1 Proximal Anastomosis

Internal thoracic artery graft (ITA) in coronary artery bypass surgery (CABG) contributes to excellent long-term survival, and bilateral ITA grafts offer improved long-term survival compared to single ITA grafts, especially in young patients [1–3]. The use of in situ gastroepiploic artery also allows an aorta no-touch technique for off-pump coronary artery bypass (OPCAB) [4]. The gastroepiploic artery has also been reported as an ideal graft for third graft selection [5]. However, in the real world, saphenous vein grafts are still used in many patients even in Japan. This means that the ascending aorta is often used as a proximal source of blood supply.

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Because patients with coronary artery disease have a high risk of suffering from systemic atherosclerosis, including calcification and fragile plaque on the ascending aorta, preoperative evaluation for these diseases is recommended. Although routine preoperative CT is not common in the United States or Europe, simple CT is usually performed in Japan to detect atherosclerotic legion, coronary calcification, lung disease (especially emphysematous disease), and peripheral artery disease, including abdominal aortic aneurysm. Simple CT, however, cannot detect soft plaque or moderate thickening of the ascending aorta. Contrast-enhanced CT offers greater ability to detect a thickened aorta or irregularity of the intima of the ascending aorta. However, this modality is not routinely performed because of concerns about renal influence and cost. Intraoperative epiaortic ultrasonography is recommended to detect atherosclerosis and soft plaque on the ascending aorta [6]. Simple CT and even contrast-enhanced CT cannot detect severe atherosclerosis of the aorta, which is detected on ultrasonography (Fig. 17.1). When epiaortic echoes show

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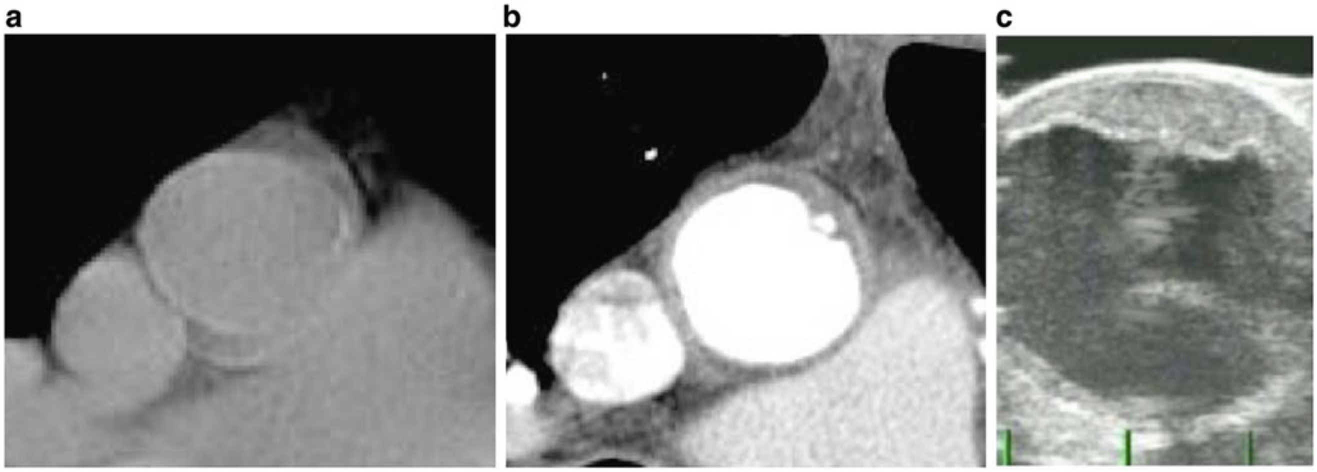

Fig. 17.1 Sample images of the ascending aorta. (**a**) is a simple CT image, (**b**) shows contrast-enhanced CT, and (**c**) shows epiaortic ultrasound echography image

atherosclerosis on the aorta, a proximal anastomosis procedure should be selected.

Aortic side clamping has been routinely used for proximal anastomosis, even for SVG, radial artery, or free arterial graft. The aortic side clamp deforms, distorts, and compresses the ascending aorta, which might crush the plaque and result in embolization, depending on the characteristics of the aorta. Lev-Ran et al. reported the usage of partial clamping as a risk factor for postoperative cerebral infarction [7]. Edelman et al. reported that postoperative cerebral infarction was observed significantly more often in a clamp group than in a clampless group [8]. On the other hand, Yamaguchi reported that if intraoperative ultrasonography showed no plaque on the ascending aorta, no significant difference in risk of postoperative cerebral infarction existed between clamp and clampless groups [9]. In Japan, intraoperative epiaortic ultrasonography is recommended and used by many surgeons.

The ascending aorta is usually used as the site of proximal anastomosis. Brachiocephalic artery and ITA graft for Y-shaped or I-shaped grafts or aortocoronary bypass graft (SVG or RA) as Y-shaped graft are other options. An I-shaped graft might sacrifice the capacity for long-term patency of the ITA graft, while a Y-shaped graft requires careful consideration about the blood contributions of each branch to avoid steal phenomenon or string sign [10].

17.2 Simple Aortic Side Clamp

The aortic side partial clamp is usually placed after finishing the distal coronary artery anastomosis and aortic declamping with heart beating. The partial clamp is placed on the anterior face of the ascending aorta, and a hole is made with a puncher following a small cut with a spit knife on the ridge of the partially clamped aorta to avoid aorta injury. Anastomosis for the circumflex artery should be made slightly toward the left side of the wall to create proximal anastomosis rising from the ascending aorta. Proximal anastomosis can be set on the anterior aspect, making the graft run parallel to the aorta, or it can pass down toward the right-sided space of the right atrium. The size of the puncher is usually 4.5 mm for vein grafts and 3.5 mm for free ITA graft or radial artery graft. A hole that is too big for the graft risks stenosis at the heel side and excessive tension on the graft on the toe side. Blood pressure should be kept low by lowering the perfusion flow when using a heart-lung machine or by administration of vasodilator to avoid aortic injury or dissection. At the same time, compression on the carotid arteries by the anesthesiologist might help debris from the clamp side escape to proceed into the arch branches.

17.3 Selection of Proximal Anastomosis Techniques

The aorta no-touch technique might carry a low risk of cerebral embolization for patients with some degree of atherosclerosis on the aorta. Some surgeons have recommended the usage of anastomosis devices [11–13, 17–19, 22–25]. However, should these aorta no-touch techniques or anastomosis devices be used in all patients? Is there any evidence that these techniques make any difference regarding cerebral infarction in patients with a normal aorta? Yamaguchi reported that when intraoperative epiaortic ultrasonography showed no atherosclerotic change on the ascending aorta, simple aortic side clamping was not associated with any significant increase in cerebral infarctions [9]. However, presence of some degree of atherosclerotic change, fragile plaque, thickening, or debris should be taken into consideration and other techniques applied to avoid manipulation of the aorta.

Fig. 17.2 PAS-Port system (http://www.cardica.com/pas-port-system.php)

17.4 Symmetry Aortic Connector (St. Jude Medical, Minneapolis, MN)

As the first device for proximal anastomosis available in Japan, the aortic connector was introduced in 2002. Results of short- and long-term studies on patency rates for this device are ambiguous [11–13]. Farhat reported histological damage to saphenous vein grafts with this device [14], which was withdrawn from use in Japan in 2006.

17.5 PAS-Port System (Cardiac, Menlo Park, CA)

The PAS-Port system was introduced in 2004 in Japan and has been used under specific conditions. It can be used for cases showing severe atherosclerosis on the ascending aorta with one spot where the aortic wall is suitably thin and smooth. The stent anchoring the vein graft to the aorta is placed external to graft, whereas the stent was inside the vein graft in the symmetry aortic connector. Although Izutani reported one case of ostial stenosis at 4 months postoperatively [15], this structure may decrease the possibility of thrombosis inside the graft and is morphologically acceptable according to Kawasaki [16]. Many groups have reported better results after clampless OPCAB using the PAS-Port system compared with conventional CABG [17–19] (Fig. 17.2).

These two anastomosis devices allowed automatic connection of the grafts on the aorta. However, some concerns have been raised regarding the quality of anastomosis, due to the need for metal stents for anchoring. The following are two new anastomosis devices that enable hand-sewn anastomosis:

Fig. 17.3 Heartstring III system (http://www.maquet.com/int/product/HEARTSTRING-III-Proximal-Seal-System-with-Aortic-Cutter?parentNodeId=hcqmzcnz#tab=Gallery)

17.6 Heartstring System (MAQUET, San Jose, CA)

The Heartstring was introduced to Japan in 2003. A hole is made with the original punch, then pressure is placed over the hole with a finger to stop the bleeding, and the sealing umbrella is inserted into the aorta. Hemostasis is achieved by blood pressure pushing the umbrella against the aorta wall [20]. Once hemostasis is obtained, anastomosis can be completed with a standard hand-sewn technique not only for the saphenous vein but also for radial artery grafts. After completing hand-sewn sutures, the sealing string comes out of the suture line as a single string. Sometimes bleeding cannot be completely controlled, but in such cases, use of the blower helps to make the hole bloodless. Thourani reported the Heartstring proximal anastomotic device could be safely used with all grades of aortic atherosclerosis, especially with moderately diseased aorta [21]. Stroke has been reported to occur with usage of this device in OPCAB [22–25] (Fig. 17.3).

17.7 Enclose II System (Novare Surgical Systems, Cupertino, CA)

This is another manual proximal anastomosis device that enables the surgeon to perform proximal hand-sewn anastomosis without side clamping. The lower jaw of the device is

Fig. 17.4 Enclose II system (http://www.vitalitecusa.com/items.php?path=/Anastomosis/Enclose%20II&id=24&tpl_id=24)

inserted into the aorta through a small hole made by a 14-G needle 2 cm above the anastomosis point. The jaw is advanced toward the point of anastomosis. The membrane of the lower jaw is opened, and the upper jaw is lowered toward the aortic wall to compress the lower jaw onto the inside of the aorta. A small incision is made in the aorta and excess aortic tissue is removed using the 3.5-mm aortic punch. Proximal anastomosis can be performed in the usual fashion. An overly deep bite might tear the membrane. After the first anastomosis is finished, the device can be repositioned for the next. This technique is not a real aorta no-touch technique. Care should be taken to avoid atherosclerotic sites for the needle hole or anastomosis position using epiaortic ultrasonography. Many reports have shown good results using this device, which is popular in Japan [25–28] (Fig. 17.4).

In OPCAB, an aorta no-touch technique using in-site arterial graft including bilateral ITA and GEA might be an optimal graft design from the perspectives of long-term patency and stroke avoidance. However, truly optimal graft selection differs according to the characteristics of the individual patient, such as age, comorbidities, hemodialysis, frailty, and so on. Manipulation of the aorta represents one of the biggest risk factors for postoperative stroke after CABG. We should know the significant effects of epiaortic echography of the ascending aorta and should select the appropriate proximal anastomosis technique and anastomosis devices to obtain optimal results and avoid stroke after CABG.

References

1. Boylan MJ, Lytle BW, Loop FD et al (1994) Surgical treatment of isolated left anterior descending coronary stenosis. Comparison of left internal mammary artery and venous autograft at 18 to 20 years of follow-up. J Thorac Cardiovasc Surg 107:657–662
2. Lytle BW, Blackstone EH, Sabik JF, Houghtaling P, Loop FD, Cosgrove DM (2004) The effect of bilateral internal thoracic artery grafting on survival during 20 postoperative years. Ann Thorac Surg 78:2005–2012; discussion 2012
3. Puskas JD, Sadiq A, Vassiliades TA, Kilgo PD, Lattouf OM (2012) Bilateral internal thoracic artery grafting is associated with significantly improved long-term survival, even among diabetic patients. Ann Thorac Surg 94:710–715; discussion 715
4. Nishida H, Tomizawa Y, Endo M, Koyanagi H, Kasanuki H (2001) Coronary artery bypass with only in situ bilateral internal thoracic arteries and right gastroepiploic artery. Circulation 104:I76–I80
5. Suzuki T, Asai T, Matsubayashi K et al (2011) In off-pump surgery, skeletonized gastroepiploic artery is superior to saphenous vein in patients with bilateral internal thoracic arterial grafts. Ann Thorac Surg 91:1159–1164
6. Das S, Dunning J (2004) Can epiaortic ultrasound reduce the incidence of intraoperative stroke during cardiac surgery? Interact Cardiovasc Thorac Surg 3:71–75
7. Lev-Ran O, Braunstein R, Sharony R et al (2005) No-touch aorta off-pump coronary surgery: the effect on stroke. J Thorac Cardiovasc Surg 129:307–313
8. Edelman JJ, Yan TD, Bannon PG, Wilson MK, Vallely MP (2011) Coronary artery bypass grafting with and without manipulation of the ascending aorta–a meta-analysis. Heart Lung Circ 20:318–324
9. Yamaguchi A, Adachi H, Tanaka M, Ino T (2009) Efficacy of intraoperative epiaortic ultrasound scanning for preventing stroke after coronary artery bypass surgery. Ann Thorac Cardiovasc Surg 15:98–104
10. Kawamura M, Nakajima H, Kobayashi J et al (2008) Patency rate of the internal thoracic artery to the left anterior descending artery bypass is reduced by competitive flow from the concomitant saphenous vein graft in the left coronary artery. Eur J Cardiothorac Surg 34:833–838
11. Kachhy RG, Kong DF, Honeycutt E, Shaw LK, Davis RD (2006) Long-term outcomes of the symmetry vein graft anastomosis device: a matched case-control analysis. Circulation 114:I425–I429
12. Bergmann P, Meszaros K, Huber S et al (2007) Forty-one-month follow-up of the symmetry aortic connector system for proximal venous anastomosis. J Thorac Cardiovasc Surg 134:23–28
13. Verberkmoes NJ, Mokhles MM, Bramer S et al (2013) Long-term clinical outcome of the symmetry aortic connector system in off-pump coronary artery bypass grafting. Thorac Cardiovasc Surg 61:669–675
14. Farhat F, Chalabreysse L, Diab C, Aubert S, Jegaden O (2004) Histological aspects of the saphenous vein damage with the use of the symmetry aortic connector system. Interact Cardiovasc Thorac Surg 3:373–375
15. Izutani H, Yoshitatsu M, Kawamoto J, Katayama K (2005) A case of ostial stenosis with the PAS-Port proximal anastomosis system in off-pump coronary artery bypass grafting. Interact Cardiovasc Thorac Surg 4:341–343
16. Kawasaki M, Fujii T, Hara M, Sasaki Y, Katayanagi T, Okuma S, Watanabe Y (2015) Morphological evaluation of proximal anastomosis by PAS-Port(®) system in patients with long-term patent grafts. Ann Thorac Cardiovasc Surg 21(2):172–177
17. Bassano C, Bovio E, Sperandio M et al (2014) Five-year clinical outcome and patency rate of device-dependent venous grafts after clampless OPCAB with PAS-port automated proximal anastomosis: the PAPA Study. J Card Surg 29:325–332
18. Verberkmoes NJ, Mokhles MM, Bramer S et al (2013) Clinical outcome of the PAS-Port(R) proximal anastomosis system in off-pump coronary artery bypass grafting in 201 patients. J Cardiovasc Surg (Torino) 54:389–395
19. Puskas JD, Halkos ME, Balkhy H et al (2009) Evaluation of the PAS-Port Proximal Anastomosis System in coronary artery bypass surgery (the EPIC trial). J Thorac Cardiovasc Surg 138:125–132
20. Takemura H, Fukumoto Y, Miyauchi T, Shimabukuro K, Imaizumi M, Ishida N (2007) Easy technique for mounting the Heartstring system into the sheath. Asian Cardiovasc Thorac Ann 15:444–445
21. Thourani VH, Razavi SA, Nguyen TC et al (2014) Incidence of postoperative stroke using the Heartstring device in 1,380 coronary

artery bypass graft patients with mild to severe atherosclerosis of the ascending aorta. Ann Thorac Surg 97:2066–2072; discussion 2072
22. Emmert MY, Grunenfelder J, Scherman J et al (2013) HEARTSTRING enabled no-touch proximal anastomosis for off-pump coronary artery bypass grafting: current evidence and technique. Interact Cardiovasc Thorac Surg 17:538–541
23. Wilhelm MJ, Syburra T, Furrer L et al (2011) Avoidance of aortic side-clamping for proximal bypass anastomoses: better short-term outcome? Heart Surg Forum 14:E360–E365
24. El Zayat H, Puskas JD, Hwang S et al (2012) Avoiding the clamp during off-pump coronary artery bypass reduces cerebral embolic events: results of a prospective randomized trial. Interact Cardiovasc Thorac Surg 14:12–16
25. Manabe S, Fukui T, Miyajima K et al (2009) Impact of proximal anastomosis procedures on stroke in off-pump coronary artery bypass grafting. J Card Surg 24:644–649
26. Kikuchi K, Tambara K, Yamamoto T, Yamasaki M, Hirose H, Amano A (2010) The use of enclose((R))II anastomosis assist device for the proximal coronary branch anastomosis to vascular graft. Ann Vasc Dis 3:84–86
27. Seto Y, Yokoyama H, Takase S et al (2012) The results of the enclose II proximal anastomotic device in 178 off-pump coronary artery bypass surgeries. Innov (Phila) 7:242–246
28. Shimokawa T, Manabe S, Sawada T, Matsuyama S, Fukui T, Takanashi S (2009) Intermediate-term patency of saphenous vein graft with a clampless hand-sewn proximal anastomosis device after off-pump coronary bypass grafting. Ann Thorac Surg 87:1416–1420

18 Intraoperative Graft Assessment OPCAB Made in Japan

Takeshi Kinoshita and Tohru Asai

Abstract

Intraoperative graft evaluation is important because early graft failure is not rare. Several investigators have reported that graft failure at one year after surgery is approximately 20 % and immediate graft failure occurs in 3.2 % of the grafts (7.6 % of patients) during surgery. These early failures are often associated with technical issues that could be solved promptly if adequately diagnosed intraoperatively. Transit-time flow measurement (TTFM) and intraoperative fluorescence imaging (IFI) are currently most commonly used systems for intraoperative graft assessment. Both systems will reliably detect occluded grafts but cannot consistently detect more minor, nonocclusive abnormalities. The strengths of the IFI system are that it is a safe, simple, and repeatable technique, but its limitations are that it only provides a semiquantitative estimate of graft flow and does not show accurate anastomotic quality. On the other hand, TTFM provides more objective measurements of graft flow but is more likely to both underestimate and overestimate the need for graft revision. High-frequency epicardial ultrasound effectively helps the surgeons to cope with intraoperative challenges: (1) identify the location of target coronary arteries, (2) select the optimal anastomotic sites, and (3) assess the quality of constructed anastomoses.

Keywords

Intraoperative graft evaluation • Transit-time flow measurement • Intraoperative fluorescence imaging • High-frequency epicardial ultrasound

18.1 Intraoperative Graft Evaluation: How and What for?

Intraoperative validation of graft patency is an essential element of coronary artery bypass grafting (CABG) because early graft failure is not rare. In recent studies of postoperative angiographic graft evaluation [1–7], graft failure rate at one year after surgery is approximately 20 %. Graft failure is not only a major cause of cardiac surgical morbidity and mortality but also results in an unfavorable long-term outcome [8]. Immediate graft failure has been reported to occur in 3.2 % of the grafts (7.6 % of patients) during surgery [9]. The PREVENT IV trial reported 25 % failure rates in vein grafts at one year. Although this trial emphasized the potential advantages of arterial grafts, we also need to know that the failure rate was 8 % even for internal thoracic artery [10]. Furthermore, arterial graft and off-pump technique have been promoted to improve long-term outcome [11, 12] and reduce the complications of cardiopulmonary bypass, respectively [13], but both techniques are technically more demanding [14]. The ROOBY trial has suggested that there may be a reduced graft patency with off-pump CABG [15]. Many of these early failures are often secondary to technical issues that could be solved promptly if adequately diagnosed

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Table 18.1 Technique for intraoperative graft assessment

Technology	Advantages	Limitations
Conventional angiography	Precise definition of graft patency, gold standard	Invasive, requires contrast agent, hybrid operating room, and catheter skills
Transit-time flowmetry	Precise graft flow value	Nonvisual, inability to define degree of stenosis
Thermal angiography	No contrast agent or radiation	Needs temperature differential to image, no clarity with increasing depth
Intraoperative fluorescence imaging	Real-time angiographic images	Only semiquantitative, limited experience

intraoperatively. Being complementary to percutaneous coronary intervention, cardiac surgeons should concentrate on how to optimize the quality of care they are providing.

18.1.1 Techniques for Intraoperative Assessment of Graft Patency

Coronary angiography is the gold standard for graft assessment. Hol and colleagues [16] reported that 4.2 % of the grafts were revised due to the findings at intraoperative angiography (1.1 % after on-pump surgery and 6.4 % after off-pump through a sternotomy). The limitation of this technique is that it requires additional machineries, personal resource, potentially nephrotoxic contrast agents, and additional operating time. Thermal coronary angiography uses infrared light to detect temperature differences generated between the myocardium and coronary arteries by the infusion of cold or warm saline or cardioplegic solutions, but image resolution is often unsatisfactory [17]. Among the available techniques for evaluating graft patency, the currently most commonly used systems are transit-time flow measurement (TTFM) [18] and intraoperative fluorescence imaging (IFI) [19]. Both systems will reliably detect occluded grafts but cannot consistently detect more minor, nonocclusive abnormalities. The strengths of the IFI system are that it is a safe, simple, and repeatable technique, but its limitations are that it only provides a semiquantitative estimate of graft flow and does not show accurate anastomotic quality. On the other hand, TTFM provides more objective measurements of graft flow but is more likely to both underestimate and overestimate the need for graft revision. Table 18.1 summarizes the strengths and limitations of other techniques which have been used to assess intraoperative graft patency.

18.2 Transit-Time Flow Measurement

18.2.1 Principle

Transit-time flow measurement is based on the transit-time principle. It uses a flow probe, which is placed around the vessel and creates a uniform ultrasound field across the vessel. Two separate piezoelectric crystals, which are located on the same side of the probe, send ultrasound pulses. A reflector is located on the opposite side of the probe and at the same distance from the two crystals. Ultrasound pulses transmit the vessel and are reflected back to the crystals. The duration spent by the ultrasound pulse to travel from one crystal across the vessel and then to be reflected (by the reflector on the opposite side of the probe) and reach the other crystal is called transit time. Ultrasound waves that travel upstream of the flow will travel slower than those going downstream. The difference in transit time between the pulse going upstream and the one going downstream is used to provide a precise measure of the volume of flow passing through the probe.

18.2.2 Practice

As shown in Fig. 18.1, TTFM provides a synchronous flow waveform and various calculated derivatives including mean graft flow, flow curve pattern, and pulsatility index.

Mean graft flow is expressed as mL/min: this value depends on many factors such as mean arterial pressure, graft-coronary resistance, and run-off in the distal microvasculature. The vascular resistance is calculated in the following formula: R = 8Lr4, where myu refers to blood viscosity, L to graft length, and r to the radius of the graft. The mean flow value per se should not be considered as a good indicator of the quality of the anastomosis because it often alters even if the anastomotic quality is excellent. Therefore, it's always interpreted with taking the other parameters into consideration [20].

The flow curve is the visual representative of the hemodynamic function of the graft. It provides the percentage of the systolic and diastolic flow and the total areas under the curve for the systolic and diastolic flow. The curves should always be linked with the electrocardioghic tracing in order to correctly differentiate the systole from the diastole.

Diastolic filling percentage (DF %) indicates the percentage of coronary filling in diastole (the blood volume filling in diastole divided by the total blood volume in one heart cycle). The flow curve patterns can be classified according to dominancy, systolic dominant when peak systolic flow exceeds peak diastolic flow by 10 % and diastolic dominant or balanced when peak diastolic flow exceeds peak systolic

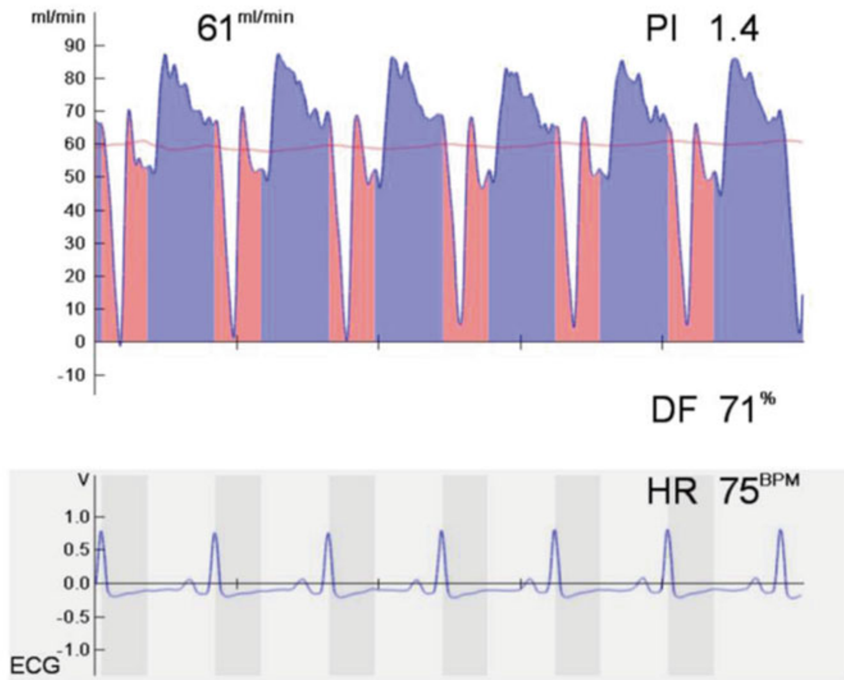

Fig. 18.1 Transit-time flowmetry display (Medistim ASA, Oslo, Norway) showing the flow waveform in a right internal thoracic artery grafting to the left anterior descending artery with a mean graft flow of 61 mL/min, pulsatility index (*PI*) of 1.4, and diastolic flow (*DF*) of 71 %. Simultaneous electrocardiogram (*ECG*) is displayed on the auxiliary option

flow by 10 % [21]. Different flow patterns may be related to the target vessel and grafts. The proportion of measured diastolic flow may increase as the flow probe is placed distally on the graft. The flow dominancy in diastolic phase is more marked in the left coronary system because of a comparatively greater systolic flow component in grafts to the right coronary system because of a lower right ventricular transmyocardial pressure gradient.

The percentage of backward flow (%BF) is another parameter provided by the flow curve. It is the percentage of flow that is directed backward within the graft compared with the total forward flow of the same cardiac cycle. The lower the rate of backward flow, the better the quality of the grafting.

The pulsatility index (PI) is an estimate of the vascular resistance and expressed as an absolute number summarized in the following formula: Qmax - Qmin/Qmean, where the mean flow is calculated across five cardiac cycles (Qmean), maximum flow is recorded in one cardiac cycle (Qmax), and minimum flow is recorded through one cardiac cycle (Qmin). The pulsatility index can be affected by several factors that increase the resistance to blood flow, including graft stenosis or occlusion, distal native coronary artery stenosis, and poor run-off in the distal microvasculature. Generally a pulsatility index value of more than 5 is considered to indicate unsatisfactory graft flow.

18.2.3 Current Experience and Results

A recent meta-analysis summarizes the clinical outcome of TTFM [22]. A total of 1411 grafts in 509 patients were assessed; 3.2 % of the grafts in 8.8 % of the patients were revised based on the TTFM findings. Many authors have tried to define threshold values for the different TTFM findings and to distinguish patent from occluded grafts. A mean flow of 15 mL/min or less, a PI of 5 or higher, and a BF of 4 or higher seem to be the optimal cutoff criteria to predict early graft failure [23–25]. A systolic dominant flow curve pattern is a risk factor in grafts to the left coronary artery [25].

18.2.4 Limitations

Although transit-time flowmetry reliably validates graft patency in the majority of grafts with good flow, in some cases interpretation of the TTFM parameters is difficult and substantial uncertainty about graft patency may remain. Hirotani and colleagues [26] compared intraoperative TTFM results in 291 internal thoracic artery grafts and 190 saphenous vein grafts in 171 patients with postoperative coronary angiography performed before hospital discharge. They reported that although the graft flow was significantly correlated with the grafted perfusion areas and the diameter of the bypassed coronary arteries, no significant difference was observed between the flows of the ITA grafts with and without stenosis or string sign. Hol and colleagues [27] investigated TTFM measurements and angiography in 124 grafts in 72 patients, reported that TTFM did not detect significant angiographic abnormalities in arterial and venous grafts including an occluded internal mammary artery graft, and concluded that TTFM alone may underestimate graft failure.

18.3 Intraoperative Fluorescence Imaging

18.3.1 Principle

Intraoperative fluorescence imaging is a novel vascular imaging technique based on the fluorescent properties of indocyanine green (ICG) dye. After intravenous injection, ICG quickly binds to plasma proteins, and, when illuminated with a monochromatic light source at 806 nm (near infrared), it emits light with a wavelength of 830 nm. This fluorescence is then captured and analyzed with a charge-coupled device video camera. The total output of the laser is 2.7 W, and the camera is placed 30 cm above the heart and analyzes an area of 7.5 cm × 7.5 cm. The laser light depth of tissue penetration is about 1 mm and has been demonstrated not to cause myocardial thermal damage. This laser light source has been shown to be safe. No protective eyewear is necessary, and ICG has been demonstrated safe over a 40-year period. The incidence of allergic reaction to ICG is strongly dose dependent, being greatest with doses in excess of 0.5 mg/kg, and is reported to be approximately 1:40000, especially in patients allergic to iodine [28].

18.3.2 Practice

The camera is covered with a sterile polyethylene drape and positioned 30 cm above the heart. ICG is made up of a concentration of 2.5 mg/mL. At the completion of the distal anastomoses, a bolus of 1 mL of ICG dye can be injected wither in the ascending aorta [29] or in the central venous pressure catheter (if the operation is performed off pump) or directly into the oxygenator in on-pump surgery. The dye is rapidly flushed with 10 mL of normal saline. Immediately after intravenous dye injection (or after a 5-s delay if the dye is injected into the oxygenator), the laser power is activated and captured images are recorded on the computer hard drive. The appearance of fluorescent ICG dye passing antegradely inside the bypass grafts and perfusing the coronary artery tree confirms graft patency (Fig. 18.2). This procedure takes approximately 3 min per graft. The visualization of dye fluorescence is better with skeletonized conduits compared with pedicled conduits. ICG injections can be administered repeatedly.

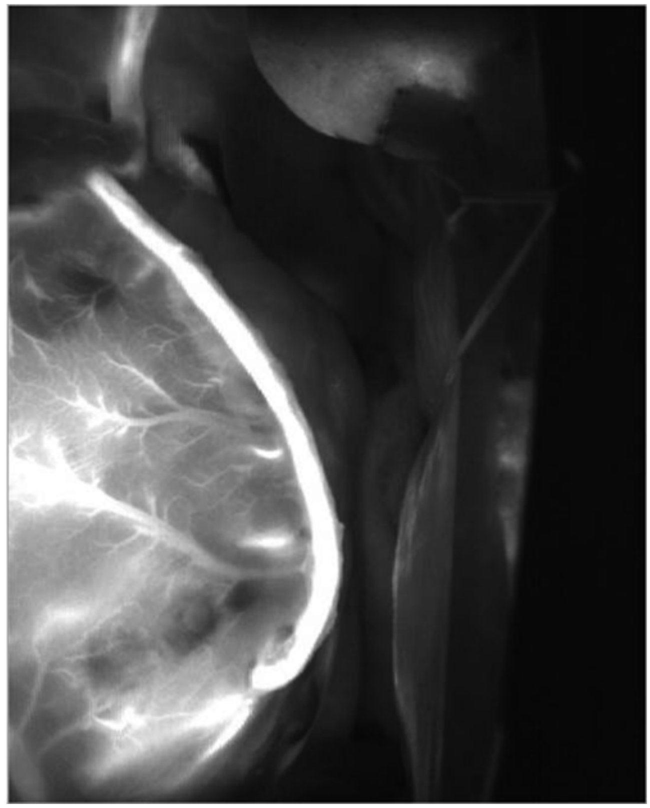

Fig. 18.2 Left internal thoracic artery graft to the left circumflex artery demonstrated by intraoperative fluorescence imaging (SPY, Novadaq, Toronto, Canada)

18.3.3 Current Experience and Results

The first experience with intraoperative fluorescence imaging in coronary artery surgery was reported by Rubens [30] in 2002. As listed in Table 18.2, several investigators have reported their experience with this technology [19, 31–37]. The assessment of 2,197 bypass grafts in 783 patients demonstrated an overall graft revision rate of 2.0 % in 6.2 % of patients. The sensitivity and specificity of IFI to detect graft occlusion or stenosis greater than 50 % was 83–100 % and 100 %, respectively.

18.3.4 Strength

The great advantage of IFI assessment is that it makes blood flow through a grafted vessel visible, and where there is no enhancement in the graft, revision of the graft is obviously

Table 18.2 Studies with IFI

				Revised grafts				
Year	First author	No. patients	No. grafts	No	% of grafts	% of patients	Sensitivity	Specificity
2002	Rubens [23]	20		1	N/A	N/A	N/A	N/A
2003	Reuthebuch [24]	38	107	4	3.7	10.5	N/A	N/A
2003	Taggart [11]	84	213	4	1.9	5	N/A	N/A
2004	Balacumaraswami [25]	200	533	8	1.5	4	N/A	N/A
2004	Takahashi [26]	72	290	4	1.4	5.6	N/A	N/A
2005	Desai [27]	120	348	5	1.4	4.2	83.3	100
2009	Handa [28]	39	116	2	1.7	5.1	100	100
2010	Handa [29]	51	153	4	2.6	7.8	85.7	100
2012	Kuroyanagi [30]	159	437	12	2.1	7.5	N/A	N/A
		783	2197	44	2	6.2		

required. Furthermore, it does a more physiologic assessment of graft flow than conventional angiography because there is no selective pressure injection into a graft that changes the baseline physiologic state.

18.3.5 Limitations

Fluorescence imaging does not produce precise measurements of flow in patent grafts, but gives a semiquantitative and monoplane assessment of graft patency. There are no clear intermediate criteria between "enhanced" and "not enhanced" by which to assess graft quality, and it may be difficult to decide whether to revise in cases where IFI indicates positive but slow enhancement of the graft vessel (Fig. 18.3). In IFI, the enhancement effect develops from ICG injected through the venous line, through the superior vena cava and right side of the heart, and the pulmonary vasculature, emerging from the left side of the heart. The time until enhancement of graft or other vessels is thus influenced by various factors such as arterial anatomic path length and blood flow velocity (involving cardiac output, systemic vascular resistance, and any limitation of blood flow velocity in a graft vessel as dictated by flow rate through anastomoses). Thus, for example, the enhancement effect normally arrives later in the GEA than in the ITA because of greater distance from the heart, but when enhancement begins, it should move along each graft vessel at a speed dictated by the blood flow velocity through the anastomoses. For the same reason, intraoperative fluorescence imaging arrival times can be important. In view of path length differences, it might seem inappropriate to use the delay until manifestation of fluorescent enhancement to assess graft quality. However, in a situation where both RITA and LITA are used together, the delay to start of enhancement is very important. They represent similar path lengths from the heart, and if blood flows through both at similar rates, then the time to start of enhancement should also be similar. In practice, delayed enhancement can be very useful for finding problematic grafts.

Because this system requires direct "line-of-sight" imaging, the heart needs to be distracted from its native position to visualize the grafts and anastomoses. Therefore, grafts are not evaluated in their native state when graft kinking could theoretically be present and absent when the heart is in the distracted position to allow access to the camera. This is particularly problematic for circumflex grafts.

Since tissue penetration is limited and image is acquired from directly above the anastomoses, precise assessment of anastomotic quality cannot be provided. This is particularly problematic when the anastomosis is located subepicardially or ITA or GEA grafts are not completely skeletonized.

Fluorescence imaging may not allow complete visualization of the whole length of a graft, and, whenever an abnormality (a compression, twist, or bend) occurs in the graft at a point far away from the laser light, the finding may be erroneously interpreted as a graft failure.

In conditions in which the native flow creates competition, the reason for poor graft flow may not be immediately evident and fluorescence imaging may lead to erroneous interpretation of the graft status. If competitive flow is suspected to be the cause, snaring of the native coronary artery proximal to the anastomosis may elucidate suspicious findings.

18.3.6 Prospective Comparison of IFI and TTFM

In a prospective comparison of IFI and TTFM, Balacumaraswami [38] compared the simultaneous use of IFI and TTFM to evaluate graft patency and found that although in the majority of the patients both techniques are useful to confirm graft patency (91 % of the grafts), in 3.8 % of grafts (10 % of patients) TTFM showed persistently poor flow when IFI demonstrated satisfactory flow. They concluded that the use of TTFM alone may prompt unnecessary

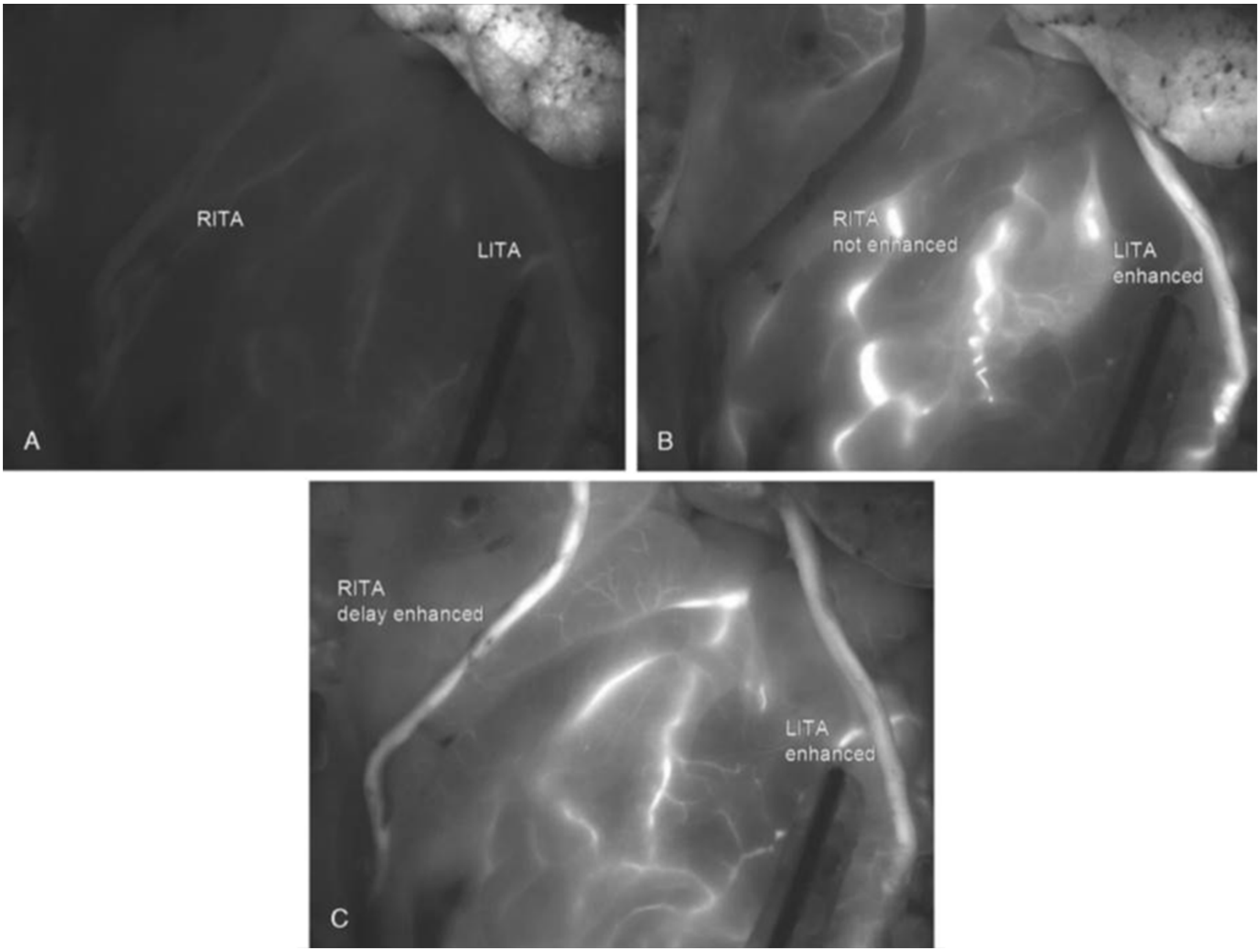

Fig. 18.3 Bilateral ITAs were enhanced, but there was a little time lag between the RITA and the LITA. The LITA graft to the left circumflex coronary artery showed slower blood flow than the RITA. (**a**–**c**): Progress is shown in chronological order: (**a**, **b**, and **c**)

graft revision. Desai studied 46 patients receiving 139 grafts; the sensitivity and specificity for detecting graft failure (defined as occlusion or stenosis greater that 50 % at postoperative standard angiography) was 83.3 % and 100 % for IFI and 25 % and 95 % for TTFM, respectively [39]. The difference in sensitivity between IFI and TTFM in detecting graft failure was significant ($p = 0.023$), and the authors concluded that IFI provided better diagnostic accuracy for detection of graft failure. Kuroyanagi investigated outcomes in 159 patients receiving off-pump CABG with 435 grafts and commented that delayed enhancement of one ITA in comparison with the other suggested either native competitive flow or a bypass graft problem [37].

18.4 Epicardial Ultrasound

High-frequency (6.5–15 MHz) epicardial ultrasound (ECUS) helps the surgeons to cope with intraoperative challenges: (1) identify the location of target coronary arteries, (2) select the optimal anastomotic sites, and (3) assess the quality of constructed anastomoses.

18.4.1 Equipment and Scanning

Linear array transducer has a high imaging frequency (6.5–15 MHz) for detailed visualization of small coronary arteries. The phantom resolution of the probes is in the range of 0.10–0.25 mm with approximately 4 cm penetration depth. The size of transducers gradually decreased from rod-shaped transducers as large as 24*2.5 cm to those as small as 3*1 cm (Fig. 18.4). Mini-transducers can reach all parts of the heart and easily pass through a trocar for endoscopic use. The transducer needs to be placed in a sterile cover or to be sterilized. The beating heart with a stabilization device provides an ideal condition for detailed visualization because it represents the physiologic blood pressure and flow in the coronary arteries and anastomoses. Without stabilization, it is more difficult to obtain an accurate imaging

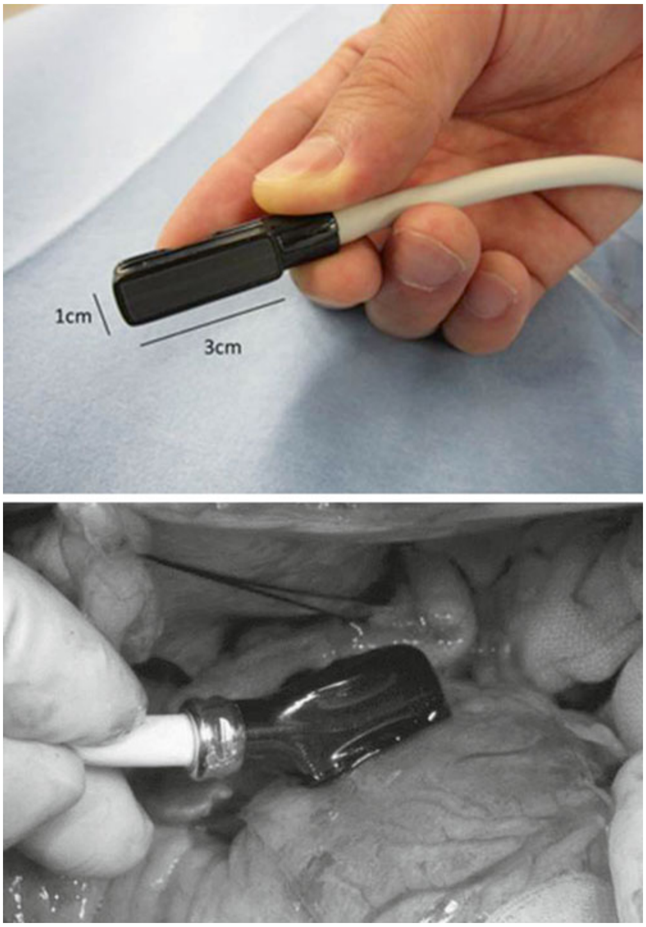

Fig. 18.4 Epicardial ultrasound mini-transducer (*upper panel*). Positioned along the left circumflex coronary artery (*lower panel*)

due to motion artifacts. Warm saline and/or sterile gel employed on the epicardial surface facilitates contact and clear imaging. Assessment of the target vessels and/or anastomosis requires only a few minutes. The indications for use of ECUS include a difficult to interpret angiogram (including chronic total occlusion lesion specifically), extensive epicardial fat, an intramural vessel, diffuse coronary artery disease, and discrepancies between preoperative angiographic and intraoperative findings.

18.4.2 Identification of the Target Coronary Artery

Identification of vessels covered with thick epicardial fatty tissue or myocardium is challenging using visual or palpation information alone. If detection by visual inspection or palpation is impossible, the surgeon usually spends several minutes seeking the targets and may also dissect the epicardial or myocardial tissue unnecessarily. Inessential dissection after heparinization is dangerous and sometimes causes uncontrolled bleeding, which hampers anastomosis. These technical errors may force conversion from off-pump coronary bypass surgery to cardiopulmonary bypass. ECUS requires only a few minutes for visualizing a target vessel and minimizes risk and time consumption. When identifying the LAD, the underlying ventricular septum and the presence of septal perforators serve as remarkable echocardiographic markers. Arteries can be easily differentiated from accompanying veins by the presence of calcification and plaque (Fig. 18.5). Figure 18.6 demonstrated the left anterior descending coronary artery embedded in the myocardium and located at a depth of 4 mm from the surface. Veins are more easily compressed than arteries when applying gentle pressure with a transducer (Fig. 18.7). ECUS is especially useful to assess the sections that cannot be well visualized on the angiograms such as chronic total occlusion lesion.

Several investigators reported their experience to coronary artery visualization by ECUS. Isringhaus used ECUS in 630 coronary segments in 112 patients and examined the vessel diameter, the absence of stenoses, the condition of the vessel wall, and the localization of occlusions [40]. Of these, fifty vessels not visible to the eye (8 %) could be imaged by ECUS. Hayakawa and his colleagues assessed 299 target vessels during off-pump CABG in 89 consecutive patients and found that 12 vessels (4 %) not identified either visually or on palpation could be located by ECUS [41].

18.4.3 Selection of Optimal Anastomotic Sites

The surgeons usually rely on visual information and palpation to detect the coronary lesions and select the optimal anastomotic sites. However, the angiography does not always delineate all stenoses or plaque accurately [42]. Digital palpation is subjective and easily fails to catch soft plaques. Furthermore, because septal perforators or side branches cannot be conventionally detected before opening the coronary, bleeding through the arteriotomy from these small vessels extremely interferes with suturing, especially in off-pump CABG [43]. The anastomotic sites often turn out to be suboptimal after the artery is opened. ECUS can evaluate the quality of the target coronary arteries rapidly and accurately and allow deviation to a more optimal suture site [44]. Intraoperative change of anastomotic site from the initial conventionally selected sited after ECUS scanning has been reported to occur in 24 % of cases [40, 43–45].

18.4.4 Assessment of Anastomosis Quality

Intraoperative quality assessment of constructed anastomoses will help to increase graft patency because suboptimal anastomoses can be revised before chest closure. ECUS can

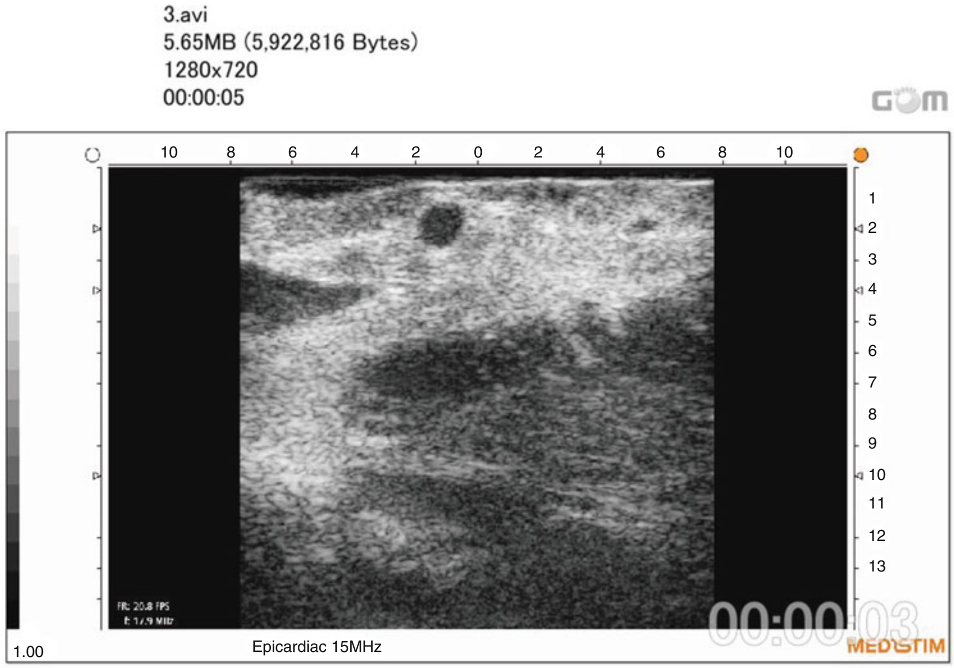

Fig. 18.5 ECUS demonstrates the LAD with calcification and accompanying acoustic shadow

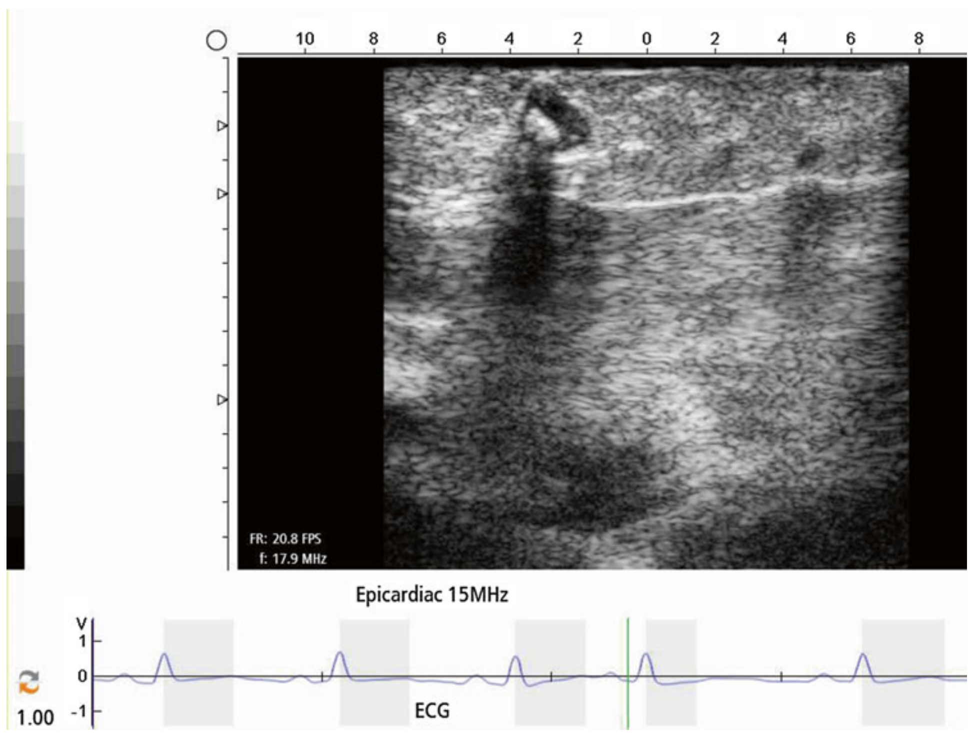

Fig. 18.6 ECUS demonstrated the left anterior descending coronary artery embedded at a depth of 4 mm from the surface

provide highly detailed images of the anastomotic sites (Figs. 18.8 and 18.9). In studies reporting on quality assessment by ECUS [42–57], approximated 2 % of distal anastomoses were revised based on abnormal findings including misplaced sutures, thrombus, dissection, and calcifications. Minor irregularities were seen in 5 %. Dissection may be detected by ECUS [58]. Based on studies of ex vivo porcine and human hearts, ECUS has high sensitivity (0.98) and specificity (1.00) for the detection of anastomotic errors, which was significantly higher than those obtained from the gold standard angiography (sensitivity 0.75, specificity 0.81) [59].

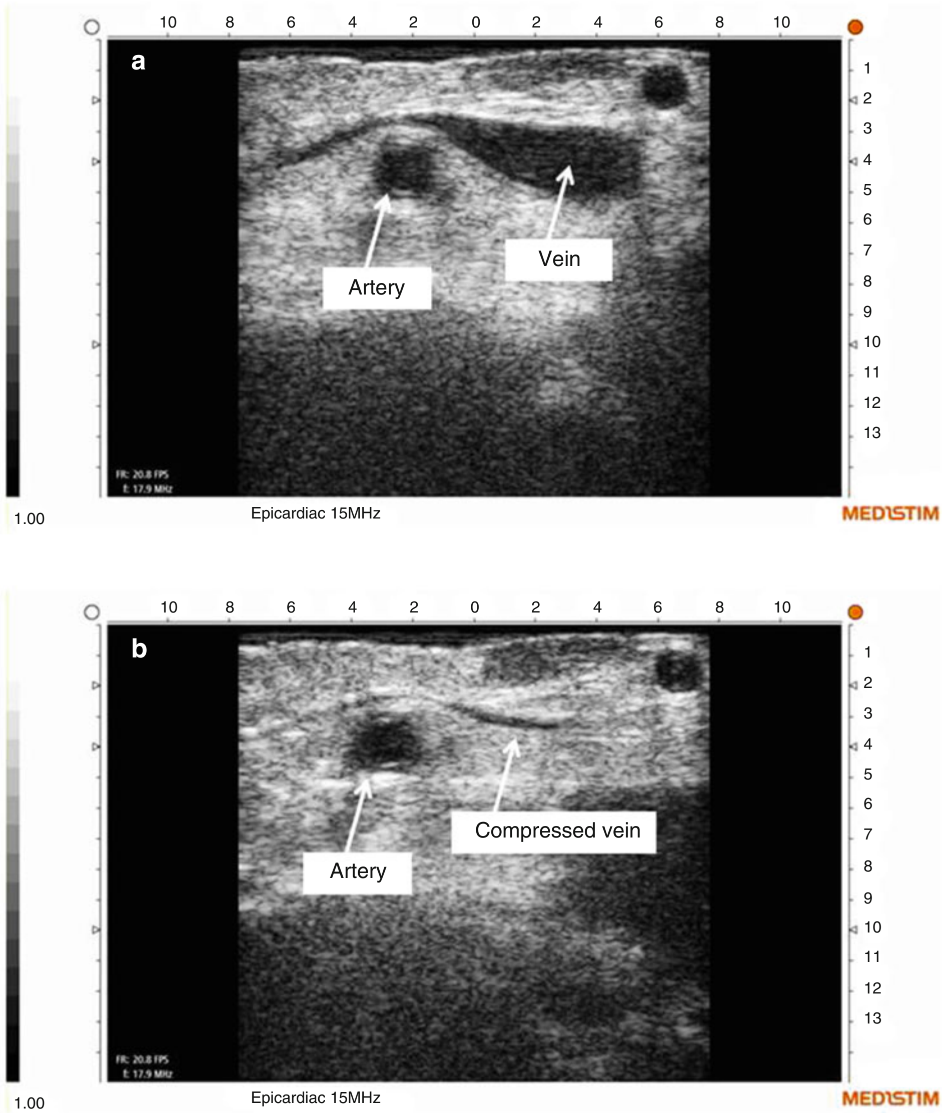

Fig. 18.7 Differentiation between artery and vein. (**a**): normal condition, (**b**): under gentle pressure with a transducer

18.4.5 Comments

It is plausible that a number of anastomosis irregularities identified on postoperative angiography are actually related to selection of suboptimal anastomotic sites, rather than to suture errors. ECUS is a promising multipurpose intraoperative diagnostic tool that is likely to benefit patients undergoing CABG but requires larger patient studies to determine what kind of ECUS findings will predict a graft stenosis or occlusion at follow-up period and justify intraoperative anastomosis revision.

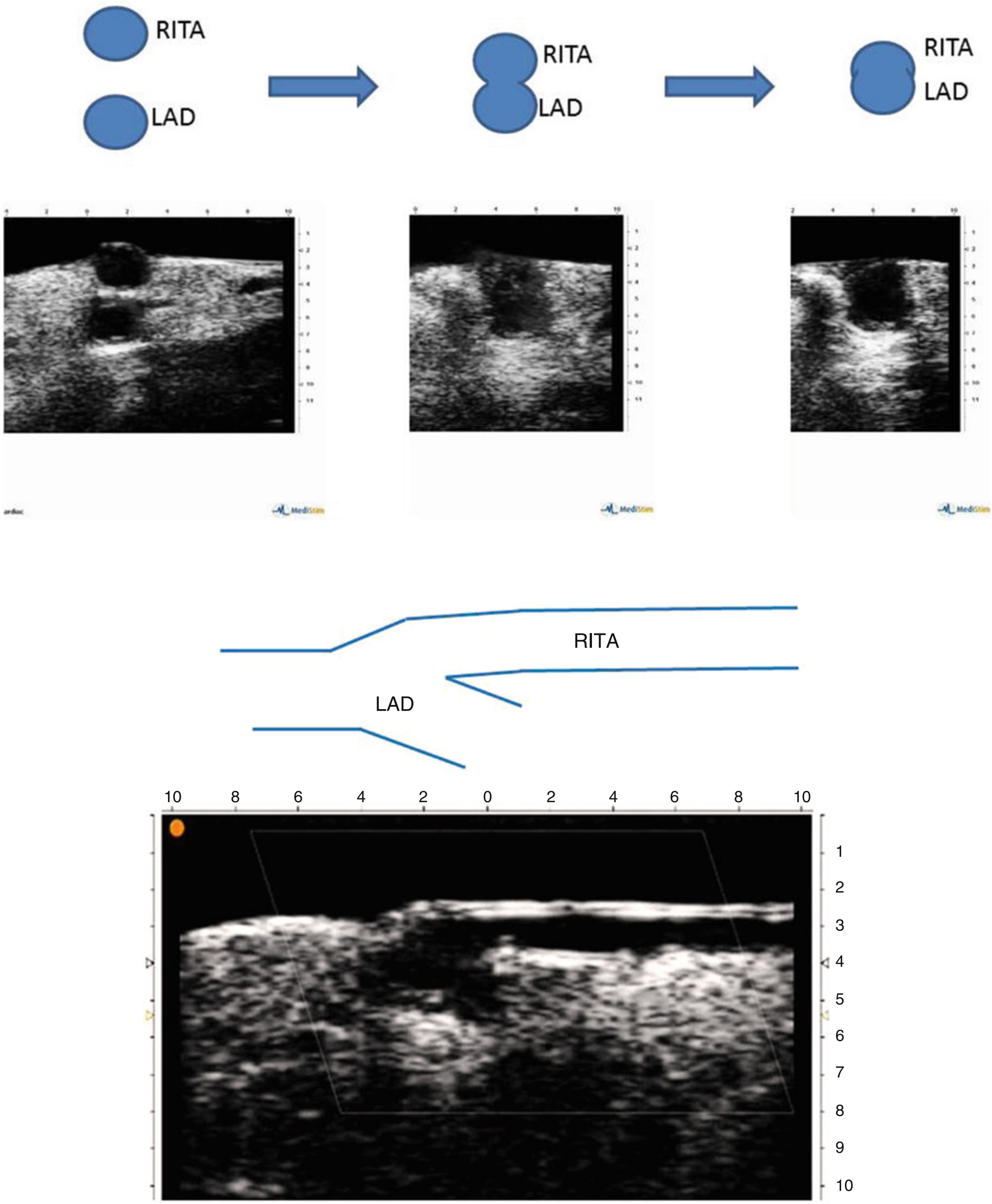

Fig. 18.8 Epicardial ultrasound image of a patent right internal thoracic artery grafting (RITA) to left anterior descending artery (LAD): longitudinal image (*upper panel*) with corresponding transverse image (*lower panel*)

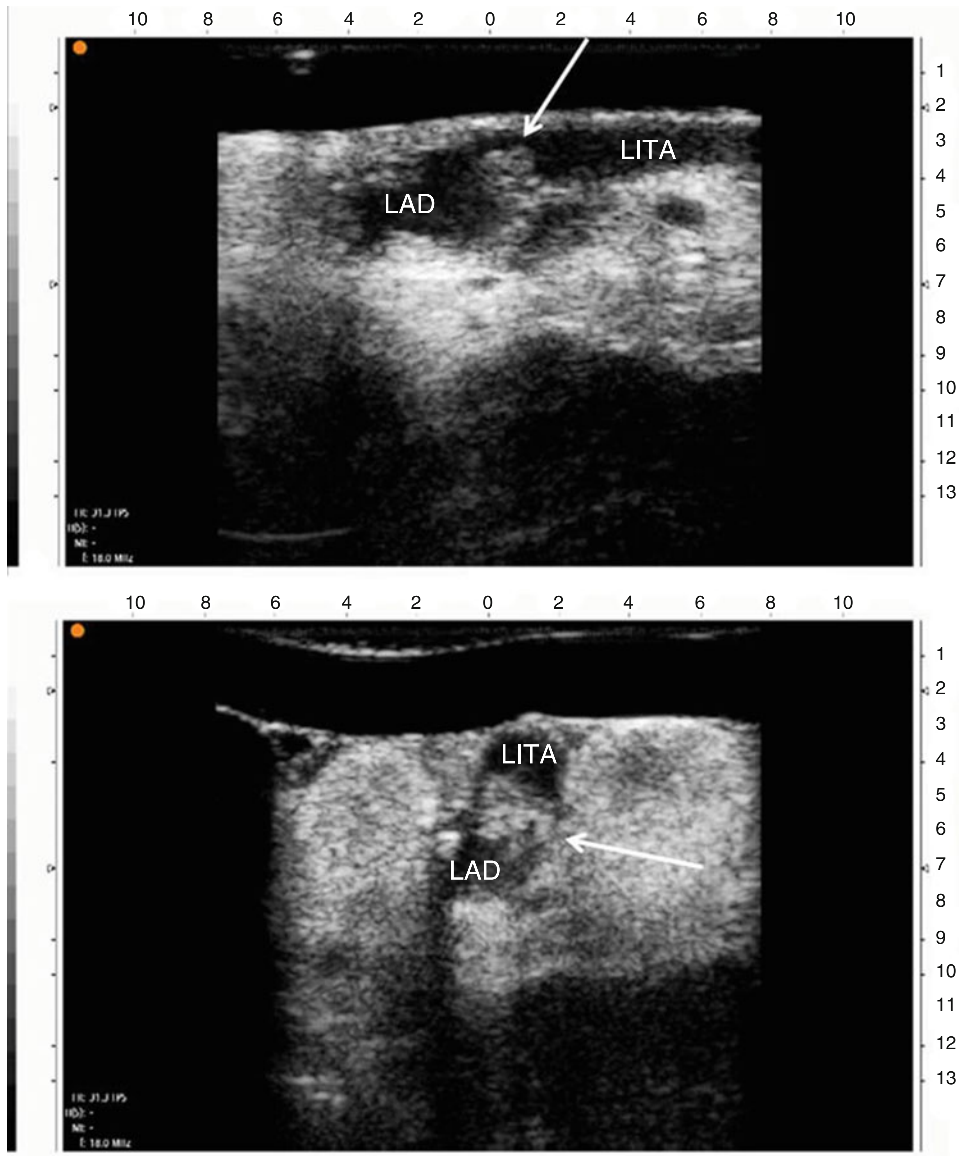

Fig. 18.9 A mobile mass (*arrow*) identified in the lumen of the left internal thoracic artery grafted to the left anterior descending artery: longitudinal image (*upper panel*) with corresponding transverse image (*lower panel*)

References

1. Poirier NC, Carrier M, Lesperance J et al (1999) Quantitative angiographic assessment of coronary anastomoses performed without cardiopulmonary bypass. J Thorac Cardiovasc Surg 117:292–297
2. Nathoe HM, van Dijk D, Jansen EW et al (2003) A comparison of on-pump and off-pump coronary bypass surgery in low-risk patients. N Engl J Med 348:394–402
3. Widimsky P, Straka Z, Stros P et al (2004) One-year coronary bypass graft patency: a randomized comparison between off-pump and on-pump surgery angiographic results of the PRAGUE-4 trial. Circulation 110:3418–3423
4. Lingaas PS, Hol PK, Lundblad R et al (2004) Clinical and angiographic outcome of coronary surgery with and without cardiopulmonary bypass: a prospective randomized trial. Heart Surg Forum 7:37–41
5. Khan NE, DeSouza A, Mister R et al (2004) A randomized comparison of off-pump and on-pump multivessel coronary artery bypass surgery. N Engl J Med 350:21–28
6. Puskas JD, Williams WH, Mahoney EM et al (2004) Off-pump vs conventional coronary artery bypass grafting: early and 1-year graft patency, cost, and quality-of-life outcomes: a randomized trial. JAMA 291:1841–1849
7. Alexander JH, Hafley G, Harrington RA et al (2005) Efficacy and safety of edifoligide, an E2F transcription factor decoy, for prevention of vein graft failure following coronary artery bypass graft surgery: PREVENT IV: a randomized controlled trial. JAMA 294:2446–2454
8. Yusuf S, Zucker D, Peduzzi P et al (1994) Effect of coronary artery bypass graft surgery on survival: overview of 10-year results from randomised trials by the Coronary Artery Bypass Graft Surgery Trialists Collaboration. Lancet 344:563–570
9. D'Ancona G, Karamanoukian HL, Ricci M et al (2000) Graft revision after transit time flow measurement in off-pump coronary artery bypass grafting. Eur J Cardiothorac Surg 17:287–293
10. Magee MJ, Alexander JH, Hafley G, Ferguson TB Jr, Gibson CM, Harrington RA, Peterson ED, Califf RM, Kouchoukos NT, Herbert MA, Mack MJ, PREVENT IV Investigators (2008) Coronary artery bypass graft failure after on-pump and off-pump coronary artery

bypass: findings from PREVENT IV. Ann Thorac Surg 85: 494–499
11. Lytle B, Blackstone E, Loop F et al (1999) Two internal thoracic artery grafts are better than one. J Thorac Cardiovasc Surg 117:855–872
12. Taggart DP, D'Amico R, Altman DG (2001) Effect of arterial revascularisation on survival: a systematic review of studies comparing bilateral and single internal mammary arteries. Lancet 358:870–875
13. Abu-Omar Y, Taggart DP (2002) Off-pump coronary artery bypass grafting. Lancet 360:327–330
14. Parolari A, Alamanni F, Polvani G et al (2005) Meta-analysis of randomized trials comparing off-pump with on-pump coronary artery bypass graft patency. Ann Thorac Surg 80:2121–2125
15. Shroyer AL, Grover FL, Hattler B, Collins JF, McDonald GO, Kozora E, Lucke JC, Baltz JH, Novitzky D, Veterans Affairs Randomized On/Off Bypass (ROOBY) Study Group (2009) On-pump versus off-pump coronary-artery bypass surgery. N Engl J Med 361:1827–1837
16. Hol PK, Lingaas PS, Lundblad R et al (2004) Intraoperative angiography leads to graft revision in coronary artery bypass surgery. Ann Thorac Surg 78:502–505
17. Falk V, Walther T, Philippi A et al (1995) Thermal coronary angiography for intraoperative patency control of arterial and saphenous vein coronary artery bypass grafts: results in 370 patients. J Card Surg 10:147–160
18. Canver CC, Dame NA (1994) Ultrasonic assessment of internal thoracic artery graft flow in the revascularized heart. Ann Thorac Surg 58:135–138
19. Taggart DP, Choudhary B, Anastasiadis K et al (2003) Preliminary experience with a novel intraoperative fluorescence imaging technique to evaluate the patency of bypass grafts in total arterial revascularization. Ann Thorac Surg 75:870–873
20. D'Ancona G, Karamanoukian HL, Ricci M et al (2000) Graft revision after transit time flow measurement in off-pump coronary artery bypass grafting. Eur J Cardiothorac Surg 17:287–293
21. Kim KB, Kang CH, Lim C (2005) Prediction of graft flow impairment by intraoperative transit time flow measurement in off-pump coronary artery bypass using arterial grafts. Ann Thorac Surg 80:594–598
22. Balacumaraswami L, Taggart DP (2007) Intraoperative imaging techniques to assess coronary artery bypass graft patency. Ann Thorac Surg 83:2251–2257
23. Kim KB, Kang CH, Lim C (2005) Prediction of graft flow impairment by intraoperative transit time flow measurement in off-pump coronary artery bypass using arterial grafts. Ann Thorac Surg 80:594–598
24. Di Giammarco G, Pano M, Cirmeni S et al (2006) Predictive value of intraoperative transit-time flow measurement for short-term graft patency in coronary surgery. J Thorac Cardiovasc Surg 132:468–474
25. Tokuda Y, Song MH, Ueda Y et al (2007) Predicting early coronary artery bypass graft failure by intraoperative transit time flow measurement. Ann Thorac Surg 84:1928–1933
26. Hirotani T, Kameda T, Shirota S et al (2001) An evaluation of the intraoperative transit time measurements of coronary bypass flow. Eur J Cardiothorac Surg 19:848–852
27. Hol PK, Fosse E, Mork BE et al (2001) Graft control by transit time flow measurement and intraoperative angiography in coronary artery bypass surgery. Heart Surg Forum 4:254–257
28. Speich R, Saesseli B, Hoffmann U et al (1988) Anaphylactoid reaction after indocyanine-green administration. Ann Intern Med 109:345–346
29. Yasuda T, Watanbe G, Tomita S (2005) Transaortic injection technique in fluorescence imaging: novel intraoperative assessment of anastomosis in off-pump coronary artery bypass grafting. J Thorac Cardiovasc Surg 130:560–561
30. Rubens FD, Ruel M, Fremes SE (2002) A new and simplified method for coronary and graft imaging during CABG. Heart Surg Forum 5:141–144
31. Reuthebuch O, Haussler A, Genoni M et al (2004) Novadaq SPY: intraoperative quality assessment in off-pump coronary artery bypass grafting. Chest 125:418–424
32. Balacumaraswami L, Abu-Omar Y, Anastasiadis K et al (2004) Does off-pump total arterial grafting increase the incidence of intraoperative graft failure? J Thorac Cardiovasc Surg 128:238–244
33. Takahashi M, Ishikawa T, Higashidani K et al (2004) SPYTM: an innovative intra-operative imaging system to evaluate graft patency during off-pump coronary artery bypass grafting. Interact CardioVasc Thorac Surg 3:479–483
34. Desai ND, Miwa S, Kodama D et al (2005) Improving the quality of coronary bypass surgery with intraoperative angiography: validation of a new technique. J Am Coll Cardiol 46:1521–1525
35. Handa T, Katare RG, Nishimori H, Wariishi S, Fukutomi T, Yamamoto M, Sasaguri S, Sato T (2010) New device for intraoperative graft assessment: HyperEye charge-coupled device camera system. Gen Thorac Cardiovasc Surg 58:68–77
36. Handa T, Katare RG, Sasaguri S, Sato T (2009) Preliminary experience for the evaluation of the intraoperative graft patency with real color charge-coupled device camera system: an advanced device for simultaneous capturing of color and near-infrared images during coronary artery bypass graft. Interact Cardiovasc Thorac Surg 9:150–154
37. Kuroyanagi S, Asai T, Suzuki T (2012) Intraoperative fluorescence imaging after transit-time flow measurement during coronary artery bypass grafting. Innov (Phila) 7:435–440
38. Balacumaraswami L, Abu-Omar Y, Choudhary B et al (2005) A comparison of transit-time flowmetry and intraoperative fluorescence imaging for assessing coronary artery bypass graft patency. J Thorac Cardiovasc Surg 130:315–320
39. Desai ND, Miwa S, Kodama D et al (2006) A randomized comparison of intraoperative indocyanine green angiography and transit-time flow measurement to detect technical errors in coronary bypass grafts. J Thorac Cardiovasc Surg 132:585–594
40. Isringhaus H (1990) Epicardial coronary artery imaging. Echocardiography 7:253–259
41. Hayakawa M, Asai T, Kinoshita T, Suzuki T, Shiraishi S (2013) Target vessel detection by epicardial ultrasound in off-pump coronary bypass surgery. Innov (Phila) 8:249–252
42. Sahn DJ, Barratt-Boyes BG, Graham K, Kerr A, Roche A, Hill D, Brandt PWT, Copeland JG, Mammana R, Temkin LP, Glenn W (1982) Ultrasonic imaging of the coronary arteries in open-chest humans: evaluation of coronary atherosclerotic lesions during cardiac surgery. Circulation 66:1034–1044
43. Eikelaar JHR, Meijer R, van Boven WJ, Klein P, Gründeman PF, Borst C (2002) Epicardial 10-MHz ultrasound in off-pump coronary bypass surgery: a clinical feasibility study using a minitransducer. J Thorac Cardiovasc Surg 124:785–789
44. Budde RPJ, Bakker PFA, Meijer R, Borst C, Gründeman PF (2006) Ultrasound mini-transducer with malleable handle for coronary artery surgery. Ann Thorac Surg 81:322–326
45. Suematsu Y, Takamoto S, Ohtsuka T (2001) Intraoperative echocardiographic imaging of coronary arteries and graft anastomoses during coronary artery bypass grafting without cardiopulmonary bypass. J Thorac Cardiovasc Surg 122:1147–1154
46. Stein H, Smith JM, Robinson JR, Katz MR (2006) Target vessel detection and coronary anastomosis assessment by intraoperative 12-MHz ultrasound. Ann Thorac Surg 82:1078–1084
47. Hiratzka LF, McPherson DD, Lamberth WC Jr, Brandt B 3rd, Armstrong ML, Schröder E, Hunt M, Kieso R, Megan MD, Tompkins OK, Marcus ML, Kerber RE (1986) Intraoperative evaluation of coronary artery bypass graft anastomoses with high frequency epicardial echocardiography: experimental validation and initial patient studies. Circulation 73:1199–1205

48. Hiratzka LF, McPherson DD, Brandt B 3rd, Lamberth WC Jr, Sirna S, Marcus ML, Kerber RE (1987) The role of intraoperative high-frequency epicardial echocardiography during coronary artery revascularization. Circulation 76:V33–V38
49. Oda K, Hirose K, Nishimori H, Sato K, Yamashiro T, Ogoshi S (1998) Assessment of internal thoracic artery graft with intraoperative color Doppler ultrasonography. Ann Thorac Surg 66:79–81
50. Ishikura F, Matsuwaka R, Sakakibara T, Sakata Y, Hirayama A, Kodama K (1998) Clinical application of power Doppler imaging to visualize coronary arteries in human beings. J Am Soc Echocardiogr 11:219–227
51. Arruda AM, Dearani JA, Click RL, Ishikura F, Seward JB (1999) Intraoperative application of power Doppler imaging: visualization of myocardial perfusion after anastomosis of left internal thoracic artery to left anterior descending coronary artery. J Am Soc Echocardiogr 12:650–654
52. Suematsu Y, Ohtsuka T, Miyairi T, Motomura N, Takamoto S (2002) Ultrasonic evaluation of graft anastomoses during coronary artery bypass grafting without cardiopulmonary bypass. Ann Thorac Surg 74:273–275
53. Haaverstad R, Vitale N, Williams RI, Fraser AG (2002) Epicardial colour-Doppler scanning of coronary artery stenoses and graft anastomoses. Scand Cardiovasc J 36:95–99
54. Haaverstad R, Vitale N, Tjomsland O, Tromsdal A, Torp H, Samstad SO (2002) Intraoperative color Doppler ultrasound assessment of LIMA-to-LAD anastomoses in off-pump coronary artery bypass grafting. Ann Thorac Surg 74:S1390–S1394
55. Miwa S, Nishina T, Ueyama K, Kameyama T, Ikeda T, Nishimura K, Komeda M (2004) Visualization of intramuscular left anterior descending coronary arteries during off-pump bypass surgery. Ann Thorac Surg 77:344–346
56. Hol PK, Andersen K, Skulstad H, Halvorsen PS, Lingaas PS, Andersen R, Bergsland J, Fosse E (2007) Epicardial ultrasonography: a potential method for intraoperative quality assessment of coronary bypass anastomoses? Ann Thorac Surg 84:801–807
57. Schiller W, Rudorf H, Tiemann K, Probst C, Mellert F, Welz A (2007) Detection of coronary arteries and evaluation of anastomoses with a commercially available 15-MHz, broadband, linear array transducer. Heart Surg Forum 10:E387–E391
58. Suematsu Y, Takamoto S, Ohtsuka T, Motomura N, Miyairi T (2002) Power Doppler imaging for detection of harvest injury of internal mammary artery. Asian Cardiovasc Thorac Ann 10:89–91
59. Budde RPJ, Meijer R, Dessing TC, Borst C, Gründeman PF (2005) Detection of construction errors in ex-vivo coronary artery anastomoses by 13 MHz epicardial ultrasonography. J Thorac Cardiovasc Surg 129:1078–1083

Stroke

19

Yoshitaka Okamura

Abstract

Strokes after coronary artery bypass surgery are among the most devastating complications.

Because strokes can worsen early/late postoperative mortality and can also influence quality of life, the prevention of postoperative strokes is essential.

Neurological deficits can develop both intraoperatively and postoperatively. Strokes are categorized into two types based on the timing of occurrence: early and delayed. Early strokes occur immediately after surgery, and delayed strokes occur after uneventful recovery from general anesthesia. Recent advances in surgical techniques, including OPCAB surgery, have contributed to reducing the rate of early strokes, but more than half of postoperative strokes are considered to be of the delayed type; therefore, postoperative management also plays an important role in reducing the prevalence of postoperative strokes.

Keywords

Stroke, OPCAB

19.1 Background

Neurological disorders after coronary artery bypass surgery are among the most devastating complications as they affect postoperative quality of life and also increase the mortality rate by tenfold [1].

Several reports have described risk factors for neurological disorders after coronary artery bypass surgery. Advanced age, hypertension, past history of cerebral infarction, carotid artery lesions, ascending aortic lesions, ascending aortic manipulation, left ventricular venting, postoperative atrial fibrillation, hypercoagulability, and low output after surgery were documented as risk factors for stroke after coronary surgery in the 2011 ACCF/AHA Guideline for Coronary Artery Bypass Graft Surgery [1].

Recent developments in surgical techniques to avoid or minimize aortic manipulation have contributed to a decrease in early neurological complications by reducing the prevalence of macro- and microembolisms. In this regard, OPCAB surgery, especially aortic no-touch OPCAB, has been considered among the best techniques for preventing early-type strokes.

In contrast, delayed strokes occur independently of surgery. Hypotension, hypercoagulability, and atrial fibrillation are believed to cause delayed strokes, so postoperative management plays an important role in reducing this type of stroke.

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19.2 Etiology

The etiology of stroke after coronary bypass surgery is complicated and multifactorial. Systemic inflammatory response, cerebral hypoperfusion, and cerebral embolism induced by aortic manipulation have been associated with postoperative stroke [2]. In coronary surgery with cardiopulmonary bypass (CPB), rapid changes in body temperature, rapid reduction in hematocrit, and loss of pulsatile flow induced by CPB have been associated with postoperative neurological deficits [3].

19.3 Types of Strokes

There are two types of classification for postoperative strokes.

One is classification based on the timing of the stroke (early and delayed types) [2].

Early strokes involve neurological deficits occurring immediately after recovery from general anesthesia, and delayed-type strokes involve deficits after uneventful recovery from general anesthesia.

The other type of classification is based on the severity of the neurological deficit (Type 1 and Type 2) [4]. Type 1 strokes involve neurological deficits caused by focal injury or stupor or coma at discharge, and Type 2 strokes involve deterioration in intellectual function, memory deficits, or seizures.

19.4 Incidence

The incidence of postoperative stroke ranges from 0 to 4.4 %, depending on the patients' characteristics and the diagnostic criteria [5, 6].

The incidence of postoperative strokes is believed to be lower in OPCAB surgery than in conventional coronary artery bypass grafting (CCAB).

An annual report from the Japanese Association for Coronary Surgery indicated that the incidence of the stroke in all coronary artery bypass surgeries was 1.05 % in 2012. With regard to each different procedure, the stroke rate was lowest in OPCAB, with a rate of 0.81 %, whereas the rate of stroke in CCAB with cardiac arrest was 1.19 % and that in on-pump beating CABG was 1.62 %. The rate of stroke in surgery with conversion from OPCAB to CCAB was the highest, reaching 3.24 %.

19.5 Use of Epiaortic Ultrasound Scanning

From a surgical point of view, the properties of the ascending aorta are highly important. The properties of the ascending aorta should be evaluated, and a strategy should be devised regarding whether to manipulate the ascending aorta. Computed tomography is the most informative method for evaluating the ascending aorta preoperatively.

In a recent study, use of epiaortic ultrasound scanning was considered to be reasonable for evaluating the presence, location, and severity of atherosclerosis of the ascending aorta. In patients at high risk for arteriosclerosis, epiaortic ultrasound scanning contributed to reduction of postoperative strokes resulting from micro- or macroembolization from the ascending aorta.

19.6 Microembolic Signals in CABG

Transcranial Doppler monitoring has revealed microembolic signals (MSEs) during cardiac surgery with CPB. Braekken et al. [7] reported cerebral microembolic signals in all patients who underwent cardiac surgery with CPB. Furthermore, these MSEs also occurred during the postoperative phase as a result of intraoperative aortic manipulation [8]. OPCAB has the possibility of diminishing these MSEs, and it can reduce the rate of postoperative stroke [9].

19.7 Merits of OPCAB

The merits of OPCAB are less blood loss, less need for transfusion, lower incidence of postoperative strokes, and less renal dysfunction after surgery [10]. Stabilizing the hemodynamics results in the securing of cerebral perfusion. The incidence of atrial fibrillation after OPCAB was reported to be the lowest, and because atrial fibrillation is one of the major causes of postoperative strokes, OPCAB is considered the best procedure.

19.8 Surgical Strategy to Reduce Strokes

In OPCAB surgery, the postoperative stroke rate was lower than that in CCAB, as mentioned above. Additional surgical techniques should minimize or avoid aortic manipulation to reduce the rate of stroke.

Aortic cannulation, cardioplegia-venting catheter insertion, aortic clamping, and proximal anastomosis of the free graft are essential procedures for the ascending aorta in coronary surgery with CPB. However, each of these procedures incurs the possibility of a stroke developing through macro- or microembolism.

OPCAB does not require aortic cannulation or cardioplegic catheter insertion. Furthermore, recent advancements in proximal anastomotic devices have rendered side clamping of the ascending aorta unnecessary during proximal anastomosis in OPCAB surgery. These clampless techniques have contributed to reducing the rate of stroke after coronary surgery [11, 12]. Wilhelm et al. reported that the incidence of stroke after the side-clampless technique was 0.8 %. An additional technique is the aortic no-touch technique, which can be effective in patients with unfavorable ascending aortas.

To prepare for aortic no-touch strategies, I-composite and Y-composite grafting are also useful procedures. I-composite grafting and Y-composite grafting are techniques used to avoid restriction of the graft fashion in aortic no-touch surgery. I-composite grafts, Y-composite grafts, and the sequential grafting technique enable revascularization of multiple vessels in limited grafts and limited anastomotic sites in the ascending aorta.

The incidence of stroke and the short-term mortality rate were lower with these aortic no-touch techniques, and the patency and long-term survival were also found to be excellent in previous reports [10, 12, 13].

19.9 OPCAB to ONCAB Conversion

OPCAB is associated with a lower risk of postoperative stroke rate than conventional CABG. However, OPCAB patients who were converted to conventional CABG unexpectedly had a higher incidence of postoperative stroke than non-converted patients (conversion, 2.02 %; without conversion, 0.96 %). Unexpected conversion should be avoided, and if the opportunity to convert to CCAB arises, the conversion should be performed while the hemodynamics are stable [14].

19.10 Postoperative Atrial Fibrillation

The effectiveness of postoperative AF management was also documented in the ACCF/AHA Guidelines [1]. Atrial fibrillation is associated with a substantially increased risk of morbidity and mortality, and postoperative AF is associated with a 3 to 4 fold increased risk of embolic stroke. The usefulness of amiodarone and β blocker to maintain sinus rhythm and to treat atrial fibrillation have already been mentioned, especially β blocker use is strongly recommended in the ACCF/AHA Guidelines for management of postoperative AF [1].

19.11 Hypercoagulability After OPCAB

In coronary surgery with CPB, clotting disorders and platelet dysfunction are major problems after surgery. In contrast to the bleeding tendency with CCAB, increased procoagulant activity after surgery is the major concern with OPCAB surgery. Increased procoagulant activity was first reported in 1999 by Mariani et al., who showed that increased levels of prothrombin factors 1 and 2 and decreased levels of factor 7 induced procoagulant activity. Thus, a prophylactic pharmacological regimen is necessary in OPCAB management.

19.12 Team Approach

In the 2011 AHA/ACC Guidelines, a team approach, consisting of a cardiac surgeon, cardiologist, vascular surgeon, and neurologist, was recommended for patients with significant carotid lesions for whom coronary artery surgery is planned.

19.13 In My Opinion

Advances in techniques and devices, such as the off-pump technique, aortic no-touch technique, and proximal anastomotic devices, have contributed to a reduction in postoperative strokes. Minimizing or avoiding ascending aortic manipulation is the key to preventing strokes but is not the only factor. Strokes occur not only during surgery but also after postoperative hospitalization. Image of various cause of stroke are shown in Fig. 19.1.

Atrial fibrillation, hypotension, hypercoagulability, and other factors can cause strokes after surgery. Addressing postoperative management is the most important point for decreasing the rate of postoperative stroke.

Strokes can occur at any time in patients with multiple coronary risk factors. The 5-year results of the SYNTAX trial indicated a spontaneous increase in the stroke rate over time, with rates of 2.2 % at 1 year, 3.4 % at 3 years, and 3.7 % at 5 years after surgical treatment [15].

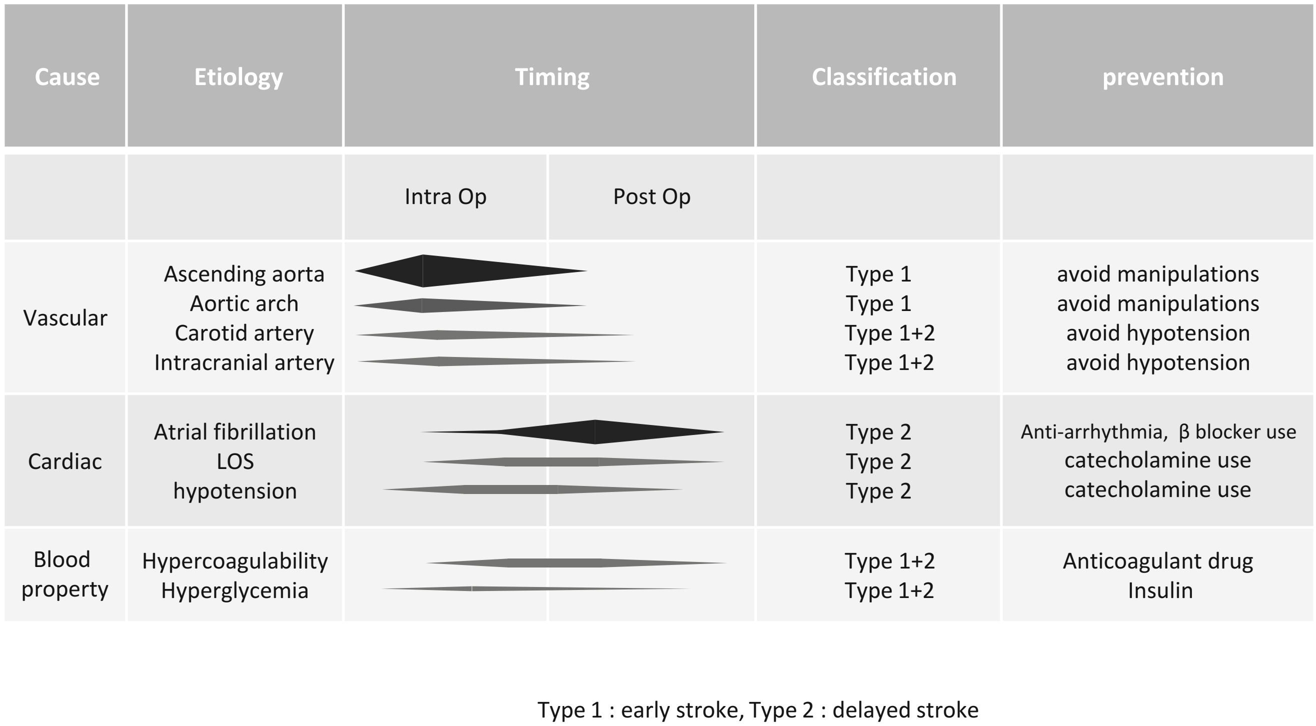

Fig. 19.1 Onset and cause of strokes after CABG

References

1. Hillis LD, Smith PK, Anderson JL et al (2011) 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. Ciruculation 124:e652–e735
2. Doi K, Yaku H (2010) Importance of cerebral artery risk evaluation before off-pump coronary artery bypass grafting to avoid perioperative stroke. Eur J Cardiothorac Surg 38:568–572
3. Takami Y, Masumoto H (2006) Brain magnetic resonance angiography-based strategy for stroke reduction in coronary artery bypass grafting. Interact Cardiovasc Thorac Surg 5:383–386
4. Roach GW, Kanchuger M, Magano CM et al (1996) Adverse cerebral outcomes after coronary bypass surgery. N Engl J Med 335:1857–1863
5. Bergman P, Hadjinikolaou L, Dellgren G et al (2004) A policy to reduce stroke in patients with extensive atherosclerosis of ascending aorta undergoing coronary surgery. Interact Cardiovasc Thorac Surg 3:28–32
6. Houlind K, Kjeldesen BJ, Madsen SN et al (2012) On-pump versus off-pump coronary artery bypass surgery in elderly patients: results from the Danish on-pump versus off-pump randomization study. Ciruculation 215:2431–2439
7. Braekken SK, Russell D, Brucher R et al (1997) Cerebral microembolic signals during cardiopulmonary bypass surgery. Frequency, time of occurrence, and association with patient and surgical characteristics. Stroke 28:1988–1992
8. Kumral E, Balkir K, Yagdi T et al (2001) Microembolic signals in patients undergoing coronary artery bypass. Tex Heart Inst J 28:16–20
9. Motallebzadeh R, Bland JM, Markus HS et al (2007) Neurocognitive function and cerebral emboli: randomized study of on-pump versus off-pump coronary artery bypass surgery. Ann Thorac Surg 83:475–482
10. Huffmyer J, Raphael J (2011) The current status of off-pump coronary bypass surgery. Curr Opin Anesthesiol 24:64–69
11. Seto Y, Yokoyama H, Takase S et al (2012) The results of the enclose II proximal anastomotic device in 178 off-pump coronary artery bypass surgeries. Innov (Phila) 7:242–246
12. Wilhelm MJ, Syburra T, Furree L (2011) Avoidance of aortic side-clamping for proximal bypass anastomosis: better short –term outcome. Heart Surg Forum 14:360–365
13. Ramadan ASE, Stefanidis C, N'Gatchou W (2010) Five years follow-up after Y-graft arterial revascularization: on pump versus off pump; prospective clinical trial. Interact Cardiovasc Thorac Surg 10:423–427
14. Zhongmin L, Timothy D, Khung K et al (2010) Off-pump bypass surgery and postoperative stroke: California coronary bypass outcome reporting program. Ann Thorac Surg 90:753–759
15. Mohr FW, Morice MC, Kappetein AP et al (2013) 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 381:629–638

Patient Management OPCAB

20

Mitsuaki Sadahiro

Abstract

Patient management is important particularly in OPCAB from the standpoint of a hypercoagulability state and an occasional complication of AF after surgery.

Hypercoagulability state after OPCAB could potentially jeopardize early graft patency, as well as induce pulmonary infarction associated with deep vein thrombosis, and stroke, especially in atrial fibrillation. Accordingly, several institutions have tried an aggressive anticoagulation strategy with a continuous postoperative heparin administration for 2–5 days after surgery and early use of aspirin or clopidogrel in addition to aspirin. Furthermore, warfarin is administered by the majority of surgeons controlling INR at around 2.0, when vein grafts are selected for coronary revascularization.

In order to prevent AF after OPCAB, several trials and studies were performed in Japan focusing on the efficacy of perioperative beta-blocker administration, including intravenous landiolol hydrochloride treatment.

Annual alternation of CABG patients demonstrated that the percentage of the elderly aged over 80 years gradually increased from 5 % in 2000 to 11 % in 2012, in Japan. Postoperative care for elderly patients, prevention of respiratory complications, wound healing and infection, and mental confusion and delirium have come to be important.

Keyword

OPCAB • Anticoagulation • Atrial fibrillation • Elderly patient • Stroke • Landiolol

20.1 Perioperative Anticoagulation Management in OPCAB Patients

Thrombocytopenia and platelet dysfunction have been documented in patients undergoing on-pump surgery and have been associated with many factors, including hemodilution, mechanical disruption, adhesion to extracorporeal circuit surface, sequestration in organs, thrombin generation, and heparin/protamine use [1]. These platelet count decreases, and platelet function abnormalities are implicated by many bleeding complications during the postoperative period.

In contrary to on-pump surgery, off-pump coronary artery bypass (OPCAB) does not use an extracorporeal circuit, thus avoiding these platelet functional problems, and could relatively "preserve hemostasis." Only a limited number of studies focus on hemostatic changes during OPCAB [2, 3]. Some authors described a reduction in postoperative blood loss following OPCAB and speculated different patterns of activated coagulation-fibrinolysis as compared to on-pump procedures [3].

Concerns have been raised regarding possible OPCAB-associated procoagulant activity and consequently a higher risk of perioperative venous thrombosis and early graft occlusion.

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In addition, other concerns have been raised regarding OPCAB-induced "hypercoagulability state," which is associated with surgery-related systemic inflammatory response and warm regional myocardial ischemia/reperfusion during distal anastomosis [4–6].

Animal studies have demonstrated an induction of thrombin production during periods of warm ischemia as little as 15 min [7, 8], and Kon et al. [9] illustrated enhanced regional coagulability after OPCAB in their pilot study.

This hypercoagulability state after OPCAB could potentially jeopardize early graft patency, as well as induce pulmonary infarction associated with deep vein thrombosis and stroke by thromboembolization from the heart, especially in atrial fibrillation. Accordingly, an aggressive anticoagulation strategy would be important during the postoperative period after OPCAB. Perioperative anticoagulation strategies as well as periprocedural and long-term antiplatelet therapy are critical in CABG patients. Standard protocols have been clearly defined for cardiac operations performed with CPB, whereas no such strategy has been clearly identified for OPCAB procedures to date.

Although the policy of perioperative anticoagulation management may differ quite significantly among institutions in Western countries as well as in Japan, consensus of anticoagulation strategies accepted among most of Japanese surgeons is demonstrated as follows.

20.1.1 Heparin Administration

Suitable dose of heparin administered intraoperatively and the need to antagonize the heparin with protamine at the end of the procedure are potential avenues for further research in Japan. There seems to be a trend toward a lower dose of heparinization as compared with standard heparin dose administered in on-pump CABG.

An initial heparin dose ranges between 100 and 200 unit/kg. In some institutions, administration of heparin with a 10 cc bolus injection or a half dose of the routine on-pump full dosage is an alternative method. However, at no institution would the same heparin dosage as the on-pump full dosage be administered. Activated clotting time (ACT) is routinely measured every 30 or 60 min, and additional heparin is given to maintain the ACT level at above 200 s. At the end of the OPCAB procedure, reversal of heparin with a protamine ratio of 1:1 or 1:2 is performed by the majority of surgeons.

Some institutions in Japan have a policy to continue postoperative heparin administration for 2–5 days after surgery until oral warfarin becomes effective by monitoring INR over 1.5–2.0. This protocol is employed in all cases routinely or in cases with chronic atrial fibrillation and a risk of early graft occlusion because of severe atherosclerotic narrow coronary artery. Moreover, many institutions would accept the strategy of restarting heparin in the postoperative period to prevent thromboembolic stroke when atrial fibrillation happens in patients. Okabayashi et al. [10] reported that cerebrovascular accidents occurred in 1.9 % of OPCAB patients. All accidents took place within 7 days postoperatively, especially in the period without heparin usage. From the point of view, it is recommended that postoperative heparin infusion was continued during 7 days. If stroke events had not been experienced in these period and total incidence of cerebrovascular accidents had been reduced to 0.5 % (Table 20.1).

20.1.2 Oral Antiplatelet Therapy

The current practice of perioperative antiplatelet therapy also differs widely between institutions. The early use of aspirin is adopted by the majority of surgeons for OPCAB patients. Some institutions prefer to use clopidogrel in addition to aspirin especially for patients with complex sclerotic or narrow coronary or anastomosed grafts and previous percutaneous coronary intervention (PCI) using drug-eluting stents. Furthermore, warfarin is administered by the majority of surgeons controlling INR at around 2.0, when vein grafts are selected for coronary revascularization. This approach may be justified, as platelet dysfunction caused by CPB is obviously absent in OPCAB patients.

Table 20.1 Cerebrovascular accidents during OPCAB

	OPCAB Postoperative heparin (–) $N=412$	OPCAB Postoperative heparin (+) $N=193$
Total CVA	8 (1.9 %)	1 (0.5 %)
Intraoperative Incidence of CVA	0	0
Postoperative Incidence of CVA	8	1

Incidence of cerebrovascular disorder was 1.9 %, which was seen mostly during the postoperative period. After postoperative heparin was started, the incidence was reduced to 0.5 %
CVA cerebrovascular accident
Reproduced from the Ref. [11]

Very few surgeons administer clopidogrel before surgery on the day of the OPCAB procedure.

Clopidogrel exposure prior to on-pump CABG is well known to increase the risk of postoperative bleeding, the need for perioperative transfusion, and the incidence of re-exploration. Conversely, clopidogrel administration following on-pump CABG is superior to aspirin in the end point of myocardial infarction, stroke, or graft patency [11]. In addition, most recent data demonstrate that early postoperative administration of clopidogrel is safe after OPCAB [12].

To date, no Japanese survey regarding strategical anticoagulation management during OPCAB has been performed, although Englberger et al. [13] conducted a European survey study to determine anticoagulation strategies in OPCAB using a questionnaire survey among 750 European cardiothoracic surgeons. A total of 325 (43.7 %) questionnaires were returned and analyzed. Perioperative protocols for administration of antiplatelets differed among the respondent surgeons, similar to those among surgeons in Japan. Intraoperative heparin dosage ranged between 70 and 300 unit/kg, and 60 % of the respondents preferred a low-dose regimen (150 or 100 unit/kg). Correspondingly, the lowest ACT during surgery was accepted to be 200 s by 24 %, 250 s by 18 %, and 300 s by 26 % of the surgeons. Protamine was used by 91 % of the respondents, while 52 % performed a 1:1 reversal. Perioperative protocols for administration of antiplatelets also differed significantly among the surgeons. Oral aspirin was given after surgery in 76 % of OPCAB patients, but 30 % of them started from the preoperative period. Clopidogrel was selected in 15 % of patients, and in half of them, clopidogrel was added to aspirin administration.

A survey of such, regarding these anticoagulation strategies in OPCAB, is necessary in Japan, where OPCAB is predominantly *performed in many institutions*.

20.2 Postoperative Atrial Fibrillation (AF) Management for OPCAB Patients

Atrial fibrillation (AF) is one of the most common complications after OPCAB and is associated with an increased risk of stroke and longer hospital stay. Hosokawa et al. [14] retrospectively reviewed 296 consecutive patients who underwent OPCAB. The incidence of AF was 32 % of all patients. In order to examine the predictors of AF after OPCAB, a stepwise multivariate analysis was performed demonstrating increasing age (odds ratio 1.44 per 10-year increase; 95 % confidence interval 1.06–1.95), intraoperative core body temperature (odds ratio 1.64; 95 % confidence interval 1.05–2.56), average cardiac index in the ICU (odds ratio 0.37; 95 % confidence interval 0.19–0.71), and intraoperative fluid balance (odds ratio 0.96 per 100-ml increase; 95 % confidence interval 0.93–0.99) as independent predictors for the development of AF.

In order to prevent AF after OPCAB, several trials and studies were performed in Japan focusing on the efficacy of perioperative beta-blocker administration. Fujii et al. [15] conducted a randomized prospective trial to determine the efficacy of intravenous landiolol administration in the early period after OPCAB followed by treatment with carvedilol for prevention of AF. Seventy consecutive patients were enrolled in the study. Patients in the treatment group received landiolol intravenously (5 μg/kg/min) in the ICU immediately after surgery until oral carvedilol was administered. All patients received oral carvedilol (2.5 mg–5 mg/day) after extubation, and this treatment was continued even after discharge. Postoperative AF occurred in 4 (11.1 %) of the 36 patients in the landiolol group and in 11 (32.3 %) of the 34 patients in the control group, indicating that development of AF was significantly inhibited by landiolol treatment ($p = 0.042$).

Wakamatsu et al. [16] reported that intraoperative low-dose infusion of landiolol hydrochloride (4.7+/−4.3 microgram/kg/min) decreased the incidence of postoperative AF from 37.8 to 18.6 % after OPCAB. In that study, no side effects, such as profound hypotension or bradycardia, were noticed during the infusion of landiolol hydrochloride.

Beside oral tablet administration with beta-blocking action, anti-arrhythmic drugs and preoperative statin preparation were emerging as promising treatments to prevent AF. Ito et al. [17] assessed the efficacy of treatment with the anti-arrhythmic drug propafenone hydrochloride, which was administered in the early postoperative period. Seventy-eight patients undergoing isolated OPCAB were divided into 2 groups: a propafenone hydrochloride group (P Group) and a control group (C Group). The patients in the P Group were given propafenone hydrochloride (150–450 mg/day orally) for 10 days from the day of surgery. The incidence of AF was 35 % in the C Group and 12 % in the P Group ($p = 0.0337$). Multiple logistic regression analysis showed that propafenone hydrochloride was the sole factor that prevented the development of AF after OPCAB (odds ratio 0.207; 95 % confidence interval 0.053–0.804; $p = 0.0229$).

Kinoshita et al. [18] assessed the preventive effect of preoperative statin treatment on the development of AF after elective isolated OPCAB. Among 584 patients, 364 received statin at least 5 days before surgery while 220 patients received no statin. They identified 195 propensity score-matched pairs. AF occurred in 14.4 % of patients in the statin group and in 24.6 % of patients in the no-statin group ($p = 0.01$). Multivariate logistic regression, including potential univariate predictors, identified statin treatment (odds ratio 0.49; 95 % confidence interval 0.22–0.81; $p = 0.01$), age (odds ratio 1.33 per 10-year increase; 95 % confidence interval 1.04–1.69; $p = 0.02$), and transfusion (odds ratio 2.21; 95 % confidence interval 1.38–3.55; $p = 0.01$) as independent predictors of postoperative AF.

Currently, many surgeons understand that postoperative episodes of AF are strongly related to the occurrence of stroke complications after OPCAB. A consensus to start anticoagulation therapy with heparin infusion or warfarin administration when AF occurs is needed to prevent severe brain complications.

20.3 Elderly Patient Management in OPCAB

With the progressive aging of the Japanese as well as Western populations, the age group defined as “elderly” has gradually increased from >65 years to >80 years. The increasing age of the elderly in the Japanese and Western populations has led to a larger number of patients undergoing coronary surgery. Annual survey conducted by the Japanese Association for Coronary Artery Surgery reported the age distribution of 9,252 patients who received CABG in 2012 (79.6 % male, 20.4 % female). Of the total number of cases, 1,009 (11 % of total – 9.2 % of total males and 17.5 % of total females) were of patients aged over 80 years (Fig. 20.1). Annual alternation of CABG patients also demonstrated that the percentage of the elderly aged over 80 years gradually increased from 5 % in 2000 to 11 % in 2012, showing that the rate doubled over a 10-year period (Fig. 20.2).

This aging surgical population has relatively greater prevalence of cerebrovascular disease, left ventricular dysfunction, diabetes mellitus, chronic obstructive pulmonary disease, renal impairment, and peripheral arterial disease; therefore, poor surgical results were expected [19–21]. However, a study by Tanaka et al. demonstrated acceptable

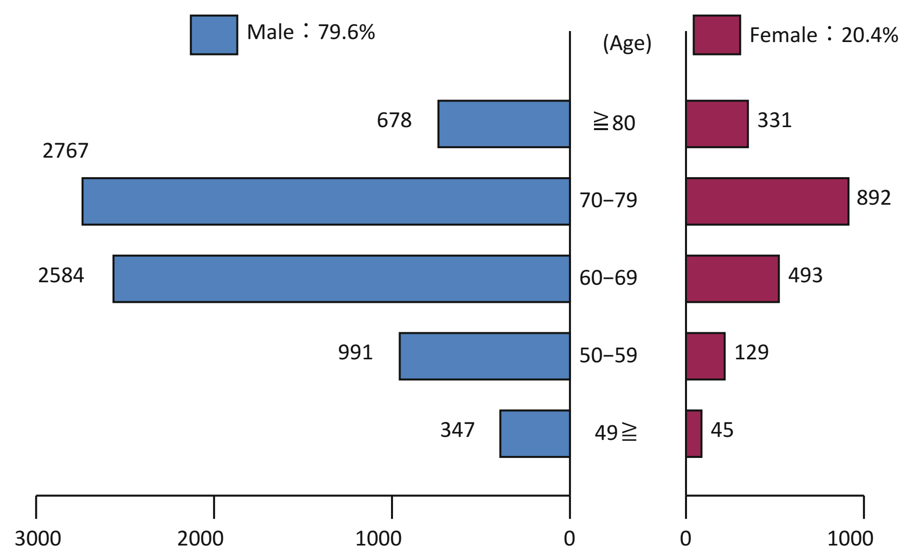

Fig. 20.1 Age distribution of patients receiving CABG. Annual survey by the Japanese Association for Coronary Artery Surgery demonstrated the age distribution of 9,252 patients receiving CABG in 2012. Number of elderly patients over 80 years was 1,009, accounting for 11 % of total number of cases (9.2 % of total males, 17.5 % of total females) (Permitted by the Japanese Association for Coronary Artery Surgery)

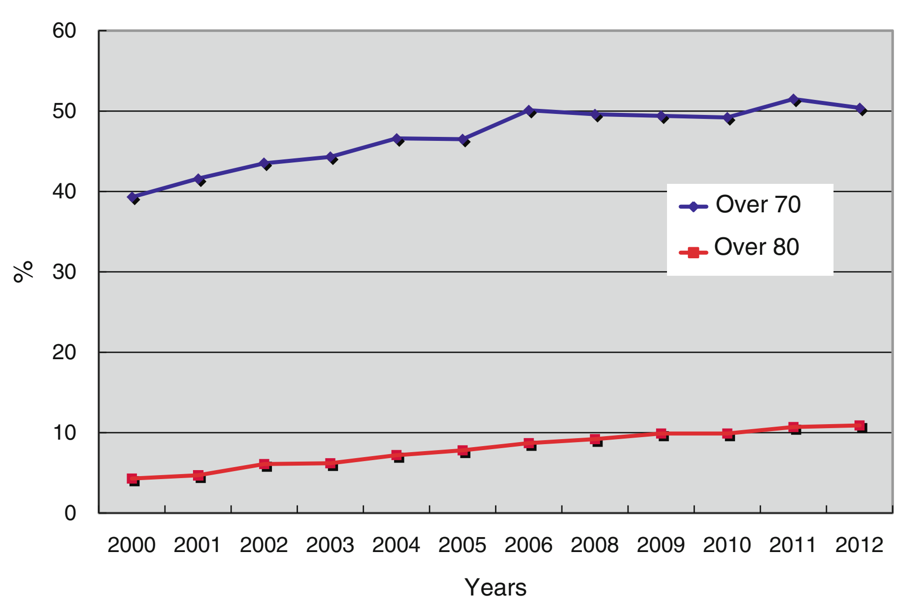

Fig. 20.2 Annual changes in percentage of elderly patients aged 70–79 years and those 80 years and older receiving CABG. Elder generation of 70–79 years gradually increased up to 50.4 %. In particular, the percentage of octogenarians doubled over a 10-year period (Permitted by the Japanese Association for Coronary Artery Surgery)

results in octogenarians regarding mortality and morbidity [22]. The authors compared perioperative outcomes between patients aged 80 years and older ($n = 15$) and those aged 70–79 years ($n = 64$). More octogenarians had congestive heart failure (40 % vs 9 %) and underwent off-pump CABG more frequently (80 % vs 42 %). However, there were no mediastinitis, stroke, or operative deaths, but higher minor wound complications (20 % vs 3 %, $p = 0.01$) in the octogenarians.

For postoperative care of elderly patients, prevention of respiratory complications, especially ventilator-associated or aspiration pneumonia, is important. Preoperative respiratory training, postoperative fast track, early consultancy to respiratory rehabilitation, and daily care for oral hygiene are essential in elective cases. More attention is necessary for wound healing and infection, mental confusion, and delirium in older patients.

References

1. Muriithi EW, Becker PR, Day SPA, Menus VC, Wheatley DJ (2000) Heparin-induced platelet dysfunction and cardiopulmonary bypass. Ann Thorac Surg 69:1827–1832
2. Paparella D, Galeone A, Venneri MT, Coviello M, Scrascia G, Marraudino N, Quaranta M, Luca Tupputi Schinosa L, Brister SJ (2006) Activation of the coagulation system during coronary artery bypass grafting: comparison between on-pump and off-pump techniques. J Thorac Cardiovasc Surg 131:290–297
3. Englberger L, Immer FF, Eckstein FS, Berdat PA, Haeberli A, Carrel TP (2004) Off-pump coronary artery bypass operation does not increase procoagulant and fibrinolytic activity: preliminary results. Ann Thorac Surg 77:1560–1566
4. Raja SG, Dreyfus GD (2006) Impact of off-pump coronary artery bypass surgery on postoperative bleeding: current best available evidence. J Card Surg 21:35–41
5. Diegeler A, Doll N, Rauch T, Haberer D, Walther T, Falk V et al (2000) Humoral immune response during coronary artery bypass grafting: a comparison of limited approach, "off-pump" technique, and conventional cardiopulmonary bypass. Circulation 102(19 Suppl 3):III95–III100
6. MacGillivray TE, Vlahakes GJ (2004) Patency and the pump–the risks and benefits of off-pump CABG. N Engl J Med 350:3–4
7. Czerny M, Baumer H, Kilo J, Lassnigg A, Hamwi A, Vukovich T et al (2000) Inflammatory response and myocardial injury following coronary artery bypass grafting with or without cardiopulmonary bypass. Eur J Cardiothorac Surg 17:737–742
8. Chong AJ, Pohlman TH, Hampton CR et al (2003) Tissue factor and thrombin mediate myocardial ischemia-reperfusion injury. Ann Thorac Surg 75:S649–S655
9. Kloner RA, Jennings RB (2006) Consequences of brief ischemia: stunning, preconditioning, and their clinical implications: Part 2. Circulaton 104:3158–3167
10. Kon ZN, Kwon MH, Collins MJ et al (2006) Off-pump coronary artery bypass leads to a regional hypercoagulable state not detectable using systemic markers. Innov (Phila) 1:232–238
11. Okabayashi H (2007) Text book of postgraduate course of the 60th annual meeting of Japanese Association for Thoracic Surgery, pp 7–13
12. Bhatt DL, Chew DP, Hirsch AT, Ringleb PA, Hacke W, Topol EJ (2001) Superiority of clopidogrel versus aspirin in patients with prior cardiac surgery. Circulation 103:363–368
13. Halkos ME, Cooper WA, Petersen R, Puskas JD, Lattouf OM, Craver JM, Guyton RA (2006) Early administration of clopidogrel is safe after off-pump coronary artery bypass surgery. Ann Thorac Surg 81:815–819
14. Englberger L, Streich M, Tevaearai H, Carrel TP (2008) Different anticoagulation strategies in off-pump coronary artery bypass operations: a European survey. Interact Cardiovasc Thorac Surg 7(3):378–382
15. Hosokawa K, Nakajima Y, Umenai T et al (2007) Predictors of atrial fibrillation after off-pump coronary artery bypass graft surgery. Br J Anaesth 98:575–580
16. Fujii M, Bessho R, Ochi M et al (2012) Effect of postoperative landiolol administration for atrial fibrillation after off pump coronary artery bypass surgery. J Cardiovasc Surg (Trino) 53:369–374
17. Wakamatsu H, Takase S, Sato Y, Seto Y, Kurosawa H, Yokoyama H (2010) Effect of intra-operative low dose infusion of landiolol hydrochloride on post-operative atrial fibrillation after off-pump coronary artery bypass grafting. Kyobu Geka 63(9):764–768
18. Ito N, Tashiro T, Morishige N et al (2010) Efficacy of propafenone hydrochloride in preventing postoperative atrial fibrillation after coronary artery bypass grafting. Heart Surg Forum 13:E223–E227
19. Kinoshita T, Asai T, Nishimura O et al (2010) Statin for prevention of atrial fibrillation after off-pump coronary artery bypass grafting in Japanese patients. Circ J 74:1846–1851
20. Peterson ED, Cowper PA, Jollis JG et al (1995) Outcomes of coronary artery bypass graft surgery in 24,461 patients aged 80 years or older. Circulation 92(Suppl):II85–II91
21. Williams DB, Carrillo RG, Traad EA et al (1995) Determinants of operative mortality in octogenarians undergoing coronary bypass. Ann Thorac Surg 60:1038–1043
22. Stamou SC, Dangas G, Dullum MKC et al (2000) Beating heart surgery in octogenarians: perioperative outcome and comparison with younger age groups. Ann Thorac Surg 69:1140–1145
23. Tanaka H, Narisawa T, Masuda M, KIshi D, Suzuki T (2004) Coronary artery bypass in patients 80 years and older: comparison with a younger age group. Ann Thorac Caridovasc Surg 10(2):85–89

Part III

A Difficult Situation: How Do I Solve This Problem?

Redo Operation

21

Yuji Maruyama and Masami Ochi

Abstract

Redo coronary artery bypass grafting (CABG) has been associated with higher mortality and morbidity when compared with first-time CABG. The problems related to redo CABG include (1) sternal reentry, (2) injury to patent grafts or the heart during dissection, (3) atheromatous embolization from diseased vein grafts, (4) inadequate myocardial protection, (5) quality and availability of conduits, and (6) incomplete revascularization. In addition, the demographics of patients undergoing redo CABG have changed, including an increasing number of patients with patent arterial grafts and higher risk profiles. As off-pump coronary artery bypass grafting (OPCAB) has evolved over the past two decades, the off-pump procedure has been applied to redo coronary surgery. Several reports demonstrated that redo OPCAB reduced mortality and the incidence of perioperative myocardial infarction, cerebrovascular accident, and other complications. However, there is some evidence that redo OPCAB patients receive fewer distal grafts with less complete revascularization than redo conventional CABG patients. Alternative approaches to avoid repeat median sternotomy, such as (1) left anterior small thoracotomy (LAST), (2) left lateral thoracotomy, (3) the transdiaphragmatic approach, and (4) combination of the left thoracotomy and transdiaphragmatic approach, may reduce risks attributable to dissection of the heart and manipulation of patent or diseased grafts. This technique is a promising option for selective reoperative patients who have patent grafts and who are not candidates for conventional coronary reoperations.

Keywords

Redo CABG • Redo off-pump CABG • Alternative approach • Left thoracotomy • Transdiaphragmatic approach

21.1 Problems Associated with Redo Conventional CABG

Redo coronary artery bypass grafting (CABG) is associated with higher mortality and morbidity when compared with first-time CABG, with a three- to fivefold increase in operative mortality in most series of reoperation [1–5]. Reoperative procedures provide several technical challenges that distinguish them from primary operations. In addition, patients undergoing redo CABG are likely to have worse ejection fraction, a history of previous myocardial infarction, and severe and diffuse coronary artery disease with more comorbidities,

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which increases the risk of complications [4, 5]. The problems related to redo CABG include (1) sternal reentry, (2) injury to patent grafts or the heart during dissection, (3) embolization of atheromatous debris caused by manipulation of diseased vein grafts, (4) inadequate myocardial protection, (5) quality and availability of conduits, and (6) incomplete revascularization.

Perioperative myocardial infarction and dysfunction contribute significantly to the increased risk of redo CABG [6]. In a series of 1,500 coronary reoperations at the Cleveland Clinic, most deaths (74 %) were related to myocardial dysfunction [1]. In a review from the Toronto General Hospital, Yau and colleagues compared the outcome of primary CABG with redo CABG and found that the incidences of perioperative myocardial infarction (3.7 % vs. 7.4 %), low-output syndrome (9.0 % vs. 24.0 %), and death (2.4 % vs. 6.8 %) were significantly increased in patients undergoing reoperation [4]. Inability to adequately protect the heart during redo CABG is attributed to three major factors, including (1) injury to patent grafts, (2) atheromatous embolization from diseased vein grafts, and (3) inadequate myocardial protection. To be consistently successful, coronary reoperation must be designed to avoid these causes of myocardial infarction.

21.1.1 Injury to Patent Grafts

Injury to a patent left internal thoracic artery (LITA) graft connected to the left anterior descending coronary artery (LAD) at reoperation can have catastrophic consequences, although the presence of a LITA graft may not be an independent predictor of morbidity and mortality at reoperation [7, 8]. Dissection and control of the LITA graft can be challenging and hazardous, with some investigators reporting injury to the LITA graft in 16–38 % of coronary reoperations [9, 10]. With advanced technique and increased experience with reoperative coronary procedures, the prevalence of injury to the LITA graft has been reduced to 5 %; however, 40 % of patients who suffered an injury to the LITA graft sustained perioperative myocardial infarction [11]. To prevent injury to the LITA graft, it is important to place the LITA graft in the adequate location at the time of the primary surgery [12]. Specifically, the LITA graft should be routed into the pericardium slit divided vertically and should lie in a posterior position, just anterior to the phrenic nerve and lateral to the pulmonary artery.

21.1.2 Atheromatous Embolization from Diseased Vein Grafts

Atheromatous debris caused by manipulation of diseased saphenous vein (SV) grafts may embolize into the coronary circulation [6]. Keon and colleagues reported a 2.3 % incidence of fatal perioperative myocardial infarction caused by manipulation of diseased but patent SV grafts at reoperation in their autopsy series [13]. Various strategies have been applied to reoperation with diseased SV grafts in order to decrease the possibility of distal atheroembolism. Grondin and colleagues introduced a new technique including minimal dissection and prompt ligation of diseased SV grafts at the start of cardiopulmonary bypass (CPB) to a small number of patients and reduced perioperative myocardial infarction (0/6 vs. 5/12) and mortality (0/6 vs. 3/12) when compared with the standard technique [14]. On the contrary, LITA to LAD grafting with interruption of the old SV grafts was an independent predictor of postoperative hypoperfusion in 387 consecutive patients undergoing redo CABG with a stenotic SV graft to a totally obstructed LAD [15]. Ligation of diseased but patent grafts is associated with its own risks of embolization and devascularization of viable myocardium. The strategy of adding an internal thoracic artery (ITA) graft to the LAD and leaving a stenotic SV graft intact at reoperation is associated with a low risk of perioperative myocardial infarction [16]. In addition, the late clinical results are favorable, and repeat angiography indicates that serious competitive flow from the stenotic SV graft is uncommon in follow-up study [16]. A patent atherosclerotic SV graft may be best managed by a “no-touch” technique.

21.1.3 Inadequate Myocardial Protection

Myocardial distribution of antegrade cardioplegia is unpredictable in redo CABG patients. Antegrade cardioplegia may not be effective for areas of myocardium that are perfused by patent LITA grafts, unless either the LITA is clamped or moderate systemic hypothermia is induced [6]. However, clamping patent in situ arterial grafts can enhance the risk of injury to these patent grafts, and moderate to deep hypothermic arrest can prolong the overall CPB time and create hematological abnormalities and tissue edema [4]. Inadequate myocardial protection is the main cause of failure to wean patients off CPB. Retrograde cardioplegia through the coronary sinus provides better myocardial protection distal to the sites of coronary artery disease [17], and the use of retrograde cardioplegia is recommended for patients with a patent LITA graft [7]. In addition, retrograde cardioplegia may reduce the risk of atheromatous embolization from diseased vein grafts [18]; therefore, retrograde cardioplegia has been proposed as a method of decreasing the risk of redo CABG [19, 20]. Lytle and colleagues found that patent ITA and atherosclerotic vein grafts did not appear to be factors specifically in increasing the risk of reoperation, which was attributed to the use of retrograde cardioplegia and increased surgical experience [7]. In a review from the Toronto General Hospital, the use of retrograde cardioplegia was more frequent in reoperative patients with stenosed grafts and was associated with improved survival; they concluded that failure to use retrograde cardioplegia was the strongest independent predictor of mortality [18]. However, previous studies have demonstrated that isolated retrograde cardioplegia may result in inadequate myocardial perfusion, which contributes to increased myocardial lactate production, increased creatine kinase MB release, and decreased adenosine triphosphate levels compared with antegrade cardioplegia [17]. Furthermore, adequate placement of a coronary sinus cannula often requires extensive mobilization of the right atrium and surrounding tissue including diseased vein grafts to the right coronary artery (RCA) [6]. Therefore, the optimal myocardial protection strategy for redo CABG may be retrograde cardioplegia combined with antegrade perfusion of new vein grafts, in particular to the RCA [17, 18].

21.2 Changing Profiles of Patients Undergoing Redo CABG

21.2.1 Prevalence of Redo CABG

Previous studies have noted an increase in the prevalence of patients referred for redo CABG [21, 22], but this prevalence has reached a plateau [4]. More recently, the proportion of redo CABG has decreased [23]. This decrease is related to several factors.

First, use of the LITA-LAD grafting decreases the likelihood of death, cardiac events, and reoperation when compared with the strategy of using only vein grafts, and LITA-LAD grafting has become a standard procedure for primary CABG [24]. In addition, the positive effect of bilateral ITA grafts has been confirmed [25]. Furthermore, multiple arterial grafts using bilateral ITA grafts and other arterial conduits, such as the radial artery (RA) and the right gastroepiploic artery (GEA), may improve long-term freedom from reintervention [26, 27].

Second, percutaneous coronary intervention (PCI) represents an alternative treatment for postoperative patients [28]. Recently, the introduction of drug-eluting stent (DES) has shown promising results in selected de novo native coronary artery lesions [29]. When compared with bare-metal stent (BMS) implantation, DES implantation in SV graft lesions appears safe with favorable and improved short-term outcomes [30]; however, the benefit of DES implantation is not apparent in terms of midterm outcomes [31]. PCI in diseased SV grafts carries a significant risk of major adverse clinical event (predominantly myocardial infarction) or reduced antegrade flow (the no-reflow phenomenon). Use of the distal protection device during stenting of stenotic vein grafts is associated with a highly significant reduction in major adverse events when compared with stenting over a conventional angioplasty guidewire [32].

Third, aggressive use of antiplatelet agents [33], which improve the patency of vein grafts, and lipid-lowering agents [34], which reduce the progression of atherosclerosis of vein grafts, may be reasons for the decrease in the numbers of reoperations.

21.2.2 Angiographic Indications for Redo CABG

Redo CABG surgery may be required as a result of graft failure, progression of native coronary atherosclerosis, or a combination of these factors [4, 5, 35]. Of these three indications, vein graft disease is by far the most common [4, 5]. According to a study that assessed angiographic indications for reoperation among different periods, the number of patients reoperated for early graft failure decreased, and patients reoperated for isolated progression of native coronary atherosclerosis increased in the later period [35]. That study also demonstrated an increasing number of patients with patent arterial grafts and a history of previous successful PCI as well as an extended time between primary CABG and redo CABG in the later period [35]. These phenomena may be attributed to the routine use of the ITA during the primary operation, development of PCI techniques, and the application of optimal medical treatment following primary CABG, as described above. It should be emphasized that the number of patients with patent ITA grafts has increased recently, because the presence of a patent LITA-LAD graft creates specific risks, including the possibility of intraoperative injury to the graft and potential difficulties with myocardial protection [11].

21.2.3 Increased Risk Profiles of Patients Undergoing Redo CABG

The risk profile of patients undergoing redo CABG is more complicated than that of patients undergoing primary CABG [4, 5, 23]. Hypertension, dyslipidemia, insulin-dependent diabetes, history of smoking, and renal insufficiency are all more frequent in reoperative patients [5]. Patients undergoing a reoperation are more likely to be male; to have left ventricular dysfunction, peripheral vascular disease, and worse symptoms; and to require an urgent operation than patients undergoing a primary operation [4, 23]. The increased mortality and morbidity of redo CABG appears to be related to the higher risk profile of redo CABG patients [23]. As in primary CABG [36, 37], the demographics of patients undergoing redo CABG have changed over time [4, 21, 22, 35]. Recently, patients undergoing reoperation are more likely to be older and to have worse left ventricular function, more extensive coronary atherosclerosis, and patent arterial grafts. Although the number of patients with high-risk profiles has increased, both morbidity and mortality remain relatively constant, which is likely a result of increased experience and advanced techniques, including perioperative management and myocardial protection.

21.3 Application of Off-Pump Procedure to Redo CABG

Off-pump coronary artery bypass grafting (OPCAB) has been increasingly adopted in an attempt to reduce mortality and morbidity that may be attributable to aortic manipulation, global myocardial ischemia, and systemic inflammatory response associated with CPB [38]. High-risk patients for whom CPB is likely to be deleterious may benefit from OPCAB. Although prior small randomized controlled trials enrolling predominantly low-risk patients have failed to show a mortality benefit for OPCAB [39], OPCAB is associated with lower operative mortality than conventional CABG for high-risk patients at primary operations [40, 41]. As OPCAB has evolved over the past two decades, the off-pump procedure has been applied to redo coronary surgery. The 2004 International Society for Minimally Invasive Cardiothoracic Surgery (ISMICS) consensus conference on OPCAB versus conventional CABG (CCAB) concluded that OPCAB should be considered to reduce mortality and perioperative morbidity in high-risk patients including those with EuroSCORE greater than 5, age >75 years, diabetes, renal failure, left ventricular dysfunction, and left main disease and those "undergoing reoperation" [42].

21.3.1 Advantages of Redo OPCAB

Several reports indicated that redo CABG without CPB significantly reduced morbidity and mortality when compared with redo CABG with CPB [43–50]. Allen and colleagues first reported that single-vessel redo OPCAB of the LAD with the LITA using a limited anterior thoracotomy reduced the incidence of atrial fibrillation (AF), time to extubation, transfusion requirements, and length of hospital stay without a significant reduction of mortality, perioperative cerebrovascular accident (CVA), and/or myocardial infarction when compared with single-vessel redo CCAB [43]. Stamou and colleagues confirmed that single-vessel redo OPCAB was associated with lower perioperative morbidity and mortality (1 % vs. 10 %) than single-vessel redo CCAB in a single institution study [44]. A subsequent report using data from the New York State database demonstrated that stroke (0 % vs. 3.8 %), cardiovascular complications (4.8 % vs. 15.8 %), and other major complications (1.9 % vs. 10.4 %) were significantly reduced in redo OPCAB patients when compared with redo CCAB patients [45].

More recently, the superiority of OPCAB in multivessel redo CABG was also confirmed [46–50]. In a propensity-matched comparison of reoperative OPCAB (132 patients) versus CCAB (639 patients), Morris and colleagues reported a significant reduction in overall postoperative complications, AF, blood transfusion, and length of hospital stay [46]. Mishra and colleagues compared 332 patients undergoing redo OPCAB with 206 patients undergoing redo CCAB in a 10-year study and found a reduction in need for prolonged ventilation, inotropic support, and length of hospital stay in the redo OPCAB group [47]. In these two large studies, there was a non-statistically significant trend toward reductions in mortality, perioperative CVA, and myocardial infarction in favor of redo OPCAB [46, 47]. Schutz and colleagues demonstrated that redo OPCAB resulted in decreased cardiac-specific enzyme release, reduced requirement of inotropes, and comparable clinical outcome in the early postoperative period [48]. Interestingly, Vohra and colleagues reported that actuarial survival (95 ± 3.2 % vs. 87 ± 5.5 %) and event-free survival (78 ± 7.2 % vs. 71 ± 8.0 %) at 5 years were comparable between redo OPCAB and redo CCAB groups, irrespective of OPCAB patients receiving fewer grafts (2.0 ± 0.6 vs. 3.0 ± 0.8) [49]. Usta and colleagues found that the shorter operation time, less blood loss, fewer perioperative myocardial infarctions, and the higher rate of total arterial revascularization were the significantly beneficial differences in the redo OPCAB group and that actuarial survival at 3 years was higher in the redo OPCAB group vs. in the redo CCAB group (81 ± 12 % vs. 63 ± 9 %) [50].

The advantage of redo OPCAB is avoidance of global ischemia induced by aortic cross-clamping and cardioplegic arrest under CPB, which can minimize the need for extensive dissection around the heart and avoid manipulation of the patent graft or diseased vein graft. These benefits can avoid the problems associated with redo CABG, including (1) injury to patent grafts, (2) atheromatous embolization from diseased vein grafts, and (3) inadequate myocardial protection. Further, these benefits may explain the reduction in mortality, perioperative myocardial infarction, CVA, and other complications. Hence, off-pump procedures may be feasible and practical for patients undergoing reoperative coronary surgery.

21.3.2 Disadvantages of Redo OPCAB

Although the off-pump procedure offers some advantages in the setting of redo CABG, redo OPCAB is criticized by many investigators for issues involving complete revascularization, graft patency, and long-term outcomes [51–53]. As in primary CABG, complete revascularization is the main goal of redo CABG. Previous studies have demonstrated that incomplete revascularization negatively affects long-term outcomes after primary operations [54].

Di Mauro and colleagues found that redo OPCAB patients had a higher percentage of incomplete revascularization than redo CCAB patients (35.3 % vs. 6.4 %) and that incomplete revascularization was an independent predictor of cardiac death and cardiac events at 5 years [51]. In the study by Czerny and colleagues, minimal tissue dissection and target vessel revascularization without CPB did not add significant benefit with regard to perioperative morbidity and mortality [52]. In addition, redo OPCAB patients received fewer distal grafts (1.3 ± 0.5 vs. 2.8 ± 0.9) with a lower percentage of complete revascularization (27 % vs. 92 %) than redo CCAB patients and had a higher rate of recurrence of angina and higher use of nitrates during 5-year follow-up periods. They concluded that the unsatisfactory relief of symptoms did not seem to justify the use of an off-pump procedure in redo CABG. Tugtekin and colleagues reported that mortality (2.9 % vs. 3.8 %) and perioperative myocardial infarction (2.9 % vs. 2.5 %) were comparable between redo OPCAB and redo CCAB groups [53]. They emphasized that these results might be attributed to short cross-clamp time (38.9 ± 16 min), since a prolonged cross-clamp time in redo CABG had been pointed out as a predictor of mortality in previous studies [2, 55]. They also used the inversed index for completeness of revascularization (iICOR, preoperative planned/performed anastomoses) to compare redo OPCAB with redo CCAB and found that iICOR was higher in redo OPCAB than in redo CCAB (1.7 vs. 1.0); this resulted in a higher incidence of recurrent angina in redo OPCAB during follow-up periods. Interestingly, actuarial survival at 5 years was comparable between OPCAB and CCAB groups. These studies also suggest that redo OPCAB patients receive fewer distal grafts with less complete revascularization than redo CCAB patients. Off-pump procedure in redo CABG might be limited due to incomplete revascularization and might be offered exclusively to high-risk patients with complete revascularization using CPB. If complete revascularization can be achieved in most reoperative patients, then off-pump procedure could be a standard technique in redo CABG.

One of the other important drawbacks of off-pump procedure is the hemodynamic deterioration that can occur during manipulation of the heart, resulting in acute conversion to CPB support with a subsequent increased risk of mortality and serious complications [56, 57]. Acute conversion from off-pump to on-pump procedure in redo CABG has not been discussed previously. Morris and colleagues demonstrated that 16.7 % (22/132) of patients were converted from off-pump to on-pump for hemodynamic instability, severe adhesions, or graft injury in reoperations and that conversion did not reduce the benefit of OPCAB [46]. Great care must be taken when dissecting the dense adhesions around the heart and patent grafts, as the rate of acute conversion in reoperations may be higher than that in primary operations (1.1–3.1 %), and these risks of acute conversion are difficult to quantify preoperatively [56, 57]. In situations associated with increased risk during a repeat median sternotomy, vessels for arterial and venous access for CPB should be exposed prior to sternal reentry. The axillary artery is an important alternative cannulation site, because atherosclerotic disease is usually not present in that vessel and its cannulation allows antegrade perfusion. As an alternative technique in reoperations, on-pump beating CABG may be a good choice for high-risk patients with unstable hemodynamic conditions [58]. The advantages of this strategy are avoidance of aortic cross-clamping and cardioplegic arrest and reduction of the risks of hemodynamic deterioration and acute conversion to CPB support.

21.3.3 Repeat Median Sternotomy in Redo OPCAB

Standard off-pump techniques are used for redo OPCAB using repeat median sternotomy. These include the use of a suction stabilizer and heart positioner, vascular loops for proximal target vessel occlusion, and CO_2 blowers for vessel visualization. Maneuvers to optimize intraoperative hemodynamics and right ventricular performance, especially during displacement of the heart, are routinely employed, including Trendelenburg position, tilting the table, and adequate volume loading. Both the LAD and RCA could be grafted without much displacement of the heart. For exposure of the left circumflex coronary artery (LCx), deep pericardial traction sutures are placed to pull the heart vertically. A vertical right pericardiotomy is performed to herniate the heart to the right chest cavity under the sternum, as required. The use of vasopressors and inotropes is avoided whenever feasible.

An oscillating saw is used to divide the sternum for repeat median sternotomy. Leaving the sternal wires in place behind the sternum might help; however, this is not necessarily safe, as the SV grafts or right ventricle can get stuck behind the sternum between the wires [3]. Lifting the edges of the sternum and careful dissection of the posterior table of the sternum under direct vision can help avoid surgical disaster. All bypass grafts except for the ITA should be prepared prior to sternal reentry. In redo CCAB patients, initial exposure of the ascending aorta and right atrium is needed for cannulation to establish CPB; by contrast, this is not necessarily needed in redo OPCAB patients. The bilateral ITAs are used as inflow sources whenever possible to avoid manipulation of the ascending aorta for proximal anastomosis, because approaching the ascending aorta is frequently a significant challenge in reoperative surgery. When the RA or SV graft is anastomosed to the ascending aorta, a proximal anastomosis device should be applied. This allows a sutured free graft to be placed onto the ascending aorta without the necessity for extensive dissection and partial clamping. When beating heart surgery (with or without CPB) is planned, a "no-touch" technique should be employed for all patent grafts. In most cases, it is safest to find the correct dissection plane at the level of the diaphragm and then continue around the right atrium to the aorta. This technique may be dangerous in situations where a diseased vein graft to the RCA lies over the right atrium, because manipulation of diseased vein grafts can cause embolization of atherosclerotic debris into coronary arteries. It is best to employ a "no-touch" technique with such grafts. One of the most difficult points is to dissect and control a patent LITA graft in redo CCAB, whereas an off-pump procedure makes it possible to leave a patent LITA graft in place and to dissect the left side of the heart safely. Heparin (100 U/kg) is administrated to maintain the activating clotting time at longer than 250 s during anastomosis and is reversed by protamine at the end of the procedure.

21.4 Alternative Approach to Avoid Repeat Median Sternotomy

Alternative approaches to avoid repeat median sternotomy, such as (1) left anterior small thoracotomy (LAST), (2) left lateral thoracotomy, (3) the transdiaphragmatic approach, and (4) combination of the left thoracotomy and transdiaphragmatic approach, may reduce risks attributable to dissection of the heart and manipulation of patent or diseased grafts in selected patients [43, 59–72]. The risk of catastrophic hemorrhage at sternal reentry is estimated at 0.5–1 %, with an associated mortality of 21 % [73]. The risk of injury to a patent ITA graft is 5 %, and this event is associated with a mortality of 9 % and myocardial infarction of 40 % [11]. Situations associated with increased risk during resternotomy include (1) a patent right ITA (RITA) graft that runs across a midline to the LAD, (2) a patent LITA graft that curls under the sternum, and (3) right ventricular or aortic enlargement beneath the sternum. An alternative approach should also be considered in cases with prior mediastinitis or radiation treatment, calcification of the ascending aorta, and presence of a tracheostomy. In addition, this approach could eliminate morbidity associated with CPB. It is likely that the benefits of avoiding CPB are greatest in patients with increased age, diffuse atherosclerosis, and other serious comorbidities. Patients requiring redo CABG generally have higher risk profiles, and they may derive particular benefits from off-pump techniques. Thus, an alternative approach to avoid repeat median sternotomy without CPB is an ideal procedure for selected reoperative patients, particularly in those with patent grafts and higher risk profiles, in terms of avoiding an extensive dissection and the use of CPB. It is important to keep dissection limited; more extensive dissection results in troublesome venous bleeding and reduces the natural stabilization provided by adhesions.

One of the important drawbacks of redo OPCAB is incomplete revascularization, which is further magnified when using an alternative approach to avoid resternotomy. Complete revascularization should be the goal in redo operations as well as in primary operations. Although it is possible that selected patients may benefit from incomplete revascularization with bypass only of the "culprit" vessel, there are insufficient data to determine which patients might be in this category. Thus, this approach should be reserved for only selected patients. However, target vessel revascularization via an alternative approach integrated with PCI may offer multivessel revascularization with minimal morbidity in high-risk patients. This hybrid procedure, which was proposed by Angelini and colleagues, combines LITA-LAD grafting through a LAST approach with staged PCI of stenotic non-LAD vessels [74]. This integrated approach has tremendous appeal by offsetting the invasiveness of redo CCAB but retaining the benefits of LITA-LAD grafting. This procedure is a practical alternative for patients with multivessel disease who are not candidates for conventional coronary reoperations.

Another disadvantage of redo CABG is the lack of available bypass conduit that is also magnified further in this alternative approach because of the impossibility of RITA use. The ascending aorta also cannot be used as an inflow source in this alternative approach. Preoperative angiography of the ITA and GEA is essential when these vessels are used. Venous ultrasound studies can be used to assess the presence of SV segments [75]. Volume rendering computed tomography (CT) without contrast medium clearly demonstrates the three-dimensional mapping of the SV and may be helpful in redo CABG to characterize the remaining SV [76]. Arterial ultrasound studies can assess the RA and inferior epigastric artery (IEA). Use of the RA in redo CABG allows additional conduit choice, reduces donor site and sternal infections, and may avoid further vein graft failure [77].

21.4.1 Left Anterior Small Thoracotomy (LAST)

As the minimally invasive direct coronary artery bypass (MIDCAB) procedure, performed with a LAST approach and without CPB, has gained acceptance, this procedure is applied to redo coronary operations [43, 61–63]. This alternative approach seems to be an ideal procedure for redo CABG only if the LAD needs to be revascularized and if the LITA has not been used previously. In addition, reoperative patients who have single or multivessel disease but who are considered to be too high risk for CPB are also candidates for MIDCAB via a LAST approach. If the LITA is not available, a segment of the SV can be anastomosed to the left subclavian artery (LSCA) and routed in a transthoracic path to the LAD.

The chest is opened in the fourth or occasionally fifth intercostal incision. The techniques are similar to those of primary operations via a LAST approach [61]. Identification of the LAD is often easy in a redo MIDCAB procedure via a LAST approach because the LAD almost always has been bypassed previously and because the SV graft acts as a guide. Pericardial adhesions are typically dense beneath the sternum, and therefore approaching the LAD through LAST is usually not particularly difficult.

21.4.2 Left Lateral Thoracotomy

Redo OPCAB via a left lateral thoracotomy is indicated for selective reoperative patients who present with the need for isolated revascularization of the LCx system [64–68]. This approach is of particular benefit in patients with accessible targets for whom resternotomy or CPB presents particular hazards, especially in patients with patent ITA grafts.

After double-lumen endotracheal intubation, a transesophageal echocardiographic probe is inserted to assess the descending thoracic aorta for atheromatous changes and overall cardiac function. Preoperative chest CT and intraoperative epiaortic ultrasound are also useful to evaluate the descending thoracic aorta as a site for proximal anastomosis [64, 65]. When the descending thoracic aorta is heavily calcified with atheromatous changes, there is an obvious risk of dissection or distal embolism due to partial clamping. In such cases, the LSCA is used as an inflow source and is prepared with the patient in a supine position. Otherwise, proximal anastomosis devices are extremely useful, because these devices can obviate the need for partial clamping for proximal anastomosis [66]. An external defibrillator is placed on the patient before draping for subsequent defibrillation, as necessary. The patient is first positioned supine for harvesting of all conduits, exposure of femoral vessels for possible peripheral CPB cannulation, and placement of femoral arterial line for intra-aortic balloon pump (IABP) backup, if deemed necessary. Then, the patient is repositioned in a right lateral decubitus position with the pelvis externally rotated to allow access to the femoral vessels for CPB cannulation. The left lung is deflated, and an incision is made in the fifth or sixth intercostal space. The thoracotomy is generally extended a few centimeters anteriorly or posteriorly as necessary to gain exposure of the target vessels and the inflow sources. The lung is dissected free, and the inferior pulmonary ligament is incised. The pericardium is opened posterior to the phrenic nerve. In the presence of a patent LITA-LAD graft, the anteromedial aspect of the lung is dissected from the pericardium only enough to locate the LCx target. In such situations, the LITA graft is usually not encountered. Establishing the optimal length of free graft (SV or RA graft) may be particularly problematic. If these grafts are too long, they may kink, whereas if left too short, they may be stretched by respiratory excursions of the left lower lobe of the lung [67]. The grafts should lie in a gentle loop under the mobilized inferior pulmonary ligament. The lungs are inflated to ensure that the free graft is not stretched before chest closure.

21.4.3 Transdiaphragmatic Approach

Off-pump procedure via a transdiaphragmatic approach using the in situ skeletonized GEA graft is useful in selective patients who present with the need for isolated revascularization of the RCA system at reoperations as well as primary operations [63, 69–71]. This approach is of particular benefit in reoperative patients with accessible targets for whom resternotomy or CPB presents particular hazards, especially in patients with patent ITA grafts.

As in situ arterial grafts, the GEA is secondary to the ITA, and the excellent long-term patency rate of the skeletonized GEA has been confirmed recently [78]. Preoperative GEA angiography is essential, because the luminal diameter and length are not consistent in the GEA, unlike the ITA; hence, this often causes a limited flow reserve [79]. When the GEA has already been excised or is too small to serve as an effective graft, the GEA is cut proximally and can be extended with the RA or SV grafts, or the gastroduodenal or common hepatic artery is used as an inflow source [70, 71].

To complete this procedure via a transdiaphragmatic approach, it is important to ensure a comfortable operative field. The patient is positioned supine, and a pillow is placed between the patient's back at the level of the liver and the operating table. A 10–15 cm incision is made in the upper abdominal midline extending along the previous sternotomy incision to allow access to the lower 3 cm of the sternum with excision of the xiphoid process and the lower part of the sternum as necessary. A Kent's retractor is then positioned at the left and right costal arches, and this is pulled in a cranial direction to create a large gap between the liver and the diaphragm. The diaphragm is divided vertically to expose the inferior wall of the heart, and the edges of the diaphragm are then retracted using stay sutures. Usually, it is easy to follow the previous graft leading to the branches of the RCA. After the target vessel is then stabilized, the subsequent procedure is performed in a usual manner.

21.4.4 Combination of the Left Thoracotomy and Transdiaphragmatic Approach

Target vessel revascularization through an alternative approach to avoid repeat median sternotomy is very useful in selective reoperative patients; however, incomplete revascularization remains one of the problems in redo CABG. The distal branches of the RCA can be exposed by careful dissection even in left lateral thoracotomy. When left thoracotomy is combined with the transdiaphragmatic approach in redo OPCAB, all territories of the coronary artery, including the posterior descending artery (PDA) of the RCA, can be approached to avoid manipulation of patent or diseased grafts and dissection of the heart [71, 72]. Shennib and colleagues demonstrated that five patients underwent redo multivessel OPCAB with this combined approach and that the SV or RA grafts (one is connected to the PDA and the other is connected to the LCx branch) are pulled into the left chest and are anastomosed to the descending thoracic artery under partial clamping [72]. Takahashi and colleagues reported that 79 patients underwent redo OPCAB through an alternative approach to avoid resternotomy without major complications over 15 years and that 13 patients (16 %) underwent redo multivessel OPCAB with this combined approach [71]. This procedure is technically simpler and carries potentially fewer risks than a resternotomy in the presence of patent grafts to the LAD territory or when resternotomy is contraindicated for other reasons. This technique could be an attractive option for selected patients with patent grafts who require multivessel redo CABG.

21.5 Redo OPCAB in Our Institute

Thirty-seven patients who underwent redo OPCAB at Nippon Medical School Hospital from March 1997 to December 2009 were examined. During the same period, four patients underwent redo CCAB via repeat median sternotomy. Redo CCAB was performed in early periods (until 2002) when our off-pump protocol had just been started. Patients' preoperative characteristics are listed in Table 21.1. The group of patients consisted of 24 men and 13 women with a mean age of 71.6 ± 8.1 (range, 50–88) years. All patients underwent their first reoperation. The mean duration between primary CABG and redo CABG was 10.1 ± 7.5 (range, 0.1–32.7) years. Twenty-two patients (59 %) had diabetes mellitus, 23 patients (62 %) had prior myocardial infarction, five patients (14 %) had decreased cardiac function with an ejection fraction of less than 35 %, five patients (14 %) had renal dysfunction, four patients (11 %) underwent emergent or urgent operation, and 15 patients (41 %) had a history of PCI. The type of previous operation was CCAB in 34 patients, OPCAB via median sternotomy in two patients, and OPCAB via LAST in one patient. The mean number of distal anastomoses at primary operation was 2.4 ± 0.9 (range, 1–4), and grafts used at primary operation were LITA in 25 patients, RITA in four patients, GEA in one patient, RA in three patients, and SV in 41 patients (Table 21.2). Twenty-five patients (68 %) had at least one patent graft, and 16 patients (48 %) had a patent ITA-LAD graft. Reasons for reoperation included de novo coronary lesions in four (11 %) patients, graft failure in 18 (49 %) patients, and de novo coronary lesions plus graft failure in 15 (40 %) patients.

The approaches used to access the target coronary arteries were (1) repeat median sternotomy in ten (27 %) patients, (2) left thoracotomy in 11 (30 %) patients, (3) the transdiaphragmatic approach in seven (19 %) patients, and (4) combination of the left thoracotomy and transdiaphragmatic approach in nine (24 %) patients (Table 21.3). The relationship of each

Table 21.1 Preoperative characteristics of patients undergoing redo CABG

Characteristics	Value
Male/female	24/13
Mean age (years)	71.6 ± 8.1
Diabetes mellitus	22 (59 %)
Dyslipidemia	23 (62 %)
Hypertension	34 (92 %)
Smoking	20 (54 %)
Cerebrovascular accident	5 (14 %)
Renal dysfunction	5 (14 %)
Low ejection fraction	5 (14 %)
Prior myocardial infarction	23 (62 %)
Previous PCI	15 (41 %)
Preoperative use of IABP	5 (14 %)
Emergent/urgent operation	4 (11 %)
Presence of a patent graft	25 (68 %)
Presence of a patent ITA-LAD graft	16 (43 %)

CABG coronary artery bypass grafting, *PCI* percutaneous coronary intervention, *IABP* intra-aortic balloon pump, *ITA* internal thoracic artery, *LAD* left anterior descending artery

Table 21.2 Graft selection in primary CABG and redo CABG

	LITA	RITA	GEA	RA	SV	IEA
Previous CABG	25	4	1	3	41	–
Patent	(16)	(3)	(0)	(1)	(8)	–
Stenosis	(2)	(0)	(0)	(0)	(3)	–
Occlusion	(7)	(1)	(1)	(2)	(30)	–
Redo CABG	9	8	20	16	12	1

CABG coronary artery bypass grafting, *LITA* left internal thoracic artery, *RITA* right internal thoracic artery, *GEA* right gastroepiploic artery, *RA* radial artery, *SV* saphenous vein, *IEA* inferior epigastric artery

Table 21.3 Approach to the heart in reoperative patients

Approach	Value
Repeat median sternotomy	10 (27 %)
Avoiding repeat median sternotomy	27 (73 %)
Left thoracotomy	11 (30 %)
Transdiaphragmatic approach	7 (19 %)
Combination of left thoracotomy and transdiaphragmatic approach	9 (24 %)

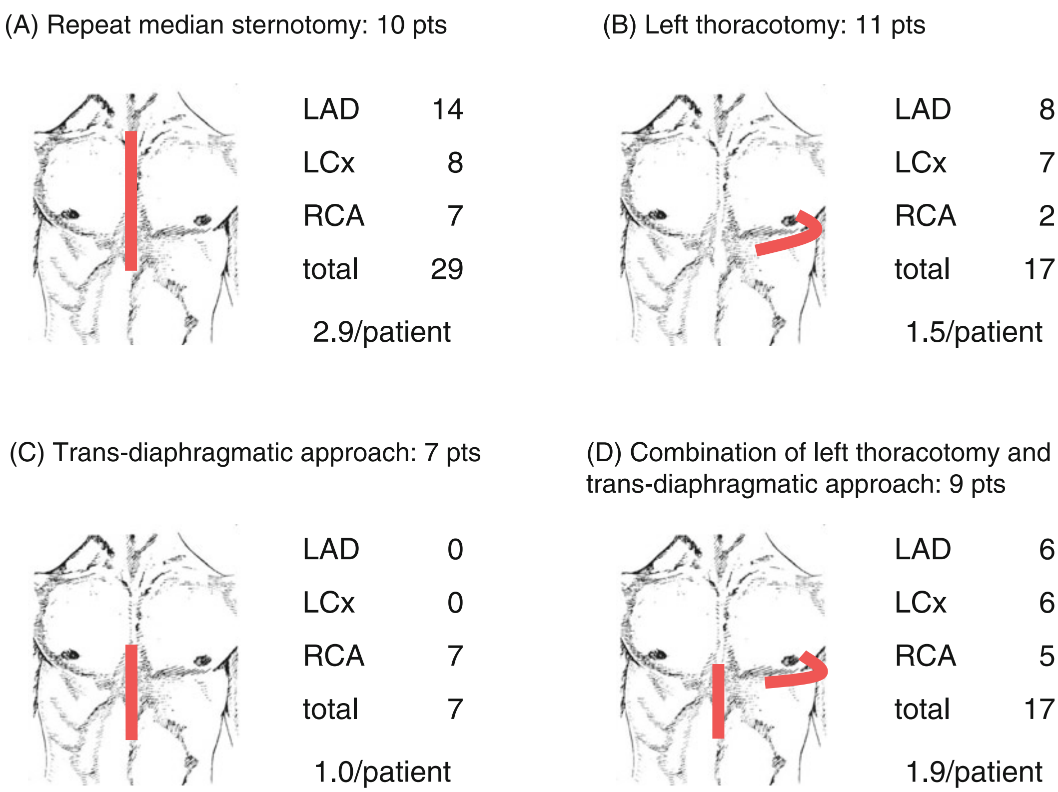

Fig. 21.1 The relationship of each approach and target vessels is described. (**b**) Left thoracotomy is used for revascularization of the LCA and distal branches of the RCA, and (**c**) transdiaphragmatic approach is used for revascularization of the RCA. Target vessels in all territories are revascularized by (**d**) combination of left thoracotomy and transdiaphragmatic approach. The mean number of distal anastomoses is 2.9 in (**a**) repeat median sternotomy, 1.5 in (**b**) left thoracotomy, 1.0 in (**c**) transdiaphragmatic approach, and 1.9 in (**d**) combination of left thoracotomy and transdiaphragmatic approach. *LCA* left coronary artery, *RCA* right coronary artery, *LAD* left anterior descending artery, *LCx* left circumflex artery

approach and target vessels is described in Fig. 21.1. Left thoracotomy was used for revascularization of the left coronary artery and distal branches of the RCA, and the transdiaphragmatic approach was used for revascularization of the RCA. Target vessels in all territories could be revascularized by combination of the left thoracotomy and transdiaphragmatic approach. Twenty-seven patients (73 %) avoided repeat median sternotomy in redo OPCAB. In 25 patients who had at

Table 21.4 The relationship of target vessels and inflow sources

Inflow source	LAD (28)	LCx (21)	RCA (21)
LITA	9	2	1
RITA	7	0	2
GEA	5	5	14
AsAo	4	6	1
LSCA	2	5	2
DsAo	1	3	1

LAD left anterior descending artery, *LCx* left circumflex artery, *RCA* right coronary artery, *LITA* left internal thoracic artery, *RITA* right internal thoracic artery, *GEA* right gastroepiploic artery, *AsAo* ascending aorta, *LSCA* left subclavian artery, *DsAo* descending thoracic artery

least one patent graft, 22 patients (88 %) avoided resternotomy. The mean number of distal anastomoses at redo operation was 1.9 ± 1.1 (1–5), and grafts used at redo operation were LITA in nine patients, RITA in eight patients, GEA in 20 patients, RA in 16 patients, SV in 12 patients, and IEA in one patient (Table 21.2). Total arterial revascularization was completed in 25 patients (68 %). The number of distal anastomoses in each territory was 28 in LAD, 21 in LCx, and 21 in RCA. The relationship of target vessels and inflow sources is listed in Table 21.4. The GEA, LSCA, and descending thoracic aorta played an important role as inflow sources for revascularization to the LCx and RCA in redo OPCAB via an alternative approach. Complete revascularization was achieved in 27 patients (73 %), and when combined with staged PCI, complete revascularization was achieved in 29 patients (78 %). In a later period (when off-pump procedure was applied in all elective primary cases after 2002), complete revascularization was achieved in 23 of 26 patients (88 %).

One patient (3 %; age, 85 years) died due to sepsis. Injury of the right ventricle requiring repair was observed in one patient (3 %) who needed conversion to CPB support without cardioplegic arrest. No perioperative myocardial infarction occurred, and only one patient (3 %) needed prolonged ventilation (>48 h) postoperatively. Twenty patients (54 %) underwent postoperative angiography, and all grafts were found to be patent.

In our experience, an off-pump procedure in redo CABG can be performed with a low perioperative morbidity and mortality and satisfactory graft patency. An alternative approach to avoid repeat median sternotomy is a promising option for selected patients who have patent grafts and higher risk profiles for resternotomy or CPB.

References

1. Lytle BW, Loop FD, Cosgrove DM, Taylor PC, Goormastic M, Peper W, Gill CC, Golding LA, Stewart RW (1987) Fifteen hundred coronary reoperations: results and determinants of early and late survival. J Thorac Cardiovasc Surg 93:847–859
2. He GW, Acuff TE, Ryan WH, He YH, Mack MJ (1995) Determinants of operative mortality in reoperative coronary artery bypass grafting. J Thorac Cardiovasc Surg 110:971–978
3. Machiraju VR (2004) How to avoid problems in redo coronary artery bypass surgery. J Card Surg 19:284–290
4. Yau TM, Borger MA, Weisel RD, Ivanov J (2000) The changing pattern of reoperative coronary surgery: trends in 1230 consecutive reoperations. J Thorac Cardiovasc Surg 120:156–163
5. Christenson JT, Schmuzinger M, Simonet F (1997) Reoperative coronary artery bypass procedures: risk factors for early mortality and late survival. Eur J Cardiothorac Surg 11:129–133
6. Fazel S, Borger MA, Weisel RD, Cohen G, Pelletier MP, Rao V, Yau TM (2004) Myocardial protection in reoperative coronary artery bypass grafting: toward decreasing morbidity and mortality. J Card Surg 19:291–295
7. Lytle BW, McElroy D, McCarthy P, Loop FD, Taylor PC, Goormastic M, Stewart RW, Cosgrove DM (1994) Influence of arterial coronary bypass grafts on the mortality in coronary reoperations. J Thorac Cardiovasc Surg 107:675–683
8. Coltharp WH, Decker MD, Lea JW 4th, Petracek MR, Glassford DM Jr, Thomas CS Jr, Burrus GR, Alford WC, Stoney WS (1991) Internal mammary artery graft at operation: risks, benefits, and methods of preservation. Ann Thorac Surg 52:225–229
9. Ivert TS, Ekestrom S, Peterffy A, Welti R (1988) Coronary artery reoperations: early and late results in 101 patients. Scand J Thorac Cardiovasc Surg 22:111–118
10. Verkkala K, Jarvinen A, Virtanen K, Keto P, Pellinen T, Salminen US, Ketonen P, Luosto R (1990) Indications for and risks in reoperation for coronary artery disease. Scand J Thorac Cardiovasc Surg 24:1–6
11. Gillinov AM, Casselman FP, Lytle BW, Blackstone EH, Parsons EM, Loop FD, Cosgrove DM III (1999) Injury to a patent left internal thoracic artery graft at coronary reoperation. Ann Thorac Surg 67:382–386
12. Elami A, Laks H, Merin G (1994) Technique for reoperative median sternotomy in the presence of a patent left internal mammary artery graft. J Card Surg 9:123–127
13. Keon WJ, Heggtveit HA, Leduc J (1982) Perioperative myocardial infarction caused by atheroembolism. J Thorac Cardiovasc Surg 84:849–855
14. Grondin CM, Pomar JL, Hebert Y, Bosch X, Santos JM, Enjalbert M, Campeau L (1984) Reoperation in patients with patent atherosclerotic coronary vein grafts. A different approach to a different disease. J Thorac Cardiovasc Surg 87:379–385
15. Navia D, Cosgrove DM 3rd, Lytle BW, Taylor PC, McCarthy PM, Stewart RW, Rosenkranz ER, Loop FD (1994) Is the internal thoracic artery the conduit of choice to replace a stenotic vein graft? Ann Thorac Surg 57:40–43
16. Turner FE, Lytle BW, Navia D, Loop FD, Taylor PC, McCarthy PM, Stewart RW, Rosenkarz ER, Cosgrove DM 3rd (1994) Coronary reoperation: results of adding an internal mammary artery graft to a stenotic vein graft. Ann Thorac Surg 58:1353–1355
17. Yau TM, Ikonomidis JS, Weisel RD, Mickle DA, Hayashida N, Ivanov J, Carson S, Mohabeer MK, Tumiati LC (1993) Which techniques of cardioplegia prevent ischemia? Ann Thorac Surg 56:1020–1028

18. Borger MA, Rao V, Weisel RD, Floh AA, Cohen G, Feindel CM, Scully HE, Mickleborough LL, Yau TM (2001) Reoperative coronary bypass surgery: effect of patent grafts and retrograde cardioplegia. J Thorac Cardiovasc Surg 121:83–90
19. Rosengart TK, Krieger K, Lang SJ, Gold JP, Altorki N, Roussel M, Debois WJ, Isom OW (1993) Reoperative coronary bypass surgery: improved preservation of myocardial function with retrograde cardioplegia. Circulation 88:II-330–II-335
20. Savage EB, Cohn LH (1994) 'No touch' dissection, antegrade-retrograde blood cardioplegia, and single aortic cross-clamp significantly reduce operative mortality of reoperative CABG. Circulation 90:II-140–II-143
21. Loop FD, Lytle BW, Cosgrove DM, Woods EL, Stewart RW, Golding LA, Goormastic M, Taylor PC (1990) Reoperation for coronary atherosclerosis: changing practice in 2509 consecutive patients. Ann Surg 212:378–385
22. Akins CW, Buckley MJ, Daggett WM, Hilgenberg AD, Vlahakas GJ, Torchiana DF, Austen WG (1994) Reoperative coronary grafting: changing patient profiles, operative indications, techniques, and results. Ann Thorac Surg 58:359–364
23. Sabik JF 3rd, Blackstone EH, Houghtaling PL, Walts PA, Lytle BW (2005) Is reoperation still a risk factor in coronary artery bypass surgery? Ann Thorac Surg 80:1719–1727
24. Loop FD, Lytle BW, Cosgrove DM, Stewart RW, Goormastic M, Williams GW, Golding LA, Gill CC, Taylor PC, Sheldon WC, Proudfit WL (1986) Influence of the internal-mammary-artery graft on 10-year survival and other cardiac events. N Engl J Med 314:1–6
25. Lytle BW, Blackstone EH, Loop FD, Houghtaling PL, Arnold JH, Akhrass R, McCarthy PM, Cosgrove DM (1999) Two internal thoracic artery grafts are better than one. J Thorac Cardiovasc Surg 117:855–872
26. Locker C, Schaff HV, Dearani JA, Joyce LD, Park SJ, Burkhart HM, Suri RM, Greason KL, Stulak JM, Li Z, Daly RC (2012) Multiple arterial grafts improve late survival of patients undergoing coronary artery bypass graft surgery: analysis of 8622 patients with multivessel disease. Circulation 126:1023–1030
27. Barner HB, Sundt TM (1999) Multiple arterial grafts and survival. Curr Opin Cardiol 14:501–505
28. Weintraub WS, Jones EL, Craver JM, Guyton RA (1994) Frequency of repeat coronary bypass or coronary angioplasty after coronary artery bypass surgery using saphenous venous grafts. Am J Cardiol 73:103–112
29. Moses JW, Leon MB, Popma JJ, Fitzgerald PJ, Holmes DR, O'Shaughnessy C, Caputo RP, Kereiakes DJ, Williams DO, Teirstein PS, Jaeger JL, Kuntz RE (2003) SIRIUS investigators. Sirolimus-eluting stents versus standard stents in patients with stenosis in a native coronary artery. N Engl J Med 349:1315–1323
30. Ge L, Iakovou I, Sangiorgi GM, Chieffo A, Melzi G, Cosgrave J, Montorfano M, Michev I, Airoldi F, Carlino M, Corvaja N, Colombo A (2005) Treatment of saphenous vein graft lesions with drug-eluting stents: immediate and midterm outcome. J Am Coll Cardiol 45:989–994
31. Gioia G, Benassi A, Mohendra R, Chowdhury K, Masood I, Matthai W (2008) Lack of clinical long-term benefit with the use of a drug eluting stent compared to use of a bare metal stent in saphenous vein grafts. Catheter Cardiovasc Interv 72:13–20
32. Baim DS, Wahr D, George B, Leon MB, Greenberg J, Cutlip DE, Kaya U, Pompa JJ, Ho KK (2002) Saphenous vein graft angioplasty free of emboli randomized (SAFER) trial investigators. Randomized trial of a distal embolic protection device during percutaneous intervention of saphenous vein aorto-coronary bypass grafts. Circulation 105:1285–1290
33. Chesebro JH, Fuster V, Elveback LR, Clements IP, Smith HC, Holmes DR Jr, Bardsley WT, Pluth JR, Wallace RB, Puga FJ, Orszulak TA, Piehler JM, Danielason GK, Schaff HV, Frye RL (1984) Effect of dipyridamole and aspirin on late vein-graft patency after coronary bypass operations. N Engl J Med 310:209–214
34. The Post Coronary Artery Bypass Graft Trial Investigators (1997) The effect of aggressive lowering of low-density lipoprotein cholesterol levels and low-dose anticoagulation on obstructive changes in saphenous-vein coronary-artery bypass grafts. N Engl J Med 336:153–162
35. van Eck FM, Noyez L, Verheugt FWA, Brouwer RMHJ (2002) Changing profile of patients undergoing redo-coronary artery surgery. Eur J Cardiothorac Surg 21:205–211
36. Abramov D, Tamariz MG, Fremes SE, Guru V, Borger MA, Christakis GT, Bhatnagar G, Sever JY, Goldman BS (2000) Trends in coronary artery bypass surgery results: a recent, 9-year study. Ann Thorac Surg 70:84–90
37. Noyez L, Janssen DP, van Druten JA, Skotnicki SH, Lacquet LK (1998) Coronary bypass surgery: what is changing? Analysis of 3834 patients undergoing primary isolated myocardial revascularization. Eur J Cardiothorac Surg 13:365–369
38. Angelini GD, Taylor FC, Reeves BC, Ascione R (2002) Early and midterm outcome after off-pump and on-pump surgery in Beating Heart Against Cardioplegic Arrest Studies (BHACAS 1 and 2): a pooled analysis of two randomised controlled trials. Lancet 359:1194–1199
39. Gerola LR, Buffolo E, Jasbik W, Botelho B, Bosco J, Brasil LA, Branco JN (2004) Off-pump versus on-pump myocardial revascularization in low-risk patients with one or two vessel disease: perioperative results in a multicenter randomized controlled trial. Ann Thorac Surg 77:569–573
40. Kerendi F, Morris CD, Puskas JD (2008) Off-pump coronary bypass surgery for high-risk patients: only in expert centers? Curr Opin Cardiol 23:573–578
41. Puskas JD, Thourani VH, Kligo P, Cooper W, Vassiliades T, Vega JD, Morris C, Chen E, Schmotzer BJ, Guyton RA, Lattouf OM (2009) Off-pump coronary artery bypass disproportionately benefits high-risk patients. Ann Thorac Surg 88:1142–1147
42. Puskas J, Cheng D, Knight J, Angelini G, DeCannier D, Diegeler A, Dullum M, Martin J, Ochi M, Patel N, Sim E, Trehan N, Zamvar V (2005) Off-pump versus conventional coronary artery bypass grafting: a meta-analysis and consensus statement from the 2004 ISMICS consensus conference. Innovations 1:3–27
43. Allen KB, Matheny RG, Robinson RJ, Heimansohn DA, Shaar CJ (1997) Minimally invasive versus conventional reoperative coronary artery bypass. Ann Thorac Surg 64:616–622
44. Stamou SC, Pfister AJ, Dangas G, Dullum MK, Boyce SW, Bafi AS, Garcia JM, Corso PJ (2000) Beating heart versus conventional single-vessel reoperative coronary artery bypass. Ann Thorac Surg 69:1383–1387
45. Bergsland J, Hasnain S, Lajos TZ, Salerno TA (1998) Elimination of cardiopulmonary bypass: a prime goal in reoperative coronary artery bypass surgery. Eur J Cardiothorac Surg 14:59–62
46. Morris CD, Puskas JD, Pusca SV, Lattouf OM, Cooper WA, Vassiliades TA, Chen EP, Thourani VH, Kilgo PD, Guyton RA (2007) Outcomes after off-pump reoperative coronary artery bypass grafting. Innovations 2:29–32
47. Mishra YK, Collison SP, Malhotra R, Kohli V, Mehta Y, Trehan N (2008) Ten-year experience with single-vessel and multivessel reoperative off-pump coronary artery bypass grafting. J Thorac Cardiovasc Surg 135:527–532
48. Schutz A, Mair H, Wildhirt SM, Gillrath G, Lamm P, Kilger E, Reichart B (2001) Re-OPCAB vs. Re-CABG for myocardial revascularization. Thorac Cardiovasc Surg 49:144–148
49. Vohra HA, Bahrami T, Farid S, Mafi A, Dreyfus G, Amrani M, Gaer JA (2008) Propensity score analysis of early and late outcome after redo off-pump and on-pump coronary artery bypass grafting. Eur J Cardiothorac Surg 33:209–214

50. Usta E, Elkrinawi R, Ursulescu A, Nagib R, Madge M, Salehi-Gilani S, Franke UF (2013) Clinical outcome and quality of life after reoperative CABG: off-pump versus on-pump – observational pilot study. J Cardiothorac Surg 8:66–75
51. Di Mauro M, Iaco AL, Contini M, Teodori G, Vitolla G, Pano M, Di Giammarco G, Calafiore AM (2005) Reoperative coronary artery bypass grafting: analysis of early and late outcomes. Ann Thorac Surg 79:81–87
52. Czerny M, Zimpfer D, Kilo J, Gottardi R, Dunkler D, Wolner E, Grimm M (2003) Coronary reoperations: recurrence of angina and clinical outcome with and without cardiopulmonary bypass. Ann Thorac Surg 75:847–852
53. Tugtekin SM, Alexiou K, Kappert U, Esche H, Joskowiak D, Knaut M, Matschke K (2006) Coronary reoperation with and without cardiopulmonary bypass. Clin Res Cardiol 95:93–98
54. Caputo M, Reeves BC, Rajkaruna C, Awair H, Angelini GD (2005) Incomplete revascularization during OPCAB surgery is associated with reduced mid-term event-free survival. Ann Thorac Surg 80:2141–2147
55. van Eck FM, Noyez L, Verheugt FW, Brouwer RM (2002) Analysis of mortality within the first six months after coronary reoperation. Ann Thorac Surg 74:2106–2112
56. Reeves BC, Ascione R, Caputo M, Angelini GD (2006) Morbidity and mortality following acute conversion from off-pump to on-pump coronary surgery. Eur J Cardiothorac Surg 29:941–947
57. Calafiore AM, Di Mauro M, Canosa C, Di Giammarco G, Iaco AL, Contini M (2003) Myocardial revascularization with and without cardiopulmonary bypass: advantages, disadvantages and similarities. Eur J Cardiothorac Surg 24:953–960
58. Miyahara K, Matsuura A, Takemura H, Saito S, Sawaki S, Yoshioka T, Ito H (2008) On-pump beating-heart coronary artery bypass grafting after acute myocardial infarction has lower mortality and morbidity. J Thorac Cardiovasc Surg 135:521–526
59. Mack MJ (2004) Off-pump surgery and alternatives to standard operation in redo coronary surgery. J Card Surg 19:313–319
60. Trehan N, Mishra YK, Malhotra R, Sharma KK, Mehta Y, Shrivastava S (2000) Off-pump redo coronary artery bypass grafting. Ann Thorac Surg 70:1026–1029
61. Calafiore AM, Giammarco GD, Teodori G, Bosco G, D'Annunzio E, Barsotti A, Maddestra N, Paloscia L, Vitolla G, Sciarra A, Fino C, Contini M (1996) Left anterior descending coronary artery grafting via left anterior small thoracotomy without cardiopulmonary bypass. Ann Thorac Surg 61:1658–1663
62. Boonstra PW, Grandjean JG, Mariani MA (1997) Reoperative coronary bypass grafting without cardiopulmonary bypass through a small thoracotomy. Ann Thorac Surg 63:405–407
63. Miyaji K, Wolf RK, Flege JB Jr (1999) Minimally invasive direct coronary artery bypass for redo patients. Ann Thorac Surg 67:1677–1681
64. Azoury FM, Gillinov AM, Lytle BW, Smedira NG, Sabik JF (2001) Off-pump reoperative coronary artery bypass grafting by thoracotomy: patient selection and operative technique. Ann Thorac Surg 71:1959–1963
65. Baumgartner FJ, Gheissari A, Panagiotides GP, Capouya ER, Declusin RJ, Yokoyama T (1999) Off-pump obtuse marginal grafting with local stabilization: thoracotomy approach in reoperations. Ann Thorac Surg 68:946–948
66. Masroor S, Katariya K, Yassin S, Tehrani H, Salerno T (2004) Redo-OPCAB via left thoracotomy using symmetry aortic connector system: a report of two cases. J Card Surg 19:51–53
67. Ricci M, Karamanoukian HL, D'Ancona G, Salerno TA, Bergsland J (2000) Reoperative "off-pump" circumflex revascularization via left thoracotomy: how to prevent graft kinking. Ann Thorac Surg 70:309–310
68. Byrne JG, Aklog L, Adams DH, Cohn LH, Aranki SF (2001) Reoperative CABG using left thoracotomy: a tailored strategy. Ann Thorac Surg 71:196–200
69. Fonger JD, Doty JR, Salazar JD, Walinsky PL, Salomon NW (1999) Initial experience with MIDCAB grafting using the gastroepiploic artery. Ann Thorac Surg 68:431–436
70. Takahashi K, Minakawa M, Kondo N, Oikawa S, Hatakeyama M (2002) Coronary artery bypass surgery by the transdiaphragmatic approach. Ann Thorac Surg 74:700–703
71. Takahashi K, Takeuchi S, Ito K, Chiyoya M, Kondo N, Minakawa M (2012) Reoperative coronary artery bypass surgery: avoiding repeat median sternotomy. Ann Thorac Surg 94:1914–1919
72. Shennib H, Benhameid O (2005) Sequential subxyphoid and thoracotomy incisions with graft pull through for targeted redo multivessel surgical revascularization. Ann Thorac Surg 80:350–352
73. Follis FM, Pett SB Jr, Miller KB, Wong RS, Temes RT, Wernly JA (1999) Catastrophic hemorrhage on sternal reentry: still a dreaded complication? Ann Thorac Surg 68:2215–2219
74. Angelini GD, Wilde P, Salerno TA, Bosco G, Calafiore AM (1996) Integrated left anterior small thoracotomy and angioplasty for multivessel coronary artery revascularization. Lancet 347:757–758
75. Cohn JD, Korver KF (2005) Optimizing saphenous vein site selection using intraoperative venous duplex ultrasound scanning. Ann Thorac Surg 79:2013–2017
76. Maruyama Y, Imura H, Shirakawa M, Ochi M (2013) Preoperative evaluation of the saphenous vein by 3-D contrastless computed tomography. Interact Cardiovasc Thorac Surg 16:550–552
77. Tatoulis J, Buxton BF, Fuller JA (2001) The radial artery in coronary reoperations. Eur J Cardiothorac Surg 19:266–273
78. Suzuki T, Asai T, Nota H, Kuroyanagi S, Kinoshita T, Takashima N, Hayakawa M (2013) Early and long-term patency of in situ skeletonized gastroepiploic artery after off-pump coronary artery bypass graft surgery. Ann Thorac Surg 96:90–95
79. Ochi M, Hatori N, Fujii M, Saji Y, Tanaka S, Honma H (2001) Limited flow capacity of the right gastroepiploic artery graft: postoperative echocardiographic and angiographic evaluation. Ann Thorac Surg 71:1210–1214

Combined Surgery (TAA, AAA, or Cancer) Concomitant or Staged Surgeries?

22

Shinya Takase and Hitoshi Yokoyama

Abstract

The leading cause of death is still malignant neoplasm, but in Japan the risk of death from cardiovascular disorder is very nearly as great. Many cardiologists and cardiovascular surgeons have encountered patients who had these two diseases simultaneously since Japan became a country with the longest average life expectancy in the world. In such situations, the plan of treatment until attaining final cure is troublesome, especially if the patients require multiple surgeries to achieve the final stage.

The important factor to be considered is time. Theoretically, simultaneous surgeries seem to be ideal. However, this plan is sometimes too invasive when one of such surgeries is a heart surgery or an aortic surgery with extracorporeal circulation or circulatory arrest.

In addition, once a two-stage operation is planned for a patient, it is still difficult to decide which procedure should be done first, although the decision depends which of the two diseases is more life threatening.

At this time, less invasive procedures have been developed and are available for any type of surgery. Off-pump coronary artery surgery (OPCAB) is also a less invasive method for patients with coronary artery heart disease. In this chapter, we discuss how to treat patients who have coronary artery disease (CAD) combined with malignant neoplasm, thoracic aortic disease, or abdominal aortic disease.

Keywords

Off-pump coronary artery bypass surgery • Simultaneous surgeries • Staged surgery • Noncardiac surgery

22.1 Considerations Regarding Lesser Invasiveness of Off-Pump Coronary Bypass Surgery (OPCAB)

To decide whether a patient requires percutaneous or surgical coronary intervention, or medical therapy (oral administration), we can refer to several guidelines from the AHA/ACC [1] or the Japanese Society of Cardiology [2]. Those guidelines outline strategies for patients who have both heart disease and noncardiac disease simultaneously. OPCAB may be recommended if the patient requires surgical coronary intervention combined with noncardiac surgery because of its lesser invasiveness, described as follows. Compared with conventional coronary artery bypass surgery using

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extracorporeal circulation, OPCAB surgery provides a shorter ICU stay, bed rest, and hospital stay, a shorter period of time between the procedure and food intake, and reduced requirements for blood transfusion [3]. In addition, as shown by several inflammatory markers in laboratory data, OCPAB is less inflammatory than coronary artery bypass graft surgery (CABG) using extracorporeal circulation [4]. As another point of view, use of extracorporeal circulation suppresses the immune system [5–8].

Minimal invasiveness is a key to bridging the first-stage operation to the second stage. Or, we may be able to choose a simultaneous operation. Unfortunately, there are no standards or guidelines to lead us to decide between the "simultaneous" or "staged" operation. Ultimately we would apply either choice to an individual patient after cardiologists, cardiovascular surgeons, and related expert physicians had discussed the case together, seeking the most appropriate approach for an individual patient.

22.2 Consideration for the Patient with Combined Coronary Artery Disease and Noncoronary Heart Disease or Thoracic Aortic Disease

Coronary artery bypass surgery should be performed simultaneously when the patient requires open chest surgery for both noncoronary and coronary disease (Class I–IIb, Evidence Level B or C) [2].

Is there a case in which it is better to perform off-pump coronary artery surgery?

22.3 Valve Surgery and Intracardiac Procedure

There is no evidence that OPCAB is superior to CABG under cardiac arrest in valve surgery and intracardiac procedures, because, under aortic and mitral insufficiencies, OPCAB, which requires lifting the heart, may cause exacerbation of regurgitation but also perhaps stenosis, resulting in collapse of the circulation during beating of the heart. Primarily, in such cases, ventricular function in the patient is low and the heart volume is large, so that it would be somewhat difficult to tilt the heart properly to perform the OPCAB procedure. For these reasons, selection of OPCAB may be limited to only anastomosis between the intrathoracic artery and left descending coronary artery (LAD) and diagonal arteries, with slight lifting, to shorten the time of extracorporeal circulation and cardiac arrest. Subsequently, on beating or arrest using the extracorporeal circuit, CABG would be completed with other procedures in general.

22.4 Thoracic Aortic Disorder

Patients who have thoracic aortic disease concomitant with CAD have increased in the current era, especially with the aging of the population in Japan. Some reports describe that the combined surgery of total arch replacement and CABG was 15–30 % [9, 10]. However, the mortality rate of simultaneous surgery of total arch replacement and CABG was 14–55 %, which was worse than that of total arch replacement, which was only 7–24 % [9, 11–13]. This simultaneous surgery has been considered inevitable, with prolonged myocardial ischemia and cardiopulmonary bypass (CPB) time, which are significant risk factors for adverse outcome in aortic arch surgery [10]. On the other hand, as myocardial infarction is a main factor of early and late mortality, therefore CABG is essential to improve the overall results [14–16].

The shortening of CPB time and arrest time is one measure that can be applied to improve the outcome. We have introduced OPCAB into simultaneous CABG and total arch replacement (TAR) operations. Our procedure is illustrated in Fig. 22.1 [17]. Briefly, distal anastomoses are completed before starting CPB in OPCAB fashion. Then, total arch replacement is advanced under CPB, selective antegrade cerebral perfusion, and circulatory arrest using the open-distal method, as antegrade cardioplegic solution is also administered through the preattached coronary artery bypass grafts. Before declamping and rewarming, the proximal graft–ascending aorta (or prosthetic graft) anastomosis was performed. Applying this novel procedure for the simultaneous procedure and compared with solo TAR and conventional procedure, CPB time and myocardial ischemic time were significantly shortened. Early outcome in the OPCAB and TAR group tend to be similar to the solo TAR group (Table 22.1) [18]. Our procedure could be more effective if multiple bypass grafting is required.

As a more advanced technique, we have applied OPCAB and total debranching transluminal endovascular aortic repair (TEVAR) to avoid using CPB and cardiac arrest for high-risk patients. Theoretically this procedure is reasonable, but its early and long-term outcomes are still controversial.

22.5 Abdominal Aortic Disorder

Severe correctable CAD was identified in 34 % of patients with abdominal aortic disease [19, 20]. CAD is the leading cause of postoperative death following abdominal aortic aneurysm (AAA) repair [21]. The 5-year mortality rate of myocardial infarction in patients who had preoperative

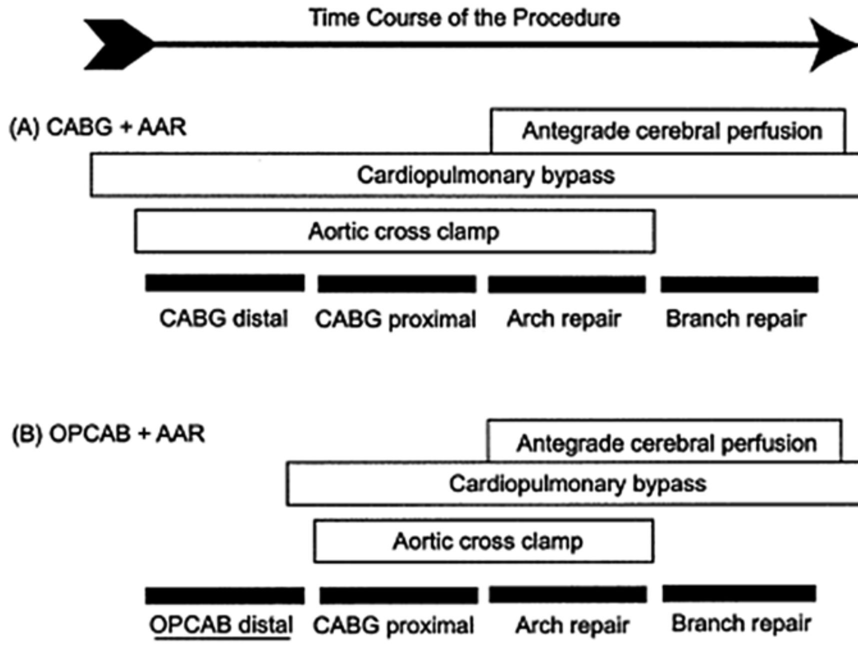

Fig. 22.1 Time course in the combined procedure of coronary artery revascularization and aortic arch aneurysm (*AAR*). (**a**) Coronary artery bypass grafting (*CABG*) on the arrested heart and AAR. (**b**) Off-pump coronary artery bypass (*OPCAB*) and AAR. Note the periods of cardiopulmonary bypass (*CPB*) and aortic cross-clamping (myocardial ischemia time) are shorter in **b** than in **a**

Table 22.1 Demographics, intraoperative data, and early outcome of patients who underwent coronary revascularization and total arch replacement for atherosclerotic aortic arch aneurysm

	Solo TAR ($n = 18$)		OPCAB ($n = 18$)		CCAB ($n = 14$)
Demography					
Age (years)	72 (58–79)		70 (62–80)		71 (64–79)
Gender (M/F)	15/3		17/1		11/3
Diseased coronary artery	0	*	1.5 (1–3)		1.5 (1–3)
Hypertension	17 (94 %)		18 (100 %)		13 (93 %)
Left ventricular hypertrophy	7 (39 %)		11 (62 %)		10 (71 %)
Old cerebral infarction	12 (67 %)	*	5 (28 %)		3 (21 %)
Intraoperative data					
CPB time (min)	206 ± 33	*	239 ± 35	*	306 ± 61
>300 min	0		1 (6 %)	*	7 (50 %)
Myocardial ischemic time (min)	125 ± 30		133 ± 24	*	180 ± 48
>180 min	1 (6 %)		0	*	5 (36 %)
Early outcome					
Perioperative myocardial infarction	1 (6 %)		0		2 (14 %)
Stroke	1 (6 %)		0		2 (14 %)
Prolonged (>48 h) intubation	6 (33 %)		6 (33 %)	*	11 (79 %)
In-hospital death	1 (6 %)		1 (6 %)		3 (21 %)

Solo TAR group: patients underwent TAR without coronary revascularization; OPCAB group: distal coronary artery anastomosis was constructed on the beating heart before cardiopulmonary bypass (CPB); CCAB group: distal coronary artery anastomosis was constructed on CPB. Data are expressed as mean ± standard deviation. Parentheses represent the value range, unless otherwise stated

TAR total arch replacement, *OPCAB* off-pump coronary artery bypass, *CCAB* conventional coronary artery bypass, *CPB* cardiopulmonary bypass

*$P < 0.01$ difference between the two groups, analyzed by Mann–Whitney *U* test or chi-square test

evidence of heart disease is four times higher than that in patients without CAD [22]. Therefore, cardiac evaluation and coronary revascularization have been recommended, if indicated, to be carried out before AAA repair [23–26]. Generally, CAD is treated first, followed by AAA repair, and improvements in CABG and percutaneous coronary intervention (PCI) before AAA operation have clearly decreased both early and late mortality [27, 28]. Single-vessel CAD can be treated by PCI, and some two-vessel diseases may be treated in accordance with guidelines of the treatment for stable ischemic coronary disease. However, there are some considerable issues after PCI. PCI requires repeated treatment more often than does CABG in early and long-term observations [29, 30]. In addition, if a drug-eluting stent or even a bare metal stent is implanted in the coronary artery, the patient requires heavy anticoagulation therapy for 3 months or more. In this situation, the patients have to wait for a long time, may experience heavy postoperative bleeding, and may require transfusion and re-exploration. In contrast, conventional CABG surgery with CPB also requires patients to wait until they recover. The duration varies depending on each individual patient. In general, after using CPB, the waiting time would be 3 weeks or more. One report says 6 weeks are needed for complete recovery after using CPB [31]. For all these reasons, OPCAB can shorten the waiting time for the second stage. Another reason is that major open chest or abdominal surgery could accelerate the enlargement of the aortic aneurysm. In addition, surgery using CPB may have a direct impact on aortic aneurysm dilation, causing further wall weakening and decreasing tensile strength, because CPB itself induces various inflammatory responses.

However, when a patient has some symptoms of AAA or when the AAA is critically enlarged, simultaneous surgery should be planned. OPCAB is superior to conventional CABG [32, 33] in simultaneous surgery with AAA repair. However, in cases of asymptomatic AAA and CAD, whether a simultaneous operation is better than a staged operation is controversial, and many surgeons are concerned over wound infection, including mediastinitis, bleeding, and prolonged ventilation-induced pneumonia, excepting the cost–benefit ratio of medical care. In not only simultaneous operation of CABG and AAA repair but also the other types of simultaneous surgeries, the outcome depends on the surgeon's skill.

In addition, currently, endovascular aortic replacement (EVAR) is widely available, although indication for EVAR is strict in terms of the morphology. The combination strategy of OPCAB and EVAR will soon be commonly adopted.

22.6 Coronary Artery Disease Combined with Cancer

22.6.1 Consideration for CAD Combined with Cancer

A one-stage operation is ideal for patients who have severe CAD and life-threatening cancer. The application of simultaneous procedures for both disorders has several advantages. It eliminates various complications related to performing two procedures that both require total anesthesia, and it prevents the disease progression of untreated lesions. Furthermore, the anxieties of patients with two life-threatening conditions are resolved at the same time.

However, the occurrence of infectious complications such as mediastinitis remains a major disadvantage of simultaneous procedures.

Therefore, a therapeutic dilemma remains for patients with concomitant occurrence of severe CAD and cancer.

22.7 Consideration in Application of Extracorporeal Circulation (CPB) to Patients with Cancer

22.7.1 Does CPB Induce Dissemination?

We have to consider the possibility of dissemination of cancer cells when we directly aspirate blood from cancer lesions in cases such as cardiovascular tumors or lung cancer. Because not all cancer cells in the suctioned blood can be removed by the filter in CPB, hematogenous dissemination may occur. Moreover, even when dissemination or metastasis is detected, it is difficult to distinguish whether it is hematogenous by suction or from other causes such as lymph node metastasis or direct invasion. In addition, the metastasis may be induced by suppression of the immune system by CPB, as already mentioned. So far, no evidence has been reported that CPB definitely accelerates the progression of isolated cancer [34].

22.8 Which Treatment Is First for Cancer or CAD, or Simultaneous Operation?

As mentioned earlier, simultaneous operations should be considered primarily. However, therapeutic priority should be judged with precise assessments of the severity and urgency of both cancer and CAD, and then simultaneous or staged procedures should be selected.

With cardiologists, cardiovascular surgeons, general surgeons, and related expertise persons, the decision must be made in accordance with the patient's wishes.

22.9 In a Staged Operation

In general, any kinds of interventions for CAD are performed before noncardiac procedures, even in a simultaneous operation.

The interval between the first- and second-stage procedures depends on the invasiveness of the procedure, necessity of posttreatment, and severity of complications should they occur. OPCAB needs only a one-stage operation or 2 weeks before the second-stage procedure [35]. CABG with CPB need a longer interval of 2–6 weeks. In addition, although the report is not recent [31], Crawford et al. reported that a second operation performed within 30 days after open heart surgery with CPB induced higher mortality than that performed after 30 days. The shorter interval, the better in CAD combined with cancer. However, if the patient's condition does not allow us to wait for even 2 weeks, then simultaneous procedures should be applied.

As another condition of simultaneous procedure, Watanabe reported that it was successful in cases which a part of the noncardiac surgery was completed within 3 or 4 h in time, with about 500 ml bleeding [36]. From reports of simultaneous operations of both CABG and pneumonectomy, this procedure was successfully performed, or successful only in cases in which the procedures were performed, only if CABGs were successfully done. Simultaneous OPCAB combined with the operation for gastric cancer could be successfully performed in our institution.

Acceptable indications of the simultaneous procedure were (1) general condition is good enough, (2) cardiac function is good, (3) no major comorbidities exist, (4) OPCAB can be performed, in addition to (5) less invasive noncardiac surgery such as a short-duration operation. For the patients with other conditions, a staged procedure could be suitable.

22.10 Which Is Suitable for Such Patients, PCI or CABG?

Basically, the choice of intervention was decided according to the guideline [2]. For a patient with CAD and cancer, we have to consider the following factors.

1. Short life expectancy
2. Worsened general condition, including bleeding tendency and inability to tolerate invasiveness of surgery
3. Longer posttreatment with heavy anticoagulants is acceptable when PCI is selected.

PCI, especially using a drug-eluting stent (DES), requires more than two different kinds of anticoagulants for a longer period, 3 or more months. However, just after PCI, a general operation for noncardiac surgery probably induces bleeding. Strict anticoagulant therapy is also required in PCI using a bare metal stent (BMS) and POBA (primary balloon angioplasty), as well takase 8, to prevent subacute occlusion of the stent, which is a potentially lethal complication.

On the other hand, CABG as the first-stage operation may force the patient to wait for a long time to be able to tolerate the second-stage operation. To shorten the interval, OPCAB is better than conventional CABG with CPB. Anticoagulants are required in OPCAB as well as in CABG, but it is possible that anticoagulants in OPCAB must be stopped to reduce the risk of bleeding in the second stage.

Again, in the foregoing conditions, a proper procedure should be selected. Whether PCI or CABG is better should be discussed with expert physicians and co-medical staff.

22.11 Graft Selection in CABG

Bypass conduit should be selected as usual. However, the gastroepiploic artery (GEA) is not appropriate if the patient is to have surgery on the upper portion of the abdomen. Even if the GEA is selected, however, it is possible that gastrectomy can be safely performed, in my experience.

Selection of the internal mammary artery (ITA) should be acceptable when the patient must wait for pneumonectomy, but the abortion if necessary should be performed carefully.

Revascularization in CABG should be performed as completely as possible. However, if CABG itself is at high risk, incomplete revascularization may be acceptable to reduce surgical risk.

Off-pump coronary artery bypass surgery is a better solution if simultaneous procedures were to be applied to such a patient. Or, even in a staged operation, OPCAB reduces the risk of the use of extracorporeal circulation as in conventional on-pump CABG. As a result, OPCAB shortens the interval between the first and the next stage. In general, OPCAB should be selected when a patient requires simultaneous or staged operations.

References

1. Fleisher LA, Beckman JA, Brown KA et al (2009) ACCF/AHA focused update on perioperative beta blockade incorporated into the ACC/AHA 2007 guidelines on perioperative cardiovascular evaluation and care for noncardiac surgery. J Am Coll Cardiol 54(22):e13–e118
2. Kyo S, Imanaka K, Kurosawa H et al (2011) Guidelines for perioperative cardiovascular evaluation and management for noncardiac surgery (JCS 2008): digest version. Circ J 75(4):989–1009

3. Lamy A, Devereaux PJ, Prabhakaran D et al (2012) Off-pump or on-pump coronary-artery bypass grafting at 30 days. N Engl J Med 366(16):1489–1497
4. Yamamoto S, Yoshimasu T, Nishimura Y et al (2011) In vitro evaluation of the effect of cardiac surgery on cancer cell proliferation. Ann Thorac Cardiovasc Surg 17(3):260–266
5. Kirklin JK, Westaby S, Blackstone EH, Kirklin JW, Chenoweth DE, Pacifico AD (1983) Complement and the damaging effects of cardiopulmonary bypass. J Thorac Cardiovasc Surg 86(6):845–857
6. Peters RM, Swain JA (1982) Management of the patient with emphysema, coronary artery disease, and lung cancer. Am J Surg 143(6):701–705
7. Eskola J, Salo M, Viljanen MK, Ruuskanen O (1984) Impaired B lymphocyte function during open-heart surgery. Effects of anaesthesia and surgery. Br J Anaesth 56(4):333–338
8. Hisatomi K, Isomura T, Kawara T et al (1989) Changes in lymphocyte subsets, mitogen responsiveness, and interleukin-2 production after cardiac operations. J Thorac Cardiovasc Surg 98(4):580–591
9. Crawford ES, Svensson LG, Coselli JS, Safi HJ, Hess KR (1989) Surgical treatment of aneurysm and/or dissection of the ascending aorta, transverse aortic arch, and ascending aorta and transverse aortic arch. Factors influencing survival in 717 patients. J Thorac Cardiovasc Surg 98(5 pt 1):659–673; discussion 673–674
10. Ehrlich MP, Ergin MA, McCullough JN et al (2000) Predictors of adverse outcome and transient neurological dysfunction after ascending aorta/hemiarch replacement. Ann Thorac Surg 69(6):1755–1763
11. Okita Y, Takamoto S, Ando M, Morota T, Matsukawa R, Kawashima Y (1998) Mortality and cerebral outcome in patients who underwent aortic arch operations using deep hypothermic circulatory arrest with retrograde cerebral perfusion: no relation of early death, stroke, and delirium to the duration of circulatory arrest. J Thorac Cardiovasc Surg 115(1):129–138
12. Hayashi J, Eguchi S, Yasuda K et al (1997) Aortic arch operation using selective cerebral perfusion for nondissecting thoracic aneurysm. Ann Thorac Surg 63(1):88–92
13. Yamashiro S, Sakata R, Nakayama Y, Ura M, Arai Y, Morishima Y (2001) One-stage thoracic aortic aneurysm treatment and coronary artery bypass grafting. Jpn J Thorac Cardiovasc Surg 49(4):236–243
14. Svensson LG, Crawford ES, Hess KR et al (1993) Deep hypothermia with circulatory arrest. Determinants of stroke and early mortality in 656 patients. J Thorac Cardiovasc Surg 106(1):19–28; discussion 28–31
15. Bachet J, Guilmet D, Goudot B et al (1999) Antegrade cerebral perfusion with cold blood: a 13-year experience. Ann Thorac Surg 67(6):1874–1878; discussion 1891–1894
16. Pressler V, McNamara JJ (1980) Thoracic aortic aneurysm: natural history and treatment. J Thorac Cardiovasc Surg 79(4):489–498
17. Yokoyama H, Sato Y, Takase S, Takahashi K, Wakamatsu H, Sato Y (2005) Introduction of off-pump coronary artery bypass into aortic arch aneurysm repair: a new solution for the surgical treatment of multiorgan arteriosclerosis. J Thorac Cardiovasc Surg 129(4):935–936
18. Takagi H, Umemoto T (2005) Does the introduction of off-pump coronary artery bypass into aortic arch aneurysm repair minimize the period of myocardial ischemia and cardiopulmonary bypass? J Thorac Cardiovasc Surg 130(3):950–951; author reply 951–952
19. Mohr FW, Falk V, Autschbach R et al (1995) One-stage surgery of coronary arteries and abdominal aorta in patients with impaired left ventricular function. Circulation 91(2):379–385
20. Hertzer NR, Beven EG, Young JR et al (1984) Coronary artery disease in peripheral vascular patients. A classification of 1000 coronary angiograms and results of surgical management. Ann Surg 199(2):223–233
21. Debakey ME, Crawford ES, Cooley DA, Morris GC Jr, Royster TS, Abbott WP (1964) Aneurysm of abdominal aorta analysis of results of graft replacement therapy one to eleven years after operation. Ann Surg 160:622–639
22. Hollier LH, Plate G, O'Brien PC et al (1984) Late survival after abdominal aortic aneurysm repair: influence of coronary artery disease. J Vasc Surg 1(2):290–299
23. Golden MA, Whittemore AD, Donaldson MC, Mannick JA (1990) Selective evaluation and management of coronary artery disease in patients undergoing repair of abdominal aortic aneurysms. A 16-year experience. Ann Surg 212(4):415–420; discussion 420–423
24. Yeager RA, Weigel RM, Murphy ES, McConnell DB, Sasaki TM, Vetto RM (1986) Application of clinically valid cardiac risk factors to aortic aneurysm surgery. Arch Surg 121(3):278–281
25. Brown OW, Hollier LH, Pairolero PC, Kazmier FJ, McCready RA (1981) Abdominal aortic aneurysm and coronary artery disease. Arch Surg 116(11):1484–1488
26. Acinapura AJ, Rose DM, Kramer MD, Jacobowitz IJ, Cunningham JN Jr (1987) Role of coronary angiography and coronary artery bypass surgery prior to abdominal aortic aneurysmectomy. J Cardiovasc Surg (Torino) 28(5):552–557
27. Reul GJ Jr, Cooley DA, Duncan JM et al (1986) The effect of coronary bypass on the outcome of peripheral vascular operations in 1093 patients. J Vasc Surg 3(5):788–798
28. Foster ED, Davis KB, Carpenter JA, Abele S, Fray D (1986) Risk of noncardiac operation in patients with defined coronary disease: the Coronary Artery Surgery Study (CASS) registry experience. Ann Thorac Surg 41(1):42–50
29. Farooq V, Serruys PW, Bourantas CV et al (2013) Quantification of incomplete revascularization and its association with five-year mortality in the synergy between percutaneous coronary intervention with taxus and cardiac surgery (SYNTAX) trial validation of the residual SYNTAX score. Circulation 128(2):141–151
30. Mohr FW, Morice MC, Kappetein AP et al (2013) 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 381(9867):629–638
31. Crawford ES, Morris GC Jr, Howell JF, Flynn WF, Moorhead DT (1978) Operative risk in patients with previous coronary artery bypass. Ann Thorac Surg 26(3):215–221
32. Morimoto K, Taniguchi I, Miyasaka S et al (2002) Combined coronary artery bypass grafting on the beating heart and abdominal aortic aneurysm repair. Circ J 66(8):755–757
33. Ascione R, Iannelli G, Lim KH, Imura H, Spampinato N (2001) One-stage coronary and abdominal aortic operation with or without cardiopulmonary bypass: early and midterm follow-up. Ann Thorac Surg 72(3):768–774; discussion 775
34. Pinto CA, Marcella S, August DA, Holland B, Kostis JB, Demissie K (2013) Cardiopulmonary bypass has a modest association with cancer progression: a retrospective cohort study. BMC Cancer 13(1):519
35. Yokoyama H (2005) Preoperative evaluation and management of patients with ischemic heart disease undergoing noncardiac surgery (in Japanese). Nihon Geka Gakkai Zasshi 106(5):323–327
36. Watanabe S, Tanaka K, Toyohira H (1998) Simultaneous operation for malignant neoplasms and cardiovascular diseases. J Jpn Surg Assoc 59(1):26–30

Difficult Heart

23

Tomoaki Suzuki and Tohru Asai

Abstract

Most randomized trials comparing off-pump CABG to on-pump CABG have reported equivalent clinical outcomes. However, these trials are often underpowered to find significant differences between the groups because most of these trials enrolled relatively low-risk patients. Most surgeons tend to avoid performing beating heart surgery in high-risk patients such as enlarged poor left ventricular function and acute coronary syndrome because of technical difficulty and risk of acute conversion to on-pump surgery. Real advantages of off-pump surgery are especially derived from these high-risk patients. In this chapter, clinical outcomes of OPCAB for these high-risk patients and technical knacks to perform a safe OPCAB for these difficult cases are presented according to my experiences.

Keywords

Conversion • Hemodynamic compromise • Low left ventricular function • Acute coronary syndrome

23.1 Enlarged Heart, Poor Left Ventricular Function

OPCAB was initially used in selected groups of patients, but it is now being used in more and more difficult situation, and many groups have reported good results in high-risk patients, including patients with poor LV function. Off-pump coronary artery bypass, however, is not yet considered the gold standard by many coronary surgeons. Furthermore, especially in high-risk patients, most surgeons are reluctant to use beating heart operations. Therefore, patients with unstable hemodynamics and low left ventricular ejection fraction are frequently cited as contraindications to beating heart interventions. The major reasons given are the difficulties for optimal coronary artery exposure in cases of low ejection fraction associated with enlarged ventricles and hemodynamic instability or severe rhythm disturbances during displacement of the heart.

Severe left ventricular dysfunction has been reported as an independent predictor of operative mortality in patients undergoing coronary artery bypass grafting [1–4]. However, the long-term benefits of coronary artery bypass grafting operation compared with medical therapy are more pronounced in patients with reduced left ventricular function [5]. In an ischemic heart or critically impaired left ventricle, any hemodynamic instability may lead to increased complication or death. Hausmann and coworkers [6] reported an operative mortality of 7.1 % in a series of 514 patients with EF ranging from 10 to 30 %. Bouchart and colleagues [7] reported an in-hospital mortality of 7 % in a series of 141 patients with poor LV dysfunction. In some previous studies, the incidence of in-hospital mortality was reported as ranging from 4.7 to 15.0 % in these groups [6–9]. For patients with congestive heart failure, mortality is directly related to the severity of their ventricular systolic dysfunction.

There have been several controversies surrounding the choice of the optimal surgical strategy in patients with reduced ejection fraction. Many surgeons prefer using CPB

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because hemodynamic instability, hypotension induced by ventricular arrhythmias, or cardiac arrests are frequent problems encountered in this specific group of patients. CABG using CPB has been safe due to recent development in myocardial protection techniques, and in majority of patients its damaging effect on myocardium is minimal and reversible, but patients with LV dysfunction have very poor reserve, and even slight damage to myocardium may have significant consequences.

Good midterm surgical results reported with OPCAB surgery were associated with an increased popularity of this revascularization technique, especially in this category of high-risk patients with poor LV function. Hemodynamic deterioration is the greatest concern during displacement of the heart in OPCAB surgery. A good hemodynamic monitoring and more attention to minor details during OPCAB are very important in this group of patients. TEE gives us good information about the wall motion and chamber filling of the left ventricle, and the heart can be displaced in a direction so that there is minimal compression of the right ventricular outflow tract and minimal hemodynamic compromise. Poor LV function is sometimes an exclusion criterion for the OPCAB approach because of the technical difficulty of safely displacing the heart under condition of hemodynamic stability. Displacement of the beating heart may be well tolerated with good LV function, but hemodynamic compromise occurs more often in patients with severe LV dysfunction, making it difficult to achieve complete revascularization in these patients using the OPCAB technique. However, several pioneer surgeons have challenged to adopt beating heart technique to these high-risk patients. Multiple single-center reports have been published detailing outcomes of OPCAB for patients with a low EF. Ascione and coworkers [4] reported an operative mortality of 7 % in a series of 74 OPCAB patients with EF <30 %. Arom and colleagues [10] found an operative mortality of 2 % in their series of 45 OPCAB patients with low EF (<30 %). Shennib and coworkers [11] compared the clinical outcome of OPCAB and conventional CABG in patients with poor LV function (EF <35 %) and reported that operative mortality was lower in the former group (3.2 % vs. 10.9 %). However, there were fewer distal anastomoses per patient (2.8 vs. 3.9) in the OPCAB group. Recently, Keeling and coworkers [12] reported a large and propensity-matched OPCAB trial. They analyzed the effect of off-pump versus on-pump coronary revascularization in patients with low ejection fraction with propensity score matching technique. They showed that patients undergoing scheduled OPCAB were older, more frequently female than those who underwent ONCAB. OPCAB was associated with a significant lower adjusted risk of death, stroke, major adverse cardiac events, and prolonged intubation, and postoperative transfusion rates were significantly lower in the OPCAB group.

We have performed OPCAB surgery in all CABG cases with no exclusion criteria since 2001 [13]. Our technical knack for the safe exposure of the heart is shown. After midline pericardiotomy, the left side of pericardium is incised from the apex to the back of the pericardial sac to the anterior of the phrenic nerve, in order that it must not be injured. The other pericardiotomy is at the level of the left atrial appendage. The right side of the pericardium is incised longitudinally around the superior vena cava. This maneuver prevents the SVC from being compressed by the pericardium and prevents disruption of venous return when the heart is lifted. Hemodynamic compromise during displacement of the heart is likely to be caused by inadequate ventricular filling due to disturbance of venous return. The incised left side of the pericardium is pulled up and retracted over the sternal retractor. The right side of the pericardium should be free for easy rotation of the heart into the free space beneath the right sternum. We also use two deep pericardial sutures which are put in the bottom of the pericardium beside the IVC and left lower pulmonary vein. The most important point for comfortable surgical view without disturbing the beating heart is that the cardiac base is rotated right-side down and left-side up and to move the center of gravity of the heart toward the right [14].

Revascularization on the branches of the circumflex and right coronary systems require a more vertical displacement that is even more pronounced in the posterolateral system. Hemodynamic instability was minimized with the patient in a Trendelenburg position, which creates bilateral filling pressures to reach adequate level. The most important is the presence of a dedicated cardiac anesthesiologist constantly vigilant of hemodynamic and progress of the operation who can alert the surgeon of the need to return the verticalized heart to a more physiological position and to rapidly create a proximal anastomosis or to insert a shunt for hemodynamically compromising ischemia. The experienced off-pump anesthesiologist is adept at using inotropes and pressors as necessary based on hemodynamics and continuous TEE evaluation of the degree of mitral regurgitation and can anticipate the next step in the operation and adjust vasoactive drips and bed positioning as necessary to ensure a smooth operation.

In actuality, a skilled OPCAB surgeon does not feel difficulty in case of enlarged heart or LV dysfunction. The change of ventricular filling volume during displacement of the heart has only a marginal effect on enlarged heart. A concentric hypertrophic heart is more irritably affected by change of filling volume. Enlarged ventricular chamber does play a buffer action against the change of filling volume that makes a little impact for hemodynamic stability. Furthermore, regional motion of the ventricular wall of an enlarged heart is smaller than normal heart that facilitates for surgeons further comfortable coronary artery anastomosis. Mitral regurgitation during displacement of the heart sometime becomes a problem in OPCAB surgery. When increases in the PAP and the CVP are observed, a TEE examination of the mitral valve can be very helpful in the diagnosis. A tethering mitral valve of enlarged heart often causes mitral regurgitation when the heart is forced to lift up and compress. However, in almost all cases of enlarged heart, acute position-related mitral regurgitation may be resolved with appropriate repositioning.

When comfort with OPCAB technique grew, data began to emerge citing the potential benefits of avoidance of CPB for high-risk subgroup. We feel that the greatest benefits derived from avoidance of extracorporeal circulation will become manifest not in low-risk individuals, but in patients with significant comorbidities, but this remains unproven.

23.2 Acute Coronary Syndrome

Several large series of surgical intervention for an acute myocardial infarction (AMI) were reported in the beginning of the 1970s. In the early days of coronary artery bypass grafting (CABG), surgical intervention within the first months of an acute myocardial infarction was associated with increased mortality rate. Early reports suggested that emergency CABG for AMI was associated with a high operative mortality rate, ranging from 9 % to as high as 60 % [15–17]. More recently, with improved anesthetic and surgical techniques, supportive pharmacologic therapy, and myocardial preservation, the perioperative mortality rate associated with emergency CABG in selected patients with AMI has fallen markedly [18].

Patients with evolving acute coronary syndrome defined as continuum from unstable angina to non-ST-segment elevation MI to ST-segment elevation MI display a high-risk entry in CABG surgery. Perioperative mortality is increased severalfold compared with patients with stable angina, and it may be advisable to delay surgical intervention whenever possible. However, in the presence of refractory symptoms, hemodynamic alterations, or in STEMI patients, emergency surgical therapy within the first hours is indicated. Current indication [19, 20] for emergency CABG surgery in ASC patients is limited to those presenting with evolving myocardial ischemia refractory to optimal medical therapy, presence of left main stenosis (≧50 %) and 3-vessel disease, ongoing ischemia despite successful or failed PCI, complicated PCI, cardiogenic shock accompanied by complex coronary anatomy, or life-threatening ventricular arrhythmias thought to be caused by myocardial ischemia. Patients that meet these indications are relatively rare. An aggressive surgical approach, when appropriate, has been shown to be the superior approach for patients presenting with moderate- to high-risk ACS and is recommended by US and European guidelines for treating these patients.

It is generally thought that the outcome in these patients may depend on factors such as the timing of the operation, left ventricular function, the presence of collateral, and hemodynamic instability. The optimal timing of operation after AMI remains undecided. Several articles [21, 22] advocating surgical revascularization within 6 h of AMI have shown improved hospital mortality rates (3.8 % vs. 8 %) and improved 10-year mortality rates (8.2 % vs. 21 %) in patients who underwent operation within 6 h, as compared with those patients whose operation was delayed longer than 6 h after an AMI. Berg and associates [21] reported a hospital mortality rate of 5.5 % and 1-year mortality rate of 6.3 %.

The patients with unstable hemodynamics possibly and more likely are treated with CCAB rather than with OPCAB. Application of OPCAB technique to the ACS patients undergoing emergency surgical revascularization remains controversial. First of all, high-risk complex cases (such as emergency cases) should not be attempted with OPCAB until the surgeon's skill has reached a plateau on the learning curve. In recent years, further efforts were made to identify high-risk subgroup that may benefit more from off-pump strategies. In actively ischemic patients, some speculate that off-pump CABG might reduce the extent of myocardial damage, perhaps through the avoidance of ischemic arrest and reperfusion injury, earlier revascularization of the culprit lesion, attenuation of the no-flow phenomenon, and reduction of myocardial edema. These included elective patients with poor LV function, enlarged heart, recent myocardial infarction, and unstable angina, but clinical results were also inconsistent. Although the adverse effects of CPB are minor and reversible in most patients, these effects may be of major importance, irreversible, and even fatal in high-risk patients. CPB and cardioplegic arrest may further damage the already jeopardized myocardium. It is therefore reasonable to assume that avoiding CPB may be advantageous for certain subgroup of patients, especially those with risk condition for conventional CABG. These patients have sustained a recent myocardial infarction within 24 h or have ongoing myocardial ischemia resulting in hemodynamic instability and are classically thought to benefit from the protection afforded by cardioplegic arrest, which reduces metabolic demand and resuscitates the ischemic myocardium. However, avoiding the inflammatory reactions incited by cardiopulmonary bypass and global ischemia of cardioplegic arrest may be of equal or greater benefit to the already injured myocardium. Several retrospective studies have indicated that these high-risk patients may benefit most from avoiding cardiopulmonary bypass and its associated inflammatory response.

Operative mortality for these patients using conventional arrested heart CABG techniques was high (1.6–32 %) and strongly depends on the preoperative hemodynamics condition. Creswell et al. [22] indicated a mortality rate of patients operated within 6 h after onset of AMI symptoms of 9.1 %. They suggested that the optimal timing is at least 2 weeks after AMI. In their study, mortality rates of patients who underwent operation within this 2 weeks was 6.5 % compared with 2.9 % in patients who underwent operation between 2 and 6 weeks after AMI. Every and associates [19] reported that in their 1,299 AMI patients who underwent CABG, there was no difference in hospital mortality rates of patients who underwent operation during the first 24 h after admission compared with those who underwent operation during their hospital course. In a multicenter analysis of 2,099 patients who underwent conventional CABG within 24 h after AMI, hospital mortality was 14 %. Tomasco et al. [23] indicated a similar mortality rate of 13.4 % for patients operated within 24 h after AMI. A retrospective analysis describing the outcomes of 12,988 unselected patients with ACS demonstrated that early CABG was an independent predictor of lower mortality [24]. Serge et al. found a remarkably lower mortality rate of 1.6 % for this subset of patients.

On the other hand, there are very little in the literature that presented the clinical results of off-pump CABG in the ACS cases. Locker and colleagues demonstrated that timing in itself is not a significant predictor of early mortality in off-pump CABG, but it is a significant predictor in patients undergoing operation with CPB. Rastan and colleagues demonstrated that beating heart techniques implemented during active ischemia reduced in-hospital adverse outcome measures such as transfusion requirements, extensive inotropic support, prolonged ventilation time, intensive care unit stay, and in-hospital stroke rate [25]. Fattouch and colleagues reported that off-pump surgery reduced early mortality and morbidity in patients with ST-segment elevation myocardial infarction in respect to the conventional procedure and showed better results than on-pump surgery in patients who underwent surgery within 6 h from the onset of symptoms and in patients with cardiogenic shock [26]. In the on-pump group, the incidence of early death in patients presenting with or without shock was 27 % and 3.7 %; however, in the off-pump group, the incidence of early death in patients presenting with or without preoperative shock was 7.5 % and 0 %, respectively. They said that preoperative cardiogenic shock increases early mortality after CABG in patients with AMI, specifically in those undergoing on-pump surgery. Parikh and colleagues reported that in-hospital mortality and the composite outcome of death, myocardial infarction, congestive heart failure, or cardiogenic shock were similar between NSTEMI patients undergoing early versus late CABG [27]. Biancari and colleagues [28] showed that off-pump CABG might reduce ischemic injury to the myocardium and suggested some early benefit for the OPCAB technique for patients presenting with active ischemia and unstable angina. Moscarelli and coworkers [29] reported a meta-analysis of OPCAB outcomes in patients with ACS that included one randomized and eight retrospective studies. They concluded that OPCAB may have a beneficial effect on 30-day mortality in hemodynamically stable patients undergoing emergency revascularization; there is a lack of high-quality data with clearly defined patient demographics.

Anesthesia management of OPCAB is challenging because of hemodynamic deterioration during anastomoses, and the hemodynamic dysfunction that occurs during OPCAB has been postulated to be induced by the effect of displacement of the heart and the unavoidable pressure applied to the heart, which affect both ventricular functions and coronary artery flow. The anesthesiologist's approach and their interaction and cooperation with the surgeon during OPCAB greatly contribute to optimize the results of OPCAB.

In OPCAB surgery, especially in ACS case, the most severe complication is hemodynamic compromise, which can occur during displacement of the heart to expose the target vessels. The vertical displacement of the heart induced a reduction in cardiac output and stroke volume that were primarily caused by impaired diastolic expansion of the right ventricle. Use of a mechanical stabilizer may further decrease cardiac output secondary to direct ventricular compression with reduced stroke volume. In the setting of OPCAB procedure, preoperative IABP therapy improves cardiac performance and facilitates access to the target vessels while maintaining hemodynamic stability, even in high-risk patients [30]. The effect of IABP support, such as the reduction of ventricular afterload, improvement of diastolic coronary perfusion, and enhancement of subendocardial perfusion, is very beneficial to the displaced heart in maintaining hemodynamic stability during OPCAB. Delayed use of IABP was associated with increased mortality, whereas the prevalence of perioperative myocardial infarction and in-hospital mortality were significantly lower among patients for whom IABP support was initiated preoperatively. Therefore, IABP therapy should be performed preoperatively in selected high-risk patients with definite indications. Common indications for preoperative IABP placement before OPCAB were severe left main coronary artery disease, unstable angina, left ventricular dysfunction, recent acute myocardial infarction, and congestive heart failure.

The TEE during OPCAB may present valuable information, such as wall motion abnormality, mitral regurgitation, and chamber volume. When increases in the PAP and the CVP are observed, a TEE examination of the mitral valve can be very helpful in the diagnosis. Positional mitral regurgitation is frequently observed and is a major factor of the hemodynamic instability that occurs during posterior- and lateral-wall revascularization during OPCAB procedure. Acute position-related mitral regurgitation may be resolved with appropriate repositioning.

In ACS case, one of the important factors is the sequence of grafting that is individualized based upon the patient's coronary artery disease pattern. In patients with severe left main coronary artery stenosis, the LAD is grafted first. Collateralized vessels should be grafted first before collateralizing vessels. Generally, culprit coronary artery should be reconstructed after the other easily accessible target is grafted. In ACS cases, experienced OPCAB surgeons should promptly decide the sequence of grafting according to accessibility of the target coronary artery, ease of grafting such as calcification and size of coronary artery, or instability of the flow of the target vessels.

Finally, the precious application of OPCAB procedure for ACS is unclear. There is insufficient evidence to determine the effect of OPCAB technique for ACS cases. There is currently insufficient evidence to determine the effect of OPCAB technique for ACS patients. However, we think that OPCAB will play its special role in ACS status in the future.

References

1. Trachiotis GD, Weintraub WS, Johnston TS, Jones EL, Guyton RA, Craver JM (1998) Coronary artery bypass grafting in patients with advanced left ventricular dysfunction. Ann Thorac Surg 66:1632–1639
2. Alderman EL, Fisher LD, Litwin P, Kaiser GC, Myers WO, Maynard C et al (1983) Results of coronary artery surgery in patients with poor left ventricular function (CASS). Circulation 68:785–795
3. Christakis GT, Weisel RD, Fremes SE, Ivanov J, Davide TE, Goldman BS et al (1992) Coronary artery bypass grafting in patients with poor ventricular function. J Thorac Cardiovasc Surg 103:1083–1092
4. Ascione R, Narayan P, Rogers CA, Lim KHH, Capoun R, Angelini GD (2003) Early and midterm clinical outcome in patients with severe left ventricular dysfunction undergoing coronary artery surgery. Ann Thorac Surg 76:793–800
5. O'Connor GT, Plume SK, Olmstead EM, Coffin LH, Morton JR, Maloney CT, Nowicki ER, Levy DG, Tryzelaar JF, Hernandez F, Adrian L, Casey KJ, Bundy D, Soule DN, Marrin C, Nugent WC, Charlesworth DC, Clough R, Katz S, Leavitt BJ, Wennberg JE (1992) Multivariate prediction of in-hospital mortality associated with coronary artery bypass graft surgery. Northern New England Cardiovascular Disease Study Group. Circulation 85(6):2110–2118
6. Hausmann H, Topp H, Siniawski H, Holz S, Hetzer R et al (1997) Decision making in end-stage coronary artery disease: revascularization or heart transplantation? Ann Thorac Surg 64:1296–1302
7. Bouchart F, Tabley A, Litzler PY, Haas-Hubscher C, Bessou JP, Soyer R (2001) Myocardial revascularization in patients with severe ischemic left ventricular dysfunction. Long-term follow-up in 141 patients. Eur J Cardiothorac Surg 20:1157–1162
8. Louagie Y, Jamart J, Buche M, Eucher P, Haxhe JP, Lhommel R et al (1996) Myocardial revascularization for severe left ventricular dysfunction. Factors influencing early and late survival. Cardiovasc Surg 4:607–617
9. Scott SM, Deupree RH, Sharma GVRK, Luchi RJ (1994) VA study of unstable angina. 10-year results show duration of surgical advantage for patients with impaired ejection fraction. Circulation 90(Suppl 2):120–123
10. Arom KV, Flavin TF, Emery RW, Kshetty VR, Petersen RJ, Janey PA (2000) Is low ejection fraction safe for off-pump coronary bypass operation? Ann Thorac Surg 70:1021–1025
11. Keeling WB, Mattew LW, Slaughter MS, Zhao Y, Puskas JD (2013) Off-pump and pn-pump coronary revascularization in patients with low ejection fraction: a report from The Society of Thoracic Surgeons National Database. Ann Thorac Surg 96:83–89
12. Shennib H, Endo M, Benhamed O, Morin JF (2002) Surgical revascularization in patients with poor left ventricular function: on- or off-pump? Ann Thorac Surg 74:1344–1347
13. Suzuki T, Asai T (2008) Early and midterm results of off-pump coronary artery bypass grafting without patient selection. Heart Surg Forum 11(4):196–200
14. Suzuki T, Okabe M, Yasuda F, Miyake Y, Handa M, Nakamura T (2003) Our experiences for off-pump coronary artery bypass grafting to the circumflex system. Ann Thorac Surg 76:2013–2016
15. Dawson JT, Hall RJ, Hallman GL, Cooley DA (1974) Mortality in patients undergoing coronary artery bypass surgery after myocardial infarction. Am J Cardiol 33:483–486
16. Miller MG, Hedley WJ, Weintraub RM, Restall DS, Alexander M (1974) Surgery for cardiogenic shock. Lancet 2:1342–1345
17. Dunkmen WB, Leinbach RC, Buckley MJ, Mundth ED, Kantrowitz AR, Austen WG et al (1972) Clinical and hemodynamic results of intraaortic balloon pumping and surgery for cardiogenic shock. Circulation 46:465–477
18. Every NR, Maynard C, Cohran RP, Martin J, Weaver WD (1996) Characteristics, management, and outcome of patients with acute myocardial infarction treated with bypass surgery: myocardial infarction triage and intervention investigators. Circulation 94(Suppl):II81–II86
19. Hamm CW, Bassand JP, Agewall S, Bax J, Boersma E, Bueno H, Caso P, Dudek D, Gielen S, Huber K, Ohman M, Petrie MC, Sonntag F, Uva MS, Storey RF, Wijns W, Zahger D (2011) ESC guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation. The task force for the management of acute coronary syndromes(ACS) in patients presenting without persistent ST-segment elevation of the European Society of Cardiology (ESC). Eur Heart J 32:2999–3054
20. Hillis LD, Smith PK, Anderson JL, Bittl JA, Bridges CR, Byrne JG, Cigarroa JE, DiSesa VJ, Hiratzka LF, Hutter AM Jr, Jessen ME, Keeley EC, Lahey SJ, Lange RA, London MJ, Mack MJ, Patel MR, Puskas JD, Sabik JF, Selnes O, Shahian DM, Trost JC, Winniford MD (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 124:2610–2642
21. Berg R, Selinger SL, Leonard JJ, Coleman WS, DeWood M (1984) Acute evolving myocardial infarction: a surgical emergency. J Thorac Cardiovasc Surg 88:902–906
22. Creswell LL, Moulton MJ, Cox JL, Rosenbloom M (1995) Revascularization after acute myocardial infarction. Ann Thorac Surg 60:19–26
23. Tomasco B, Cappiello A, Fiorilli R, Leccese A, Lupino R, Romiti A, Tesler UF (1997) Surgical revascularization for acute coronary insufficiency: analysis of risk factors for hospital mortality. Ann Thorac Surg 64:678–683
24. Monteiro P (2006) Impact of early coronary artery bypass graft in an unselected acute coronary syndrome patient population. Circulation 114(Suppl):I467–I472
25. Rastan AJ, Eckenstein JL, Hentschel B, Funkat AK, Gummert JF, Doll N et al (2006) Emergency coronary artery bypass graft surgery for acute coronary syndrome: beating heart versus conventional cardioplegic cardiac arrest strategies. Circulation 114(Suppl):I477–I485

26. Fattouch K, Guccione F, Dioguardi P, Sampognaro R, Corrado E, Caruso M, Ruvolo G (2009) Off-pump versus on-pump myocardial revascularization in patients with ST-segment elevation myocardial infarction: a randomized trial. J Thorac Cardiovasc Surg 137:650–657
27. Ben-Gal Y, Moses JW, Mehran R, Lansky AJ, Weisz G, Nikolsky E, Argenziano M, Williams MR, Colombo A, Aylward PE, Stone GW (2010) Surgical versus percutaneous revascularization for multivessel disease in patients with acute coronary syndrome: analysis from the ACUITY trial. JACC Cardiovasc Interv 3:1059–1067
28. Biancari F, Mahar MA, Mosorin M, Heikkinen J, Pokela M, Taskinen P et al (2008) Immediate and intermediate outcome after off-pump and on-pump coronary artery bypass surgery in patients with unstable angina pectoris. Ann Thorac Surg 86:1147–1152
29. Moscarelli M, Harling L, Ashrafian H, Athanasiou T (2013) Should we consider off-pump coronary artery bypass grafting in patients with acute coronary syndrome? Interact Cardiovasc Thorac Surg 16:350–355
30. Suzuki T, Manabu O, Handa M, Yasuda F, Miyake Y (2004) Usefulness of preoperative intraaortic balloon pump therapy during off-pump coronary artery bypass grafting in high-risk patients. Ann Thorac Surg 77:2056–2060

24 Difficult Coronary OPCAB Made in Japan

Takeshi Kinoshita and Tohru Asai

Abstract

Three aspects should be considered when discussing a difficult coronary for CABG. First is when the vessel is invisible. Coronary arteries sometimes run an intramyocardial course or are covered with extensive epicardial adipose tissue, making its identification and subsequent revascularization difficult and leading to complications such as bleeding from surrounding tissues, penetration into the right ventricle, formation of hematoma, and failure to find the artery in the end. Second is when vessel itself is point at issue. This includes diffusely sclerotic, calcified, or small vessels. Third is when multiple stents are placed in the vessel. The purpose of this chapter is to share the tips and pitfalls in dealing with these challenging situations on the beating heart.

Keywords

Invisible vessels • Diffusely sclerotic • Calcified • Small vessels • Stented coronary arteries

24.1 Difficult Coronary Artery

The issues of off-pump CABG remain technical difficulty and learning curve required for the surgeons. This fact is clearly evidenced by the Randomized On/Off Bypass (ROOBY) trial, showing reduced graft number resulting in incomplete revascularization and reduced graft patency at 1 year in the off-pump group [1]. Notable feature of the study includes the relative lack of experience of the surgeons particularly with off-pump technique (20 cases to be eligible). Although the CABG Off- or On-Pump Revascularization (CORONARY) trial [2] is limited to surgeons with more extensive off-pump experience, there were fewer grafts and more early repeat revascularizations in the off-pump group. On the other hand, experienced off-pump surgeons have showed similar graft patency, cardiac outcomes, and completeness of revascularization [3]. The important message from these studies is not just that off-pump CABG is worse than on-pump CABG but that for successful off-pump CABG, not only experience but also appropriate skills and surgical strategy are necessary.

24.1.1 What Is Difficult Coronary Artery?

Three aspects should be considered when discussing a difficult coronary for CABG. First is when the vessel is invisible: vessels running intramyocardially or covered with extensive fatty fibrous tissue. Second is when vessel itself is point at issue: diffusely sclerotic, calcified, or small vessels. Third is when multiple stents are placed in the vessel.

24.1.2 What Are the Pitfalls Specific for Off-Pump CABG?

Off-pump CABG required unique skill sets and different strategies compared with on-pump CABG. Among technical

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elements, the following three factors are critically important for successful results:

1. Control of backflow bleeding from coronary arteriotomy during anastomosis
2. Complete stabilization of anastomotic sites especially on more deeply located vessels
3. Adequate exposure of operative field

24.2 Invisible Coronary Arteries

The coronary arteries usually run along a surface of the heart and may be easily identified. However, in some cases, they run an intramyocardial course or are covered with extensive epicardial adipose tissue, making its identification and subsequent revascularization difficult. Routine dissection of estimated location of the vessels based on visual inspection and digital palpitation seems to be the easiest way, but can lead to complications such as bleeding from surrounding tissues, penetration into the right ventricle, formation of hematoma, and failure to find the artery in the end.

24.2.1 How to Overcome the Challenging Situations

Coronary angiography is the standard method to examine the anatomy of the coronary system. Careful examination of the angiography, especially using oblique views, often provides a useful clue as to location of the vessel. In contrast to the flexuous course of the superficial vessels, the intramyocardial portion of the vessels dives at acute angle into the myocardium and usually looks straight. The intramyocardial LAD has been reported to be usually located to the right of the great cardiac vein [4]. A small part of the vessel sometimes rises to the surface of the heart. It may be a landmark to seek other part of the vessel or can be an anastomotic site. When the vessel is covered with subepicardial fat tissue, it often pulls the epicardium making a small wrinkle. Meticulous examination of the surface of the heart can sometimes be sufficient to detect the artery. The following five techniques for determining hidden vessels have been proposed.

24.2.2 Retrograde Passage of Vascular Probe Through a Distal Arteriotomy [5, 6]

This technique involves retrograde insertion of an atraumatic vascular probe through a distal coronary arteriotomy. An incision of 1.0–1.5 mm long vertical to the long axis of the vessel is performed at the finest part of the visible LAD (usually the most distal, near to the apex). Then, a fine atraumatic vascular probe is gently inserted intraluminally and advanced proximally until a suitable site for anastomosis. This technique may allow the approximation of the quality of the vessel wall and the exact course by palpation and visual guidance. The overlying tissues (fat and/or myocardium) were dissected, and the artery is opened longitudinally over the probe tip. In case of off-pump CABG, keeping the probe inside the artery until completion of the anastomosis will help de-air and prevent excessive bleeding from the distal arteriotomy. This also certifies the good quality of the anastomosis. The distal arteriotomy is usually closed with one or two interrupted 8–0 stitches, placed vertical to the incision. The disadvantage of this technique includes a risk of arterial perforation and intimal damage while advancing the probe. Furthermore, it might not always possible to advance the probe retrogradely because of small coronary artery, calcified stenotic lesions, or tortuous course.

24.2.3 Retrograde Dissection of Tissue Overlying the Vessel [7, 8]

After the target vessel is localized, its proximal is exposed by proximally incising the muscle and adipose tissue using Potts scissors. The lower scissor blade should be kept on the anterior surface of the artery to prevent the injury of the diagonal branches and entering into the right ventricular cavity. Excess use of electric cautery for controlling hemorrhage from surrounding tissue should be avoided because it may cause thermal injury to the underlying coronary artery. Each edge is then sutured in a running fashion with 6–0 or 5–0 Prolene. The limitation of this method is that it requires large dissection under heparinization causing massive bleeding and prolonged ischemic period.

24.2.4 High-Frequency Epicardial Ultrasound

High-frequency epicardial ultrasound is a versatile technology and helps the surgeons identify the location of target coronary arteries, select the optimal anastomotic sites, and assess the quality of constructed anastomoses (refer to the ECUS section).

24.2.5 Intraoperative Cineangiography [9]

After placing a radiopaque marker for mapping the anterior surface of the heart, 10 ml of radiopaque agent is infused through the antegrade cardioplegia cannula and a cineangiographic image is obtained from a perpendicular angle using a portable C-arm cineangiographic system. This cineangiographic image can be used to locate the LAD. The limitations include requirement of a hybrid operating room and use only in patients who are on pump with cross-clamped aorta. Also, it should be used with caution in patients with kidney failure or contrast intolerance.

24.2.6 Elevation of LAD with Elastic Tape [10]

A blunt-ended needle with mounted elastic tape is put deeply into the myocardium under the coronary vessels and comes out on the opposite side. Intramyocardial vessels are elevated by the tape under tension, which makes it easier to dissect the myocardium over the LAD. This technique has a risk of injuring LAD and its branches and penetration into the right ventricle cavity.

24.3 Diffusely Stenotic, Calcified, or Small Vessels

The increased number of patients with more advanced atherosclerotic coronary disease has been referred to CABG due to rapid aging of the population and an increased prevalence of hypertension, diabetes, chronic kidney disease, or hyperlipidemia.

24.3.1 How to Overcome the Challenging Situations

The diffusely diseased vessels are the challenge for cardiac surgeons. The most critical points are to find the best possible arteriotomy sites before operation and during the procedure and to create an operative field in which the surgeon can make an anastomosis comfortably. During the procedure, the target vessel should be evaluated throughout its distal portion. Not only the endoluminal diameter of the vessel but the thickness, calcification, and other qualities of the vessel should be carefully evaluated. The site with decent endoluminal diameter and the vessel wall with the best quality should be chosen.

Careful examination of coronary angiography provides a lot of information including vessel size, irregular wall, stenoses, and location of calcification, but it does not always delineate the quality of vascular wall. Total occlusion and subtotal occlusion of coronary arteries are sometimes associated with poor filling of or absence of its distal portions.

Digital palpation is useful to assess wall stiffness, but it's subjective and easily fails to catch soft plaques. Suboptimal selection of arteriotomy site unexceptionally put the surgeons in a very difficult situation, especially when dealing with such a difficult coronary.

High-frequency epicardial ultrasound (ECUS) provides detailed imaging of the local anatomy including vessel size, vascular wall quality, and relationship between vessels, myocardium, and overlying fat tissue. This assessment is fully conducted prior to making the arteriotomy. Septal perforators or side branches cannot be conventionally detected before opening the coronary, and bleeding through the arteriotomy from these small vessels extremely interferes with suturing in off-pump CABG. ECUS can clearly delineate vessels of less than 1 mm in diameter (refer to the ECUS section).

Intracoronary shunt provides a bloodless field, the forward flow in the shunt helps prevent ischemia and facilitates precision in constructing the anastomosis by staying the vessel in its natural shape and protecting the back wall of the artery, and gentle traction on the string of the shunt presents the margins of the arteriotomy well [11–16]. Appropriate-size shunt provides space between the shunt and the edge of the vessel that facilitates suturing. Surgeons should keep in mind that the vessel quality does not always allow the insertion of the intraluminal shunt tube. However, the intraluminal shunt tube of small size (1.2 mm) should be available whenever it is necessary. A pitfall of off-pump revascularization is blood in the field making anastomosis inaccurate, rather than the heart movement. Therefore, the intracoronary shunt, no matter how small it is, and the carbon dioxide blower are of paramount importance. Precise suturing until 1 mm target vessel with fine arterial grafting should be able to be constructed. Although some surgeons may claim that quick insertion into the small coronary artery and positioning through a limited arteriotomy is difficult and time consuming, several useful techniques of introducing shunts can help them solve the problem [17, 18].

In current OPCAB practice, we always assess blood flow through the graft intraoperatively. The transit-time flowmetry and the fluorescence study are two common modalities. When surgeons observe any unexpected findings in these assessments, they should not hesitate to revise the anastomosis. Once the excellent anastomosis is constructed especially with arterial grafts of good quality, long-term patency is mostly guaranteed. The detail of transit-time flowmetry and the fluorescence study has been reported previously and may be seen in video on the Internet [19].

24.3.2 Case Presentation

A 69-year-old diabetic man with progressive dyspnea admitted in the diagnosis of congestive heart failure. He had poorly controlled diabetes complicated by retinopathy and dyslipidemia. Hemoglobin A1c level was 11.6 % at admission. The cardiac catheterization revealed severe triple-vessel coronary artery disease with depressed left ventricular function

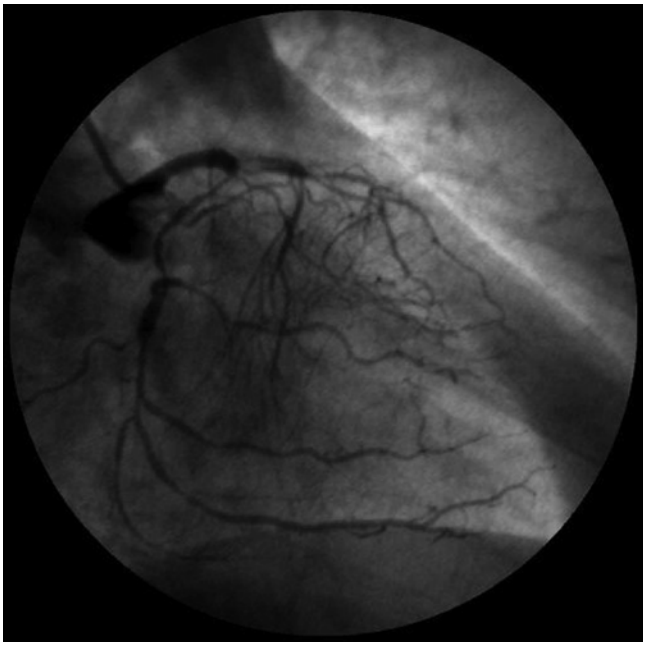

Fig. 24.1 The preoperative left coronary angiogram clearly demonstrated severe diffuse coronary artery disease. The LAD was totally occluded and its distal portion was not filled via any collaterals. The circumflex artery was tightly stenotic and the distal portions were diffusely diseased

Fig. 24.2 The left coronary arteriogram (left anterior oblique with cranial angulation) revealed severe diffuse atherosclerosis of whole left coronary artery system. Total occlusion of the proximal LAD, severe diffuse stenoses in diagonal, proximal circumflex, and three marginal branches were noted

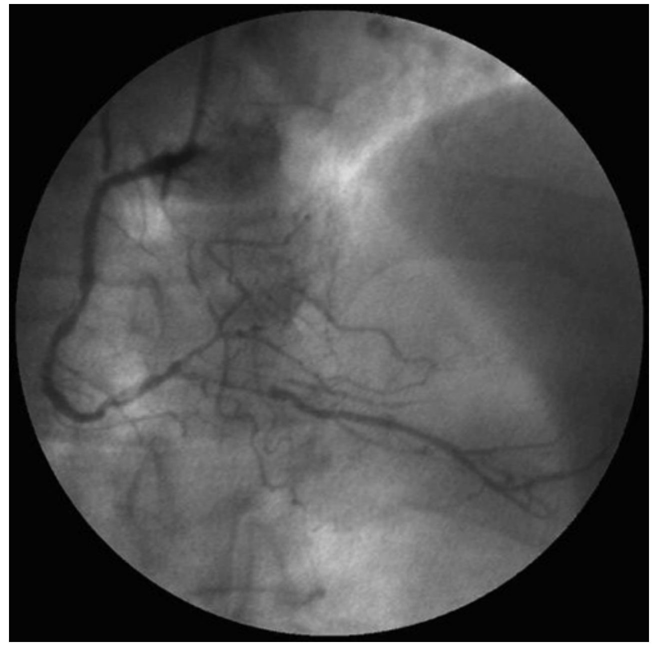

Fig. 24.3 The right coronary artery had multiple severe eccentric stenoses at its mid portion, its distal portion, and the proximal portion of PDA

(ejection fraction 44 %) (Figs. 24.1, 24.2, and 24.3). The left anterior descending artery (LAD) was totally occluded, and its distal portion was not filled through antegrade or retrograde collaterals. The circumflex and right coronary arteries were also tightly stenotic and the distal portions were diffusely diseased vessels. The patient was referred to us for CABG.

Under general anesthesia, the left and right internal thoracic arteries and the right gastroepiploic artery were harvested in the skeletonized fashion and wrapped with papaverine-soaked sponge and divided, and PDE III inhibitor was instilled within it. The LAD was carefully identified by close inspection of the anterior wall and found to be diffusely sclerotic small vessel. The target site was chosen for the best arterial wall quality. Marginal branches of the circumflex and the posterior descending artery were also found to be diffusely diseased. These were only 1.0–1.5 mm vessels and not favorable but possible for grafting.

The LAD was opened first. Internal lumen was 1.5 mm. End-to-side anastomosis was constructed using the pedicled RITA with a 7–0 polypropylene running suture. The pedicled LITA was used as a sequential graft to revascularize the two obtuse marginal branches. Both were 1.5 mm in diameter with a mildly diseased wall. The first marginal branch was grafted in side-to-side diamond fashion. Lastly, the GEA was used as a sequential graft to revascularize the posterior descending artery and the distal portion of the circumflex. Both anastomoses were constructed using 7–0 polypropylene running sutures. The PDA was grafted in side-to-side parallel fashion.

He recovered and discharged home uneventfully. Coronary angiography performed at 1 week after surgery demonstrated widely patent coronary anastomoses with excellent flow and distal runoff (Figs. 24.4, 24.5, and 24.6) and markedly improved the left ventricular function.

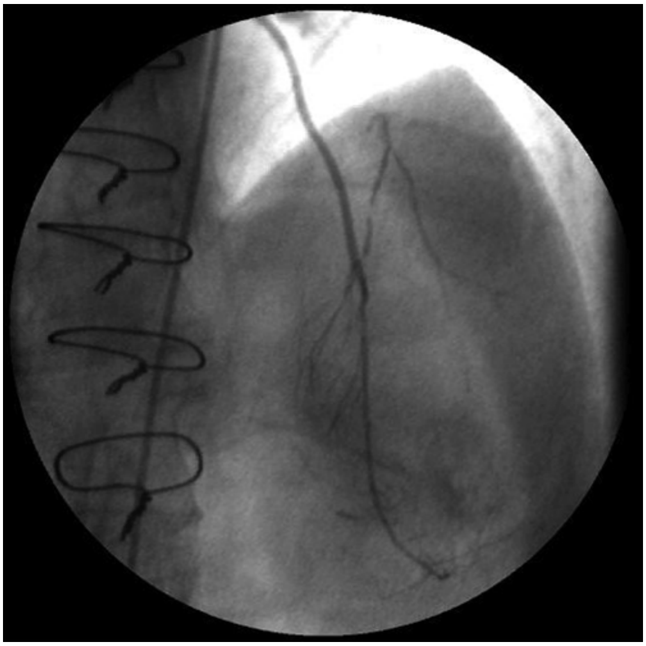

Fig. 24.4 The skeletonized right ITA was grafted to the distal LAD, totally occluded vessel. It was patent with septal branches and a diagonal branch nicely visualized

Fig. 24.6 The postoperative angiogram of the skeletonized RGEA graft demonstrated patency for sequentially bypassed the PDA and the distal portion of the circumflex artery

Fig. 24.5 The postoperative angiogram of the skeletonized left ITA graft demonstrated patency for sequentially bypassed the first and the second obtuse marginal branches of the circumflex artery

24.4 Stented Coronary Arteries

The stented coronary arteries are currently observed in more than 40 % of CABG candidates in our practice. With advent of the drug-eluting stent (DES), percutaneous coronary intervention (PCI) has been widely used for coronary revascularization. However, PCI itself cannot slow down the progressive process of coronary atherosclerosis and some patients are referred for CABG. These patients are generally more elderly, have more advanced and complex disease, and subsequently have smaller-sized target coronary arteries. They often have history of MI and are mostly on dual antiplatelet therapy (DAPT).

We observed specific patterns of lesions related to stented coronary arteries. First, “abrupt occlusion” is an in-stent lesion of the trunk of the stented vessel. This could be caused by stent thrombosis or progression of the atherosclerosis. Second, “in-segment stenosis” sometimes occurs in area outside of stented portion, but just close to the stent. It is the most stressed area with the heartbeat movement. Third, diffuse long segmental stenosis is also common among patients with progressive disease. Fourth, “candy wrapper stenosis” is often observed, just proximal or orifice location at branches of the stented coronary artery. Cardiologists often call these vessels “jailed” branches simply because metal strut of the stent caused jail-like appearance for its branch. These four patterns and progressive new atherosclerotic lesions were commonly observed.

At the time of the surgical revascularization, the stented portions of the coronary arteries are not the best site for the anastomosis of bypass conduits. The specific problems caused by coronary stentings are as follows. We need to make arteriotomy more distal and thinner sized area than that of ordinary cases. We occasionally need to make more number of distal anastomoses due to each major branch separately having tight “candy wrapper” stenosis. Mild stenosis at the in-stent site may preserve some blood flow through it; arterial grafting may be unpredictable in terms of long-term patency. We generally avoid endarterectomy with the stent removal in our practice unless it is necessary. This exposes thrombogenic media and inflamed vessel at the site of anastomosis, which would certainly increase the risk for early graft occlusion as well as native coronary thrombosis. There is no gold standard for surgical revascularization for stented coronary artery. These patients are treated individually, with special care. OPCAB for these patients is technically demanding and tactically complex even with experienced surgeons.

24.4.1 Case Presentation

A 67-year-old diabetic woman has repeatedly received percutaneous coronary intervention for recurrent angina caused by repeated in-stent restenoses during the last 2 years (over 15 times). The latest coronary angiography revealed a total of thirteen stents filling the proximal to middle portions of the three coronary territories (Figs. 24.7, 24.8, and 24.9) and in-stent total occlusion lesions in the middle portion of the LAD and the ostium of the right coronary artery. The obtuse marginal branch was also jailed by a stent (Figs. 24.10, 24.11, and 24.12). She successfully underwent off-pump CABG with in situ left internal thoracic artery graft to the second diagonal branch and the LAD; saphenous vein graft to the first diagonal branch, the OM, and the distal circumflex artery; and in situ gastroepiploic artery graft to the posterior descending artery. She recovered uneventfully, was discharged home after 2 weeks, and was followed in the outpatient clinic.

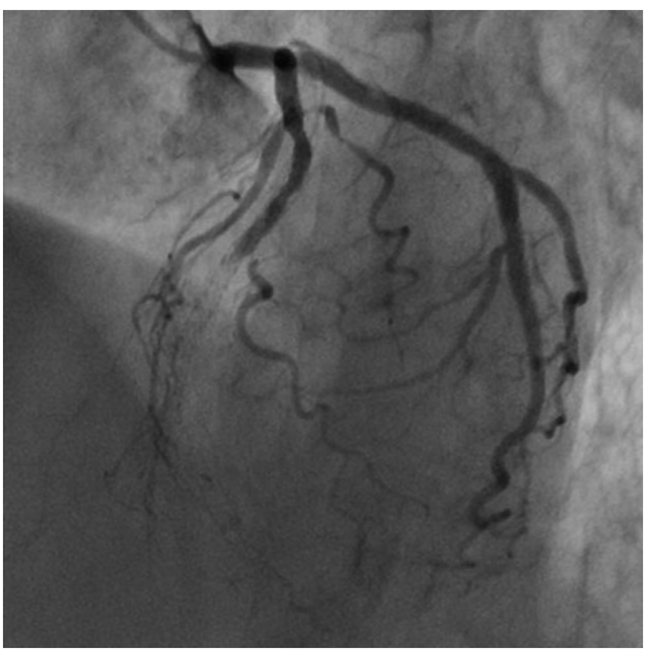

Fig. 24.7 The preoperative left coronary angiogram (left anterior oblique with cranial angulation) clearly demonstrated stent-related problems. The midportion of LAD showed “abrupt occlusion,” and the first and the second diagonal branches had tight stenoses at very proximal portions. The distal portion of LAD and PDA became visible but very thin

Fig. 24.8 The preoperative left coronary angiogram (left anterior oblique with caudal angulation) revealed that the circumflex artery had moderate stenosis at the LMCA bifurcating stented area; it was “jailed.” The obtuse marginal exhibited another severe “candy wrapper” stenosis

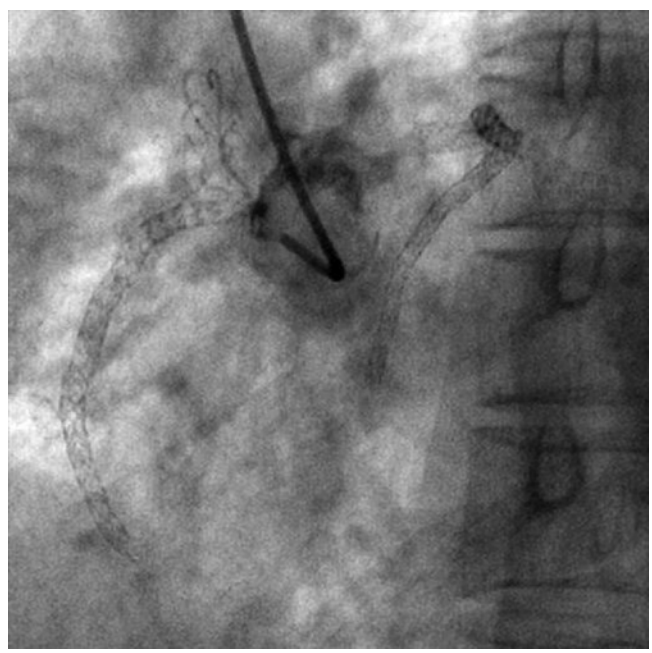

Fig. 24.9 This right coronary angiogram demonstrated not only the total occlusion at the orifice but multiple stunts implanted in all three coronary artery systems

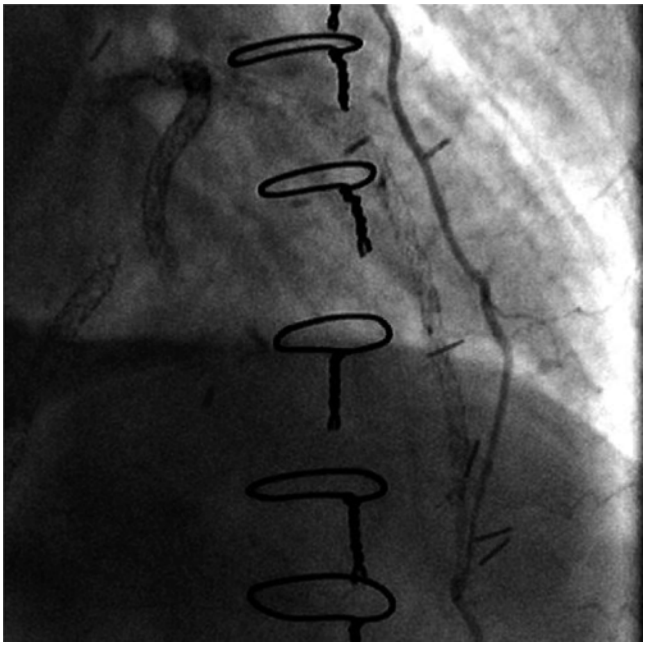

Fig. 24.10 The postoperative angiogram of the skeletonized left ITA graft demonstrated patency for sequentially bypassed the second diagonal branch and the distal portion of LAD

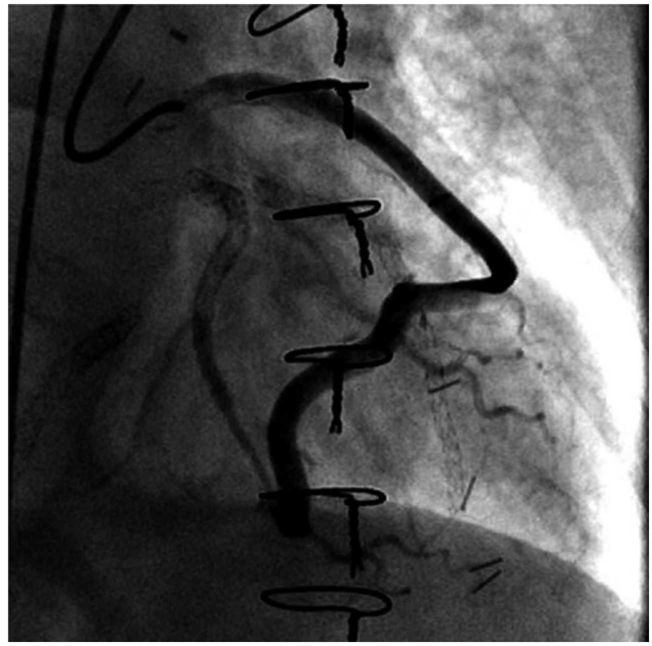

Fig. 24.12 The saphenous vein angiogram confirmed patency, to all sequentially grafted targets, the first diagonal, the obtuse marginal, and the posterolateral branch

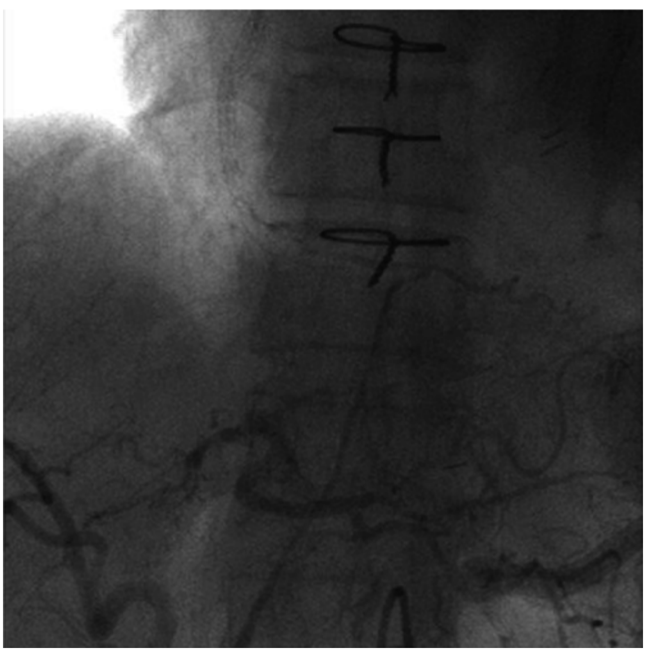

Fig. 24.11 The postoperative angiogram of the skeletonized RGEA graft demonstrated patency, thin but smooth, for the totally occluded PDA

24.4.2 Comments

Beating heart makes it more difficult to deal with invisible vessels or advanced atherosclerotic coronary arteries. A full understanding of pitfalls to be avoided, unique skill set, and adequate experience allow the surgeons to completely manage such a difficult situation. The techniques should be reproducible, widely available, less invasive, and applicable for various types of vessels. Although not all operation theaters are equipped with advanced medical technologies, both ECUS and intracoronary shunts are highly recommended devices, allowing the surgeons to make the safest approach to the most appropriate anastomotic site by the most direct way and construct secure anastomoses.

References

1. Shroyer AL, Grover FL, Hattler B, Collins JF, McDonald GO, Kozora E, Lucke JC, Baltz JH, Novitzky D (2009) Veterans affairs randomized on/off bypass (ROOBY) study group. On-pump versus off-pump coronary-artery bypass surgery. N Engl J Med 361:1827–1837
2. Lamy A, Devereaux PJ, Prabhakaran D et al (2012) Off-pump or on-pump coronary-artery bypass grafting at 30 days. N Engl J Med 366:1489–1497
3. Puskas JD, Williams WH, Mahoney EM, Huber PR, Block PC, Duke PG, Staples JR, Glas KE, Marshall JJ, Leimbach ME, McCall SA, Petersen RJ, Bailey DE, Weintraub WS, Guyton RA (2004) Off-pump vs conventional coronary artery bypass grafting: early and 1-year graft patency, cost, and quality-of-life outcomes: a randomized trial. JAMA 291:1841–1849
4. Oz MC, Cooper MM, Hickey TJ, Rose EA (1994) Exposure of the intramyocardial left anterior descending artery. Ann Thorac Surg 58:1194–1195
5. Robinson G (1973) Location of the proximal left anterior descending coronary artery. Ann Thorac Surg 8:299–300

6. Apostolakis E, Koletsis E, Leivaditis V, Lozos V, Dougenis D (2007) A safe technique of exposing of a "hidden" left anterior descending artery. J Card Surg 8:505–506
7. Gandjbakhch I, Cabrol C (1976) Techniques for discovery of a masked interventricular artery in coronary surgery. Nouv Presse Med 8:2713–2714
8. Parachuri RV, Chattuparambil B, Hasabettu PK, Punnen J, Dhaded S, Sadagopan DR, Shetty DP (2005) Marsupialization of intramyocardial left anterior descending artery: a novel approach for easy access during revascularization. Ann Thorac Surg 8:2390–2392
9. Aydin U, Kocogullari CU (2013) A method for locating embedded left anterior descending coronary arteries. Ann Thorac Surg 95:360–361
10. Zamvar V, Lawson RA (1995) Technique for finding the left anterior descending coronary artery. Ann Thorac Surg 8:1457–1458
11. Dapunt OE, Raji MR, Jeschkeit S et al (1999) Intracoronary shunt insertion prevents myocardial stunning in a juvenile porcine MIDCAB model absent of coronary artery disease. Eur J Cardiothorac Surg 15:173–178
12. Gandra SMA, Rivetti LA (2003) Experimental evidence of regional myocardial ischemia during beating heart coronary bypass: prevention with temporary intraluminal shunts. Heart Surg Forum 6:10–18
13. Sepic J, Wee JO, Soltesz EG, Laurence RG, Aklog L (2003) Intraluminal coronary shunting preserves regional myocardial perfusion and function. Heart Surg Forum 6:120–125
14. Lucchetti V, Capasso F, Caputo M et al (1999) Intracoronary shunt prevents left ventricular function impairment during beating heart coronary revascularization. Eur J Cardiothorac Surg 15:255–259
15. Menon AK, Albes JM, Oberhoff M, Karsch KR, Ziemer G (2002) Occlusion versus shunting during MIDCAB: effects on left ventricular function and quality of anastomosis. Ann Thorac Surg 73:1418–1423
16. Yeatman M, Caputo M, Narayan P et al (2002) Intracoronary shunts reduce transient intraoperative myocardial dysfunction during off-pump coronary operations. Ann Thorac Surg 73:1411–1417
17. Patel NC, Pullan DM, Fabri BM (2002) Shunt shuffle- a simple technique of introducing intracoronary shunts for off-pump coronary artery bypass. Eur J Cardiothorac Surg 21:1121
18. Yokoyama H, Takase S, Misawa Y, Takahashi K, Sato Y, Satokawa H (2004) A simple technique of introducing intracoronary shunts for off-pump coronary artery bypass surgery. Ann Thorac Surg 78:352–354
19. Asai T, Suzuki T, Nota H, Kuroyanagi S, Kinoshita T, Takashima N, Hayakawa M, Naito S (2013) Off-pump coronary artery bypass grafting using skeletonized in situ arterial grafts. Ann Cardiothorac Surg 2:552–556. http://www.annalscts.com/article/view/2420/3286

Off-Pump CABG for Patients with End-Stage Renal Failure

25

Masami Ochi

Abstract

In recent years, diabetes and hypertension have become common causes of chronic kidney disease (CKD), and patients with cardiovascular complications are common. Approximately half of the deaths within 1 year of the start of hemodialysis (HD) are due to cardiovascular complications.

Proactively providing cardiovascular treatment to HD patients is believed to improve their survival prognosis.

However, HD patients not infrequently have calcified lesions, not only in the coronary arteries but also from the aorta to the peripheral arteries beyond the cervical region. As these lesions have a tendency to hemorrhage, they are susceptible to infection and pose difficulties in perioperative fluid management. Surgical mortality after coronary artery bypass grafting (CABG) has been reported to exceed 10 % in Europe and the United States [1, 2].

In view of this, the number of patients requiring dialysis is increasing every year; therefore, the treatment of coronary artery disease in CKD patients is an important issue.

Although some studies have found that the results of percutaneous coronary intervention (PCI) and CABG are equivalent in terms of the coronary revascularization of HD patients [3], in general PCI mostly has a lower success rate in HD patients due to the presence of severe calcifications or diffuse lesions in the coronary arteries.

Keywords

End-stage renal failure • Chronic kidney disease • Hemodialysis • PCI

25.1 Characteristics of HD Patients

Because HD patients possess many coronary risk factors, including advanced age, hypertension, and diabetes, the coronary vascular pathology of HD patients is characterized not only by diffuse coronary artery lesions extending across several branches but also by the progression of atherosclerosis as a result of lipid metabolism abnormalities and severe calcification as far as the media. These pathological features develop as a result of calcium/phosphorus metabolism abnormalities.

Marked systemic atherosclerosis is also characteristic of HD patients, and calcifications and obstructive lesions of the aorta, peripheral arteries in the legs, and the carotid arteries are frequent additional complications.

Left ventricular hypertrophy is also frequently evident in HD patients, probably as a result of prolonged hypertension, and is one cause of left ventricular failure. Even if left ventricular function initially appears to be maintained, patients can easily succumb to left heart failure.

Long-term follow-up results for HD patients after CABG are comparatively poor compared with patients without complications. In particular, 5-year survival after CABG in HD patients with diabetes is below 50 % [4, 5]. It is impor-

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tant that treatment strategies be established that take into account the fact that such patients have a large number of risk factors that may affect their prognosis, not only in terms of ischemic heart disease but also other conditions, such as cerebrovascular disturbance in the context of systemic atherosclerosis and susceptibility to infection associated with compromised immune function.

25.2 On-Pump CABG (*ONCABG*) or Off-Pump CABG (*OPCABG*)

OPCABG is more frequently performed in Japan than in Europe and the United States. This is because of the high rate of use of PCI in Japan, meaning that patients who undergo CABG are frequently high-risk individuals, and surgeons are working in an environment where OPCABG is used proactively with the aim of avoiding perioperative complications. In Japan, where 65 % of isolated CABG procedures are performed off pump, OPCABG may be actively used to treat high-risk HD patients.

Numerous studies have found that OPCABG is advantageous for HD patients from the standpoint of perioperative mortality [6–8]; however, there is concern that fewer branches can be bypassed in OPCABG, resulting in poorer long-term results due to incomplete revascularization. According to Dewey et al. [9], although operative mortality in OPCABG is good, long-term survival for nondiabetic patients is better when ONCABG is used. The cause of these poor long-term results is the fact that the mean number of branches bypassed in ONCABG is 3.3, compared with 2.4 in OPCABG. In OPCABG it is difficult to perform bypasses to the circumflex branch region, meaning that revascularization is incomplete.

However, surgeons who are highly skilled at performing OPCABG are capable of achieving an equivalent level of revascularization to that attainable with ONCABG [10].

Beckermann's analysis of the United States Renal Disease System (USRDS) database [11] clearly shows the advantages of performing OPCABG. As OPCABG does not entail the risks of excessive fluid balance and inflammatory cytokine production that are involved in extracorporeal circulation, it may be a particularly beneficial surgical procedure for high-risk HD patients.

Reports from Japanese institutions have also shown the usefulness of OPCABG for HD patients [12–14].

The choice between ONCABG and OPCABG when performing CABG is made according to the policies of individual institutions, but in some cases, it is absolutely necessary to perform OPCABG in order to avoid the risks of extracorporeal circulation. In institutions that use conventional ONCABG as the basic surgical procedure for CABG, it may be difficult to use OPCABG only for high-risk patients, and proficiency in OPCABG must be acquired.

One point that should be noted is that many HD patients have poor left heart function, and it is not infrequent to encounter cases in which the coronary artery contains both strong calcified and weak noncalcified areas, making anastomosis difficult. Calcification of the ascending aorta makes acute on-pump conversion (an emergency switch to extracorporeal circulation should circulatory dynamics break down during OPCABG) problematic. In such patients, rather than persisting with OPCABG, the switch to ONCABG or on-pump beating CABG should be made before on-pump conversion becomes necessary.

25.3 Choice of Grafts for HD Patients

- Internal thoracic artery (ITA)

  As there is clear evidence for ITA–left anterior descending artery (LAD) grafting, the use of the left internal thoracic artery (LITA) should at least be recommended for HD patients.

  The use of both the left and right ITAs may produce even better results, but since many HD patients also have diabetes, in these patients the decision on the use of the bilateral ITAs should be made with caution in light of the risk of sternal infection and mediastinitis due to the patients' immunocompromised state. Kai et al. [12] used the bilateral ITAs in 76 of 101 HD patients and found that the 5-year cardiac event-free rate was better when both arteries were used. Nakayama et al. [15] reported that there were no cases of mediastinitis in 25 patients for whom the bilateral ITAs were used out of 77 patients who were undergoing dialysis. However, should mediastinitis once develop due to sternal dehiscence, it makes further treatment impossible. The treatment plan should be decided after risk analysis has been performed for each patient.
- Saphenous vein (SV)

  As little can be expected in terms of the long-term prognosis for HD patients after CABG, there is certainly logic to using multiple SVs. But as SVs are not necessarily of good quality in HD patients, the risk of postoperative cardiac events resulting from graft occlusion must also be borne in mind. Because the ascending aorta is also severely calcified in many patients, it is important to use an anastomosis assist devices *(PAS-Port®, HEARTSTRING III, Enclose®-II*) for the central anastomosis of the SV and to select the site of anastomosis with care.
- Right gastroepiploic artery (GEA)

  This artery is more widely used in Japan than in Europe and the United States. It is used mainly in the right coronary artery region. Similarly to use of the ITA, no central anastomosis is required, and long-term patency is good when an anastomosis is made with a highly stenotic coronary artery.

Calcifications and stenotic lesions may be present in HD patients, in which case there is the possibility that the poor properties of the GEA may make its use impossible. The GEA cannot be used if the patient uses peritoneal dialysis.

- Radial artery (RA)

  The use of the RA is, of course, contraindicated in HD patients. Its use is also contraindicated in patients who may potentially require dialysis in the future, even if they are not already undergoing HD.

25.4 Graft–Coronary Artery Anastomosis

As HD patients very often have severe calcification of the ascending aorta, the feasibility of blood transmission and the site of the SV central anastomosis must be considered in advance. In OPCABG, a blood transmission route must be secured for use in the event that on-pump conversion is required.

The coronary arteries of HD patients are characterized by severe calcification from the lateral wall to the floor and by diffuse lesions. There are few healthy sites for anastomosis. The anastomosis site must be carefully determined in the process of searching for resectable sections of the arterial wall. Even if the arterial wall is uncalcified, it is frequently weakened, meaning that a needle must be handled with great care.

25.5 Postoperative Management

Because a comparatively large transfusion volume is required in OPCABG in order to maintain intraoperative circulatory dynamics, continuous hemodiafiltration (CHDF) is used to improve the postoperative fluid balance in HD patients after OPCABG. If no attention is paid to fluid balance, pulmonary congestion may prevent the removal of patients from mechanical ventilation. Maintenance dialysis is initiated from postoperative day 2, but management should tend toward the wet side for 1 week to enable patients to recover from the invasiveness of surgery and anesthesia. In elderly patients in particular, erring on the dry side runs the risk of causing stroke due to paroxysmal atrial fibrillation, as well as intestinal ischemia.

25.6 Conclusions

The use of OPCABG reduces the incidence of perioperative complications during CABG for HD patients. When treating HD patients, it is important to assess their preoperative complications and use the most appropriate procedure for each patient. In recognizing that HD patients suffer from a systemic condition, carrying out complete revascularization by means of OPCABG may improve long-term results.

References

1. Franga DL, Kratz JM, Crumbley AJ et al (2000) Early and long-term results of coronary artery bypass grafting in dialysis patients. Ann Thorac Surg 70:813–819
2. Witczak B, Hartmann A, Svennevig JL (2005) Multiple risk assessment of cardiovascular surgery in chronic renal failure patients. Ann Thorac Surg 79:1297–1302
3. Fujimoto Y, Ishiwata S, Dohi T et al (2007) [Long-term prognosis after coronary revascularization in patients with end-stage renal disease on dialysis: comparison of percutaneous coronary intervention and coronary artery bypass grafting.]. J Cardiol 50:11–20. [Article in Japanese]
4. Szczech LA, Best PJ, Crowley E, Bypass Angioplasty Revascularization Investigation (BARI) Investigators et al (2002) Outcomes of patients with chronic renal insufficiency in the bypass angioplasty revascularization investigation. Circulation 105:2253–2258
5. Leavitt BJ, Sheppard L, Maloney C, Northern New England Cardiovascular Disease Study Group et al (2004) Effect of diabetes and associated conditions on long-term survival after coronary artery bypass graft surgery. Circulation 110(11 suppl 1):II41–II44
6. Al-Ruzzeh S, Ambler G, Asimakopoulos G, United Kingdom Multi-Center Comparative Analysis of Early Clinical Outcome et al (2003) Off-pump coronary artery bypass (OPCAB) surgery reduces risk-stratified morbidity and mortality: a United Kingdom Multi-Center Comparative Analysis of Early Clinical Outcome. Circulation 108(suppl 1):II1–II8
7. Reston JT, Tregear SJ, Turkelson CM (2003) Meta-analysis of short-term and mid-term outcomes following off-pump coronary artery bypass grafting. Ann Thorac Surg 76:1510–1515
8. Ascione R, Nason G, Al-Ruzzeh S et al (2001) Coronary revascularization with or without cardiopulmonary bypass in patients with preoperative nondialysis-dependent renal insufficiency. Ann Thorac Surg 72:2020–2025
9. Dewey TM, Herbert MA, Prince SL et al (2006) Does coronary artery bypass graft surgery improve survival among patients with end-stage renal disease? Ann Thorac Surg 81:591–598
10. Puskas JD, Williams WH, Duke PG et al (2003) Off-pump coronary artery bypass grafting provides complete revascularization with reduced myocardial injury, transfusion requirements and length of stay: a prospective randomized comparison of two hundred unselected patients undergoing off-pump versus conventional coronary artery bypass grafting. J Thorac Cardiovasc Surg 125:797–808
11. Beckermann J, Van Camp J, Li S et al (2006) On-pump versus off-pump coronary surgery outcomes in patients requiring dialysis: perspective from a single center and the United States experience. J Thorac Cardiovasc Surg 131:1261–1266
12. Kai M, Okabayashi H, Hanyu M et al (2007) Long-term results of bilateral internal thoracic artery grafting in dialysis patients. Ann Thorac Surg 83:1666–1671
13. Tashiro T, Nakamura K, Morishige N et al (2002) Off-pump coronary artery bypass grafting in patients with end-stage renal disease on hemodialysis. J Card Surg 17:377–382
14. Hirose H, Amano A, Takahashi A (2001) Efficacy of off-pump coronary artery bypass grafting for the patients on chronic hemodialysis. Jpn J Thorac Cardiovasc Surg 49:693–699
15. Nakayama Y, Sakata R, Ura M et al (2003) Long-term results of coronary artery bypass grafting in patients with renal insufficiency. Ann Thorac Surg 75:496–500

Part IV

Teaching and Training

How Do We Teach Off-Pump Surgery to the Next Generation?

26

Kiyoshi Doi and Hitoshi Yaku

Abstract

Comprehensive training of young surgeons is essential nowadays as the complexity of surgical techniques is increasing. This study aims to investigate the current situation of training and assessment of procedural skills in performing the off-pump coronary artery bypass. Since this procedure is technically more demanding than the conventional on-pump coronary artery bypass, some insist that off-pump surgery be performed only by experienced surgeons. However, most trainees believe that off-pump skills are necessary to be acquired during training. Experienced surgeons have demonstrated that the off-pump technique can be safely taught to trainees with no experience of the on-pump technique. These trainings have been performed gradually, where the first step is usually practicing distal anastomoses of coronary arteries located in the anterior wall of the heart and the subsequent step involves the inferior/lateral wall. At least 80–100 off-pump cases and 2 years of training seem essential for achieving proficiency. Control charts have been widely used to assess outcomes not only in retrospective studies but also for prospective monitoring of training. We also found that simulation-based training is currently a prerequisite at all high-reliability organizations, and therefore, cardiac surgical faculties plan to incorporate it into their formal curricula.

Keywords

Off-pump training • Control chart • Simulator

26.1 Introduction

Although numerous studies have demonstrated that off-pump coronary artery bypass (OPCAB) is the preferred strategy for revascularization in most patients, the adoption rate of OPCAB varies even among experienced surgeons. The main reason for this is the technical difficulty of this surgery, wherein a surgeon needs to saw moving vessels in pools of blood. On the other hand, in conventional on-pump coronary artery bypass (ONCAB), the surgeon works in a stable bloodless field.

According to a survey in the United States, 98 % of cardiothoracic residents had some interest in OPCAB, and 94 % of them believed that it is necessary to acquire off-pump skills during training [1]. However, the technical challenges of OPCAB have raised concerns about possibly worse outcomes during junior surgeons' learning curves, and most trainees may have experienced only a small number of OPCAB cases during training.

Because OPCAB has evolved significantly over the past decade, some experienced pioneer surgeons have taught their younger colleagues how to perform this technique. Additionally, the safety and efficacy of teaching OPCAB to trainee surgeons has been reported in several studies [2–4], although structured and evidence-based educational programs have not been indicated.

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The reproducibility of a new technique can only be ensured by teaching it to the next generation. A good surgery should be easy to learn and teach and thereby be accepted by most surgeons [5]. Without training of the next generation of surgeons and continuous refinements, new procedures could never be proven effective or be widely accepted in clinical practice [6]. Thus, it is undoubtedly essential to expose trainees to OPCAB techniques, which are an integral part of modern coronary surgery.

The aim of this article is to review the literature on the training and assessment of procedural skills in performing the OPCAB technique. We also discuss the future of OPCAB training curricula including new technologies such as surgical simulators.

26.2 Prerequisites for OPCAB Training

26.2.1 Trainee's Prerequisites

Thus far, there have been no definite qualifications required by trainees to start OPCAB training. Studies on the OPCAB learning curve have largely been limited to surgeons who are proficient in conventional CABG surgery and have focused on the safety of conversion from ONCAB to OPCAB [5]. It seems appropriate, and probably beneficial, for a junior surgeon to be the primary surgeon to experience more than 100 cases of ONCAB surgery before progressing to OPCAB training [6, 7]. However, Caputo et al. demonstrated that both OPCAB and ONCAB techniques could be safely taught to cardiothoracic residents simultaneously [8]. Further, at hospitals where most coronary revascularizations are performed using the OPCAB technique, many residents have performed off-pump distal anastomoses before sewing distal anastomoses on arrested hearts [9]. As previous studies have indicated, cardiothoracic trainees with stronger surgical backgrounds were able to grasp the supervising surgeon's instructions quickly and were confident about their proficiency in OPCAB surgery [1, 5]. Nonetheless, any surgeon who has adequate experience in establishing and managing the cardiopulmonary bypass (CPB) technique is qualified to participate in the OPCAB training program [5].

26.2.2 Institutional Prerequisites

Provided that OPCAB procedures are sporadically used by teaching institutions, the training programs for these techniques remain unchanged and mainly focus on the ONCAB technique. However, if coronary surgery is routinely performed without CPB, it is necessary to modify training as well as surgical, anesthesiological, and nursing procedures and technology. The proficiency of the teaching supervising surgical trainer is undoubtedly essential to the success of the training program, and the OPCAB training program should be limited to institutions that perform a large number of these operations each year [10]. However, when the OPCAB technique has been fully established, it can be safely taught to junior surgeons even in an ordinary non-teaching hospital [4].

26.3 Standardization of OPCAB Training

Any complex surgical procedures can be systematically decomposed into multiple components. The clinical training phase usually consists of a training program in which the steps gradually increase in complexity: the procedure is first observed as it is conducted by a senior surgeon; simple procedure components are then performed by the trainee, followed by more technically demanding components; and finally the trainee performs the entire procedure [11].

As mentioned before, if OPCAB surgery is to be a standard procedure, its training program should be easy to teach and learn. Therefore, we describe the procedural components of the OPCAB technique and discuss the sequence of steps as an aspect of a gradual training program.

26.3.1 Acquisition of the Knowledge Required for OPCAB

Before practicing the OPCAB procedure as a primary surgeon, trainees should serve as the first assistant for an appropriate period in order to improve their knowledge of OPCAB. They need to learn not only the sequence of the procedures but also how to judge the patient's ability to tolerate heart manipulation. Their ability to communicate well with the entire operative team is critical as well.

26.3.2 Procedural Components of OPCAB

The OPCAB procedure is simply divided into the exposure, stabilization, and anastomosis components (Fig. 26.1). In contrast to what is commonly thought, construction of distal anastomoses on the beating heart does not always represent the most difficult component of the operation. Once ideal exposure and stabilization is accomplished, even a junior surgeon can perform OPCAB easily.

26.3.2.1 Exposure (Patient and Heart Positioning)

Trainees should first become familiar with the technique of exposure of the target coronary arteries with simultaneous maintenance of adequate hemodynamics. The operating table can be rotated to facilitate exposure of the lateral/inferior wall of the heart.

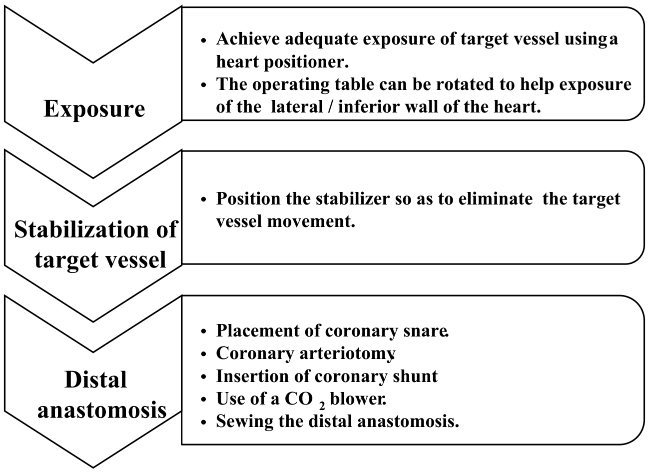

Fig. 26.1 Procedural components of OPCAB

26.3.2.2 Stabilization of the Target Vessels

The next important step is learning the techniques for positioning the stabilizer so as to eliminate target vessel movement.

26.3.2.3 Performing Distal Anastomosis on the Beating Heart

This step is further divided into five subcomponents, and the trainee needs to learn the proper sequence of these five steps.

1. *Placement of the coronary snare*: An elastic suture is placed for temporal occlusion of the target coronary artery.
2. *Coronary arteriotomy*
3. *Insertion of the intracoronary shunt*: This step provides a bloodless operative field, increases distal perfusion, and decreases the likelihood of technical errors.
4. *Use of a CO_2 blower*: This helps to maintain a bloodless operative field and is usually managed by the assistants.
5. *Sewing of the distal anastomosis*

26.3.3 Training in a Gradual Manner

According to previous reports, OPCAB training usually starts with practicing the performance of distal anastomoses of coronary arteries located in the anterior wall of the heart and then gradually progresses to distal anastomoses of coronary arteries located in the inferior/lateral wall. This is in contrast to ONCAB training, in which anastomoses on the entire territory of the heart are simultaneously practiced right from the beginning [5, 9].

Initially, all procedures are performed under direct guidance of the supervising surgeon. The trainees later graduate to independent performance of OPCAB surgery and finally serve as OPCAB surgeons, without any intervention by the supervising surgeon.

At the beginning of the training course, the heart-lung machine can be on standby as a safety measure.

The manner in which trainees graduate through the training program is not only indicated in the learning process of technical skills but also in patient selection. The trainees are usually allocated relatively simple cases when they first independently perform surgeries. Once they gain experience, they may be allocated high-risk cases, such as patients with impaired left ventricular function or unstable hemodynamics. For training, careful patient selection by experienced OPCAB surgeons is essential to ensure patient safety and good outcomes [9].

Trainees also need to learn crisis management. This includes assessment of the hemodynamic condition, correcting hemodynamic instability by discussion with the anesthetist, and conversion to ONCAB if necessary.

26.3.4 Adequate (Required) Training Duration and Extent

Proficiency is often linked to operative experience, although the number of practice cases required is unclear and appears to differ among training systems. In terms of ONCAB procedures, a cardiothoracic resident in the United States requires at least 35 cases for accreditation, while in the United Kingdom, over 100 cases is the norm [3]. However, no formal training curriculum has identified the exact number of procedures and duration of training required for acquisition of the skills needed to perform OPCAB.

The entire training process can be divided into three stages. During the first stage, trainees serve as the first assistant whereby they obtain knowledge of the OPCAB procedure. In the second stage, they practice OPCAB as the primary surgeon under close supervision. The third stage is the period in which the trainees perform OPCAB surgery without supervision (Fig. 26.2).

As mentioned before, trainees usually start practicing distal anastomoses in the anterior wall of the heart, move to the inferior/lateral wall, and finally perform multivessel anastomoses over the entire territory of the heart. Ricci et al. reported that approximately 15–20 OPCAB operations are generally required before residents can perform complete multivessel myocardial revascularization under supervision [1].

Chen et al. trained two young cardiac surgeons who had no previous coronary surgery experience to be independent OPCAB operators [5]. Their training took 24–28 months. During the first stage, the two trainees served as the first assistant in 300–400 OPCAB procedures. After practicing OPCAB under supervision, the trainees started to perform the procedure independently. Performance analysis showed

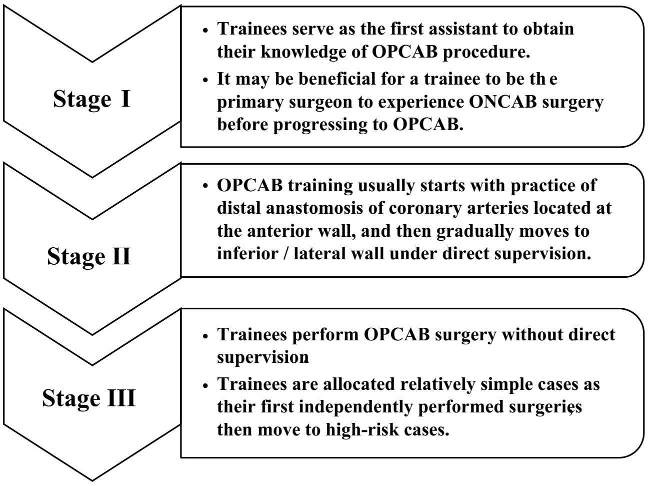

Fig. 26.2 Graduated training process

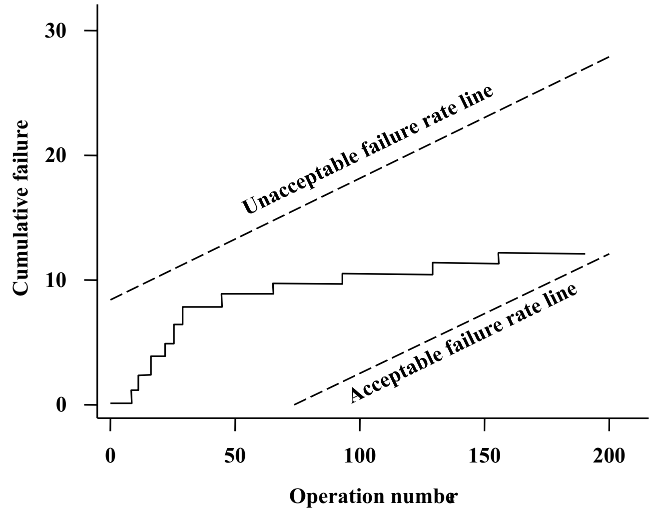

Fig. 26.3 Cumulative failure chart. X-axis denotes consecutive cases of operation. Y-axis denotes the cumulative sum of a specified outcome or failure. If the graph of cumulative failure crosses the upper boundary, the performance is concluded to be unacceptable. If it crosses the lower boundary, the performance is considered to be acceptable

that the trainees reached the proficiency standard after performing 30 surgeries independently.

At the Bristol Heart Institute in the United Kingdom, the training period lasts 6 years. At the first stage, trainees assist senior surgeons for 40–50 OPCAB procedures. Then they move to the second stage. By the end of the third year, trainees perform 30–40 surgeries as the primary surgeon under direct supervision, and proficiency is obtained after 80–100 OPCAB operations. In the last 2 years of training, as the third stage, the trainees are allowed to perform unsupervised operations [10].

26.3.5 Validation of Proficiency

As described before, the OPCAB procedure is technically demanding, and trainees face a steep learning curve. Although senior surgeons are aware of the importance of training young surgeons, they also have an overriding responsibility toward patient safety and good clinical outcomes.

Recently, statistical techniques are increasingly advocated as a means of ensuring quality control and reproducible outcomes. The control chart is one such statistical technique and has been used as a performance monitoring tool for surgical learning curves. By providing a graphic summary of changes in performance with time, control charts can provide alerts regarding suboptimal performance [8].

Cumulative sum failure analysis is the most basic control chart, and modifications of this tool have been employed in several learning curve studies regarding OPCAB surgery [3, 5, 12]. This chart is obtained by plotting the cumulative sum of a specified outcome or failure on the Y-axis versus the sequence of cases on the X-axis. An increase in the gradient (slope) indicates more frequent failures. Further, acceptable and unacceptable failure rate lines can be calculated and drawn [13]. If the graph of cumulative failure crosses the upper boundary (unacceptable failure rate line), then we conclude that the failure rate is unacceptable. If it crosses the lower boundary (acceptable failure rate line), we conclude that the failure rate is less than or equal to the acceptable rate. When a graph remains between these boundaries, the evidence remains inconclusive, and monitoring should continue (Fig. 26.3). Thus, the control chart can be used not only for retrospective studies but also for prospective monitoring of training. When a trainee's cumulative curve goes beyond the alert line, the trainee and supervisor need to look into performance-related problems.

A previous study using the control chart method indicated that residents' curves crossed the acceptable boundary after 100 OPCAB cases [3]. Chen et al. also found that trainees' curves reached a plateau after 30 OPCAB cases and crossed the acceptable boundary after 80 OPCAB cases [5].

26.4 OPCAB Training Using Simulators

The traditional model of surgical training has relied on a process of protracted exposure to supervised operations, because a trainee needs to graduate from simple procedures to complex entire surgical cases to achieve proficiency. However, this model is becoming less ideal because of ethical concerns and the increasing number of high-risk patients who require more complex procedures. Especially in coronary artery revascularization, an increasing proportion of patients is treated using catheter intervention, and surgeons encounter patients with severely calcified small arteries and poor left ventricular function. As a result, it is becoming difficult to provide suitable OPCAB training opportunities for young surgeons.

At present, simulation-based training is a prerequisite for all high-reliability organizations such as those in the airline, military, and nuclear industries. With regard to cardiac surgical education, surgical training using a simulator is in the nascent stages. Surgeons expect that these surgical simulators not only improve trainees' technical skills but also provide opportunities for situational training such as crisis management. Further, simulator-based training curricula are expected to enable assessment of competence in technical skills.

26.4.1 Currently Reported OPCAB Simulation Models

Izzac et al. developed a "beating-heart" coronary artery anastomosis simulator. In their model, a porcine mammary artery is mounted on a floating platform, which mimics the pericardial surface. A motor underneath the platform carries projecting wheels, which intermittently elevate the platform with the rotations of the motor. Trainees can practice anastomosis of the mammary artery on the beating platform. The authors found that this device was useful in preparing their trainees for OPCAB surgery [14] (Fig. 26.4a).

Fann et al. developed a beating-heart model constructed of silicone and connected to a controller and external compressor. For anastomosis practice, 2-mm synthetic coronary arteries were mounted on the silicone heart. The heart was

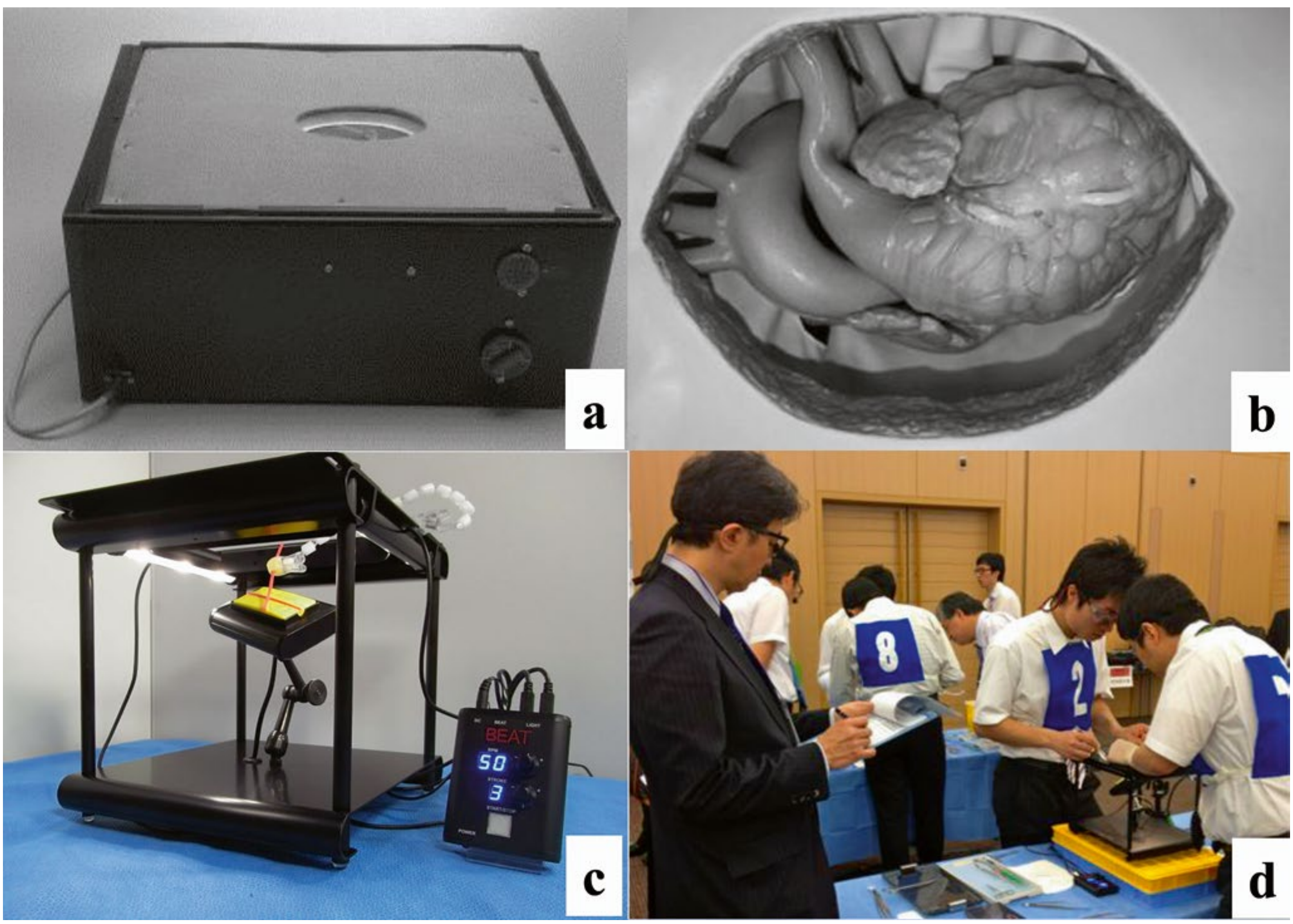

Fig. 26.4 (**a**) A "beating-heart" coronary artery anastomosis simulator developed by Izzac et al. A porcine mammary artery is mounted on a floating platform, which intermittently oscillates with the rotation of a motor mimicking the beating heart. (**b**) A beating-heart model reported by Fann et al. It is constructed of silicone and connected to a controller and external compressor. Synthetic 2-mm target coronary arteries are embedded in the myocardium. (**c**) "BEAT, YOUCAN" system consists of a pink silicone internal mammary artery model and coronary artery model embedded in a yellow silicone beating plate. (**d**) The "BEAT, YOUCAN" system was used in an OPCAB anastomosis skill competition organized for young surgeons by a cardiac surgical faculty in Japan

placed in a plastic torso simulating the pericardial well. The authors used this model for an educational program. Trainees practiced coronary anastomoses, and their skills were evaluated on the basis of the time to completion of anastomosis. Their performance was also scored using an objective structured assessment of technical skill (OSATS) tool. The analysis showed that simulation-based training improved majority of the residents' performance [15] (Fig. 26.4b).

Ito et al. evaluated the utility of the novel OPCAB simulator system "BEAT, YOUCAN" (EBM, Tokyo, Japan). In this system, a synthetic coronary artery is mounted on a silicone plate, which is attached to an oscillating metal arm. The performance of trainees was analyzed, and the time for completion of anastomosis and performance score were found to improve with practice, although they reached a plateau at approximately the 30th anastomosis [16] (Fig. 26.4c). This system was also used in an OPCAB anastomosis skill competition organized for young surgeons by a cardiac surgical faculty in Japan (Fig. 26.4d).

26.4.2 Development of a Nationwide OPCAB Training Program

Simulation-based training provides deliberate and distributed practice in a less stressful environment and may enable gradual training for the development of technical skills. Therefore, cardiac surgical communities are planning to incorporate the simulation-based learning and assessment into formal nationwide training programs. For example, in the United States, the Thoracic Surgery Residency Review Committee has mandated that all residency programs include some form of simulation training, and the American Board of Thoracic Surgery has mandated that residents have a minimum of 20 h of simulation training during their residency [17].

Given the multitude of cardiac procedures performed today such as mitral valve repair and aortic root replacement, how do we decide which procedure is required or suitable for simulation-based training? Baker et al.'s survey identified beating-heart coronary anastomosis to be the most important procedure among 54 common cardiac surgical procedures [18].

In order to design a simulation-based gradual learning curriculum, we need to understand the individual steps that comprise the entire surgical procedure and our ability to assess the progress of the learner. For this purpose, Cristancho et al. proposed performance assessment checklists for simulation-based OPCAB training programs [19]. However, performance within the operating room depends not only on technical skills but also on cognitive integration, judgment, and complex interactions among team members. Therefore, a good performance score, which is rated using the assessment checklists, may not imply the ability to perform a procedure independently in the operating room. More work is required to demonstrate the correlation between performance on the simulator models and that in the operating room. In the future, simulation-based training may provide a metric by which educators can ensure a definite level of proficiency before allowing trainees to safely perform such procedures in clinical settings [20]. Once reliable tools are developed and universally adopted, assessment using the simulator model could be applied to proficiency-based advancement in trainees' surgical careers [21].

26.5 Conclusion

Despite technical difficulties, both junior and senior cardiac surgeons perceive OPCAB as an essential procedure and believe that not only knowledge but also practical skills should be acquired during the training period. Several studies have demonstrated that OPCAB can be safely taught to every junior trainee under the supervision of experienced surgeons. Cardiac surgical faculties also recognize the importance of OPCAB training and plan to construct a formal training curriculum. Although the use of simulator models allows trainees to learn the OPCAB procedure under a stress-free environment, further studies are required to validate the efficacy and feasibility of this new teaching modality.

References

1. Ricci M, Karamanoukian HL, D'Ancona G et al (2000) Survey of resident training in beating heart operations. Ann Thorac Surg 70:479–482
2. Karamanoukian HL, Panos AL, Bergsland J et al (2000) Perspectives of a cardiac surgery resident in-training of off-pump coronary bypass operation. Ann Thorac Surg 69:42–46
3. Murphy GJ, Rogers CA, Caputo M et al (2005) Acquiring proficiency in off-pump surgery: traversing the learning curve, reproducibility, and quality control. Ann Thorac Surg 80:1965–1970
4. Messina A, Villa E, Mhagna Z et al (2010) Medium-term results of systematic off-pump coronary surgery performed by trainee surgeons. Eur J Cardiothorac Surg 38:380–386
5. Chen Y, Wan F (2009) Off-pump coronary artery bypass graft surgery: a training course for novices and its learning curve. Thorac Cardiovasc Surg 57:141–147
6. Jenkins D, Al-Ruzzeh S, Khan S et al (2003) Multivessel off-pump coronary artery bypass grafting can be taught to trainee surgeons. J Card Surg 18:419–424
7. Asimakopoulos G, Karagounis AP, Valencia O et al (2006) How safe is it to train residents to perform off-pump coronary artery bypass surgery? Ann Thorac Surg 81:568–572
8. Caputo M, Reeves BC, Rogers CA et al (2004) Monitoring the performance of residents during training in off-pump coronary surgery. J Thorac Cardiovasc Surg 128:907–915
9. Halkos ME, Puskas JD (2009) Teaching off-pump coronary artery bypass surgery. Semin Thorac Cardiovasc Surg 21:224–228

10. Murzi M, Caputo M, Aresu G et al (2012) Training residents in off-pump coronary artery bypass surgery: a 14-year experience. J Thorac Cardiovasc Surg 143:1247–1253
11. Lodge D, Grantcharov T (2011) Training and assessment of technical skills and competency in cardiac surgery. Eur J Cardiothorac Surg 39:287–294
12. Novick RJ, Fox SA, Stitt LW et al (2002) Assessing the learning curve in off-pump coronary artery surgery via CUSUM failure analysis. Ann Thorac Surg 73:S358–S362
13. Rogers CA, Reeves BC, Caputo M et al (2004) Control chart methods for monitoring cardiac surgical performance and their interpretation. J Thorac Cardiovasc Surg 128:811–819
14. Izzat MB, El-Zufari MH, Yim APC (1998) Training model for "beating-heart" coronary artery anastomoses. Ann Thorac Surg 66:580–581
15. Fann JI, Caffarelli AD, Georgette G et al (2008) Improvement in coronary anastomosis with cardiac surgery simulation. J Thorac Cardiovasc Surg 136:1486–1491
16. Ito J, Shimamoto T, Sakaguchi G et al (2013) Impact of novel off-pump coronary artery bypass simulator on the surgical training. Gen Thorac Cardiovasc Surg 61:270–273
17. Vaporciyan AA, Yang SC, Baker CJ et al (2013) Cardiothoracic surgery residency training: past, present, and future. J Thorac Cardiovasc Surg 146:759–767
18. Baker CJ, Sinha R, Sullivan ME (2012) Development of a cardiac surgery simulation curriculum: from needs assessment results to practical implementation. J Thorac Cardiovasc Surg 144:7–16
19. Cristancho S, Moussa F, Dubrowski A (2012) Simulation-augmented training program for off-pump coronary artery bypass surgery: developing and validating performance assessments. Surgery 151:785–795
20. Lee R, Enter D, Lou X et al (2013) The joint council on thoracic surgery education coronary artery assessment tool has high interrater reliability. Ann Thorac Surg 95:2064–2070
21. Fann JI, Feins RH, Hicks GL et al (2012) Evaluation of simulation training in cardiothoracic surgery: the senior tour perspective. J Thorac Cardiovasc Surg 143:264–272

Part V

Future Perspectives: What Comes Next?

27 Hybrid Approach (OPCAB+PCI/TAVI/Debranching TEVAR)

Shigeyuki Tomita and Go Watanabe

Abstract

Hybrid coronary artery revascularization (HCR) is an alternative therapy that combines advantages of coronary artery bypass grafting (CABG) and percutaneous coronary intervention (PCI) in patients with multivessel coronary artery disease. The potential advantages of the HCR depend on the proven long-term survival advantage of left internal mammary artery (LIMA) to left anterior descending (LAD) without full sternotomy and cardiopulmonary bypass and the benefits of PCI with drug-eluting stent (DES) in non-LAD lesion. Over the last 10 years, many studies of HCR have reported the feasibility and availability of this procedure with lower blood transfusion rates, lower complications, and faster postoperative recovery. However, ideal patient population, the timing of both procedure, and long-term outcomes including the cost-effectiveness remain unknown. In this chapter, we comment on the current HCR procedure including indication, procedure (single or two stages), outcomes, and future including other hybrid surgeries combined with transcatheter aortic valve implantation (TAVI) or thoracic endovascular aortic repair (TEVAR). Moreover, we emphasize the importance of the close Heart Team for the treatment of the HCR.

Keywords

Hybrid coronary artery revascularization • Coronary artery disease • Minimally invasive direct coronary artery bypass surgery • HCR • MIDCAB • TAVI • TEVAR

27.1 Introduction

The concept of an integrated hybrid coronary artery revascularization (HCR) appeared first in the mid-1990s [1] and was defined as the combination of surgical left internal mammary artery (LIMA) to left anterior descending (LAD) grafting and percutaneous coronary intervention (PCI) to non-LAD coronary lesions in selected patients with multivessel coronary artery disease. The potential advantages of HCR are superior long-term patency of LIMA to LAD bypass with predominant consensus and the conveniences of PCI [2–4]. Of course, the bypass of LIMA to LAD is carried out via left mini thoracotomy, so-called minimally invasive direct coronary artery bypass surgery (MIDCAB) [5]. MIDCAB without a full sternotomy and cardiopulmonary bypass can reduce blood transfusion, lengths of intubation, ICU stay, and also hospital stay. On the other hand, PCI is an established technique with improvements and progress for coronary revascularization, especially the outcomes of PCI therapy that have been satisfactory with lower restenosis rate of PCI site after the induction of drug-eluting stent (DES) [6,7]. Recently, midterm outcomes of larger series of HCR have been reported in some literatures. There are some differences in operative strategies; however, the results of outcomes including graft patency, reintervention rates, and freedom from major adverse cardiac and cerebral events (MACCE) are acceptable [2, 8–12]. HCR provides an

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alternative option for some clinically high-risk patients with multivessel coronary artery disease.

27.2 Indication of Hybrid Procedure and the Role of a Heart Team

As suggested in the 2011 American College of Cardiology Foundation/American Heart Association Guideline for PCI, hybrid revascularization is reasonable in patients with one or more of the following (*Level of Evidence: B*): (a) limitations to traditional coronary artery bypass grafting (CABG), such as heavily calcified proximal aorta or poor target vessels for CABG (but amenable to PCI), (b) lack of suitable graft conduits, and (c) unfavorable LAD artery for PCI [13].

The classical indication for HCR is multivessel coronary disease including LAD lesion which is favorable for LIMA to LAD surgical bypass but unfavorable for PCI with amenable non-LAD lesions. Preoperative high-risk patients with malignancy, severe diabetes mellitus, carotid stenosis, or cerebral infarction may obtain some benefits from the avoidance of cardiopulmonary bypass and full sternotomy. In hybrid procedure, LIMA to LAD bypass is performed in MIDCAB fashion or robotically endoscopic fashion through left thoracic cavity with prolonged single-lung ventilation. Therefore, the patients with severe lung disease, small thoracic cavity or obesity are contraindicated. In anatomical factors of indication for HCR, patients have no stenosis of left subclavian artery and also LIMA. Hemodynamic instability, acute coronary syndrome, and redo surgery are contraindications for HCR at present.

A Heart Team approach is very important to perform HCR with feasible outcomes and low complications [13,14]. A Heart Team composed of institutionalized interventional cardiologists and cardiac surgeons should (1) review the patient's medical condition and coronary anatomy, (2) determine that PCI and LIMA to LAD bypass are technically feasible and reasonable, (3) discuss revascularization options with the patient before a treatment strategy is selected, and (4) follow postoperative course including antiplatelet therapy [12]. The treatment discussion by this interdisciplinary team finally provides optimal strategies according to the individual patient's anatomy and risk factors.

27.3 Single-Stage Hybrid Procedure

27.3.1 Minimally Invasive Coronary Artery Bypass

All operations are performed under general anesthesia with double-lumen tube intubation. The patients are placed in the supine position with the left chest elevated by approximately

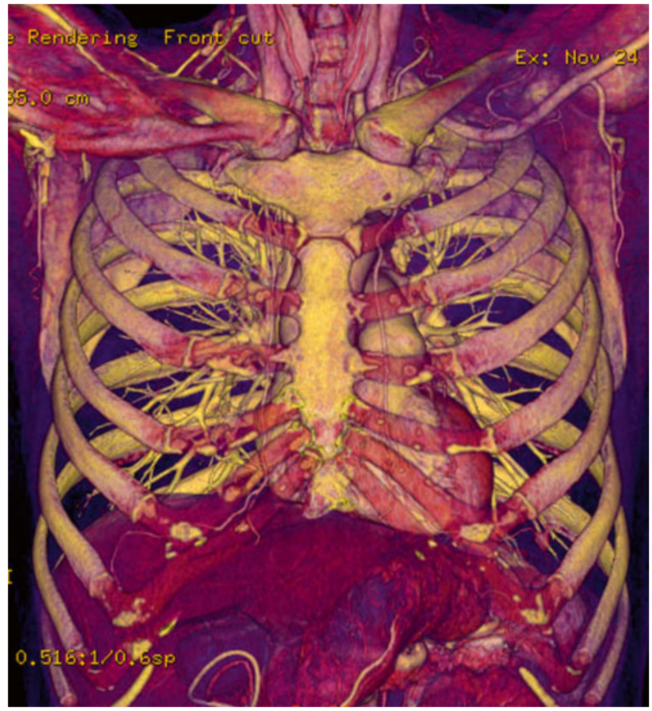

Fig. 27.1 Preoperative enhanced 3-dimensional computed tomography (3DCT) shows the precise course of both internal mammary artery and a left anterior descending artery

20°–30°. External defibrillator patches are placed on patient's chest wall preoperatively. Preoperative enhanced 3-dimensional computed tomography (3DCT) is very useful to know precise anatomical relations of LIMA and LAD (Fig. 27.1). LIMA is harvested through the left mini thoracotomy under direct vision or with the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA). In many recent reports, LIMA was harvested endoscopically with the da Vinci surgical system. After heparinization (1 mg/kg), the pericardium is opened and the LAD is exposed. The distal anastomosis of in situ LIMA to LAD grafts is carried out using off-pump beating heart techniques. There are two techniques of performing anastomosis: one is a manual anastomosis through small left skin incision, and the other is an anastomosis through thoracic ports with the da Vinci surgical system. The details of robotically LIMA to LAD anastomosis are described in the next chapter. After anastomosis, it is desirable to confirm all graft flows by transit-time Doppler assessment. The surgical procedure is ended with skin closure.

27.3.2 Percutaneous Coronary Intervention

In single-stage hybrid procedure, the PCI is performed immediately after surgical procedure in collaboration with the interventional cardiology team. Angiographic patency and quality of the LIMA to LAD graft are assessed, and then PCI for the non-LAD lesion is performed with either a bare metal stent (BMS) or drug-eluting stent (DES). A 300-mg loading dose of clopidogrel is administered through a nasogastric tube before the PCI procedure.

After the procedure, it is recommended that patients of DES implantation receive dual antiplatelet therapy with aspirin and clopidogrel for at least 1 year.

27.4 Single-Stage or Two-Stage Procedure?

The indication for single- or two-stage procedure still remain controvertial. In the ACC/AHA guideline for PCI, it is mentioned that hybrid coronary revascularization may be performed in a hybrid suite in one operative setting or as a staged procedure. This guideline also recommends that bypass surgery before PCI is preferred in the staged procedure, because this approach allows the interventional cardiologist to (1) verify the patency of the LIMA to LAD artery graft before attempting PCI of other vessels and (2) minimize the risk of perioperative bleeding that would occur if CABG were performed after PCI. The two-stage procedure was performed in the initial reports of hybrid procedure, and the benefits of this procedure are an avoidance of potentially postoperative breeding caused by longer operation time and administration of antiplatelets as in single-stage approach. However, a single-stage procedure has been performed widespread in many recent reports because of increasing facilities of the integrated hybrid operating rooms. The hybrid operation rooms can minimize the transference of the patients and also anesthesia time. Recent reports of the single-stage procedure described lower bleeding and blood requirements despite continuous use of dual aspirin and clopidogrel. If a hybrid operating room is set, the single-stage hybrid procedure is recommended for the advantages of maximal availability and minimum risk.

27.5 Outcomes of Hybrid Procedure

27.5.1 Midterm Outcomes

To date, no randomized control trials involving HCR have been published. Several retrospective series with midterm follow-up outcomes of HCR have reported survival rates of 84–93 % at 3–5 years and MACCE-free survival rates of 75–91 % at 3–5 years of follow-up in Table 27.1 [8–12, 15].

27.5.2 Hybrid Procedure vs. OPCAB

Only three studies which compared HCR with OPCAB were reported (Table 27.2) [8, 9, 16]. In these studies, blood transfusion requirements were reduced and intubation time and ICU stay were shorter in the HCR groups compared with the OPCAB groups. Furthermore, in-hospital MACCE rates were lower in the HCR groups. The HCR procedure may shorten hospital stay with less postoperative complications.

27.5.3 Cost Issues

Currently, a few papers discussed the costs of the HCR compared with OPCAB. These papers described the intraoperative costs were significantly higher in the HCR than OPCAB due to the PCI procedure and longer operative times, and on the other hand, postoperative costs were lower than OPCAB due to shorter ICU and hospital stay [16, 17]. Especially, operation time is longer in the robotically total endoscopic coronary artery bypass (TECAB) than standard MIDCAB. Shortening of operation time in TECAB will be necessary to reduce the whole costs of HCR.

Table 27.1 Systematic review of studies evaluating hybrid revascularization

Author (reference)	Date	*N*	Age	Follow-up (months)	Strategy	Surgical procedure	MACCE-free survival (%)	Mortality (%)	PCI
Halkos et al. [9]	2011	147	64.3 ± 12.8	38.4 (median)	Mainly staged	Endo-ACAB	86	0.7	DES
Bonatti et al. [10]	2012	226	61 (31–90)		Mainly staged	Arrested-heart TECAB	75.2	0	DES/BMS/PTCA
Repossini et al. [15]	2013	166	65.8 ± 10.3	54 ± 27.6	Staged	MIDCAB	83	1.2	BMS/DES
Adams et al. [12]	2013	96	64 ± 12	65.5 ± 8.4	Simultaneous	Robotic MIDCAB	NR	0	DES/BMS
Shen et al. [11]	2013	141	62.0 ± 9.9	36 (mean)	Simultaneous	MIDCAB	93.6		DES

Unless otherwise indicated, data are expressed as mean ± standard deviation
N number, *MACCE* major adverse cardiac and cerebral events, *Endo-ACAB* endoscopic atraumatic coronary artery bypass, *TECAB* totally endoscopic coronary artery bypass, *MIDCAB* minimally invasive direct coronary artery bypass, *DES* drug-eluting stent, *BMS* bare metal stent, *PTCA* percutaneous transluminal coronary angioplasty, *NR* not reported

Table 27.2 Postoperative outcomes: hybrid vs. OPCAB

	Halkos et al. [9]		Hu et al. [8]		Bachinsky et al. [16]	
Outcome	Hybrid (n = 147)	OPCAB (n = 588)	Hybrid (n = 104)	OPCAB (n = 104)	Hybrid (n = 25)	OPCAB (n = 27)
Age (years)	64.3 ± 12.5	64.3 ± 12.8	61.8 ± 10.2	62.4 ± 8.0	63.2 ± 10.5	66.8 ± 10.7
Hospital stay (days)	6.6 ± 6.7	6.1 ± 4.7	8.2 ± 2.6*	9.5 ± 4.5*	5.1 ± 2.8*	8.19 ± 5.4*
ICU stay (hours)	57.4 ± 145.0	52.7 ± 87.8	34.5 ± 35.6**	55.3 ± 46.4**	28.5 ± 13.9	57.89 ± 84.7
Intubation time (hours)	17.0 ± 30.8	22.7 ± 89.5	11.6 ± 6.3*	13.8 ± 6.8*	NR	NR
Blood transfusion	52(34.4)**	329(56.0)**	30(28.8)**	54(51.9)**	3(12)**	18(67)**
In-hospital MACCE	3(2.0)	12(2.0)	0(0)	0(0)	0(0)	1(4)
Death	1(0.7)	5(0.9)	0(0)	0(0)	0(0)	1(4)
Stroke	1(0.7)	4(0.7)	0(0)	0(0)	0(0)	0(0)
MI	1(0.7)	3(0.5)	0(0)	0(0)	0(0)	0(0)
Atrial fibrillation	109(18.5)	29(20.1)	12(11.5)	7(4.8)	4(16)	8(30)

All values represent mean ± SD or number (%)
CABG coronary artery bypass, *OPCAB* off-pump coronary artery bypass, *ICU* intensive care unit, *MACCE* major adverse cardiac and cerebral events, *MI* myocardial infarction, *N* not reported
**P* value < 0.05; ***P* value < 0.005

27.5.4 Limitation

Many reports of the HCR were retrospective investigation with small number and varied in methods of the HCR. Further studies including prospective randomized trials compared with PCI or OPCAB are needed to determine the patient population which would gain maximum benefit by taking the HCR.

27.6 The Future of Hybrid Procedure

27.6.1 OPCAB+TAVI

Some cases of coronary artery disease (CAD) are accompanied with severe aortic stenosis (AS), and both diseases are similar to their pathophysiological development mechanisms. The 2011 ACCF/AHA Guideline for Coronary Artery Bypass Graft Surgery recommends that patients undergoing CABG who have at least moderate aortic stenosis should have concomitant aortic valve replacement (Class 1) and patients undergoing CABG who have mild aortic stenosis may be considered for concomitant aortic valve replacement when evidence (e.g., moderate–severe leaflet calcification) suggests that progression of the aortic stenosis may be rapid and the risk of the combined procedure is acceptable (Class 2b). The number of patients undergoing concomitant CABG and aortic valve replacement (AVR) doubled over the last decade. However, there are many cases where cardiac surgeons hesitate to perform AVR in CABG patients with high risks such as low cardiac function, severe aortic calcification, carotid stenosis, and previous stroke. On the other hand, severe AS in patients with previous CABG troubles surgeons in operative indications because of the injury for patent grafts and AVR for such patients is associated with high comorbidities and mortality compared with isolated AS patients. Transcatheter aortic valve implantation (TAVI) has been introduced and evolved as an alternative surgical strategy for these high-risk patients. The increasing TAVI experiences along with device impovements can provide safe and effective outcomes.

Even if there has been such progress, TAVI procedure for the patients with coexisting CAD has been worse than the patients without CAD.

Combination therapy of PCI and TAVI is one of the options for concomitant CAD and AS patients and has been reported by a few institutions [18]. However, the patients with multivessel CAD or coronary disease lesions that are unsuitable for PCI are not the candidate in this treatment. Therefore, OPCAB may become another combination therapy for these concomitant patients.

The potential advantage of OPCAB is an avoidance of using cardiopulmonary bypass which triggers various perioperative complications. The patients with concomitant CAD and severe AS who cannot undergo open heart AVR with cardiopulmonary bypass may receive a combination therapy of OPCAB and TAVI. It is an ideal strategy that multivessel bypass in OPCAB is performed and after that TAVI is deployed in transcatheter approach in either a single- or two-stage procedure. Moreover, aorta non-touch technique is favorable in this procedure because the character of ascending aorta is extremely bad in these high-risk concomitant patients. OPCAB procedure is also useful in the cases that ostium of coronary artery is unfortunately occluded with deployed aortic valve. OPCAB has to be performed very carefully in the positioning of circumflex or posterior descending artery anastomosis because hemodynamics fails easily in severe AS patients. Combination therapy of OPCAB and TAVI which is never reported clinically will become a potential strategy in the future.

27.6.2 OPCAB+Debranching TEVAR

The coexistence of CAD and aortic aneurysm is common in the elderly patients, because arterial sclerosis is a significant factor of their development. When the patients with thoracic aortic aneurysm (TAA) in operative indication have CAD concomitantly, a replacement with prosthetic conduit and CABG may be selected and performed simultaneously with a few preoperative complications. However, in accordance with the localization of aneurysm, coronary lesion, and preoperative complications in the patients, surgeons have to consider different operative strategies.

On the other hand, thoracic endovascular aortic repair (TEVAR) for descending aortic disease has become an established minimally invasive technique with feasible outcomes. Furthermore, the patients with complex arch aneurysm including zone 0 or zone 1 have been treated using various debranching techniques. Therefore, the combination therapy of OPCAB and TEVAR for the treatment of high-risk patients with concomitant indicated CAD and TAA is considered to have advantageous potentials with minimal invasiveness.

Especially for the patients with both CAD and complex arch aneurysm, OPCAB and debranching TEVAR without cardiopulmonary bypass is an attractive strategy.

27.6.2.1 Supra-aortic Debranching Technique with OPCAB

Endovascular stenting requires a satisfactory landing zone that guarantees fixation and sealing of the proximal part of the endograft. Therefore, in complex aortic arch aneurysm in zone 0 or zone 1, innominate artery or common left carotid artery coverage is required when debranching these arteries. Supra-aortic debranching technique is one of the options in debranching TEVAR [20]. In this technique, after full sternotomy, debranched graft is sewn to the native ascending aorta under side clamping, and distal sides of grafts are anastomosed to innominate artery, left common carotid artery, and left subclavian artery by cases. An endovascular stent graft is deployed via other debranched limb antegrades or via a retrograde femoral artery. This technique may enable simultaneous OPCAB and debranching TEVAR for patients with concomitant CAD and TAA. Advantages of this technique are (1) to avoid cardiopulmonary bypass during both procedures, (2) to use bilateral IMA for the conduits with excellent long patency, and (3) to perform all procedures through the single wound. However, the characters of ascending aorta in such patients are sometimes too bad to avoid side clump and also to make proximal anastomosis for free grafts. Moreover, antegrade deployment of stent graft could cause intimal injury or dissection in the ascending aorta. To select this technique, the evaluation of detailed characters in major vessels using enhanced CT and intraoperative epiaortic echogram is necessary.

27.6.2.2 Debranching TEVAR Using Extra-anatomical Bypass with OPCAB

Debranching TEVAR using extra-anatomical bypass such as carotid–carotid bypass or subclavian–subclavian bypass is another option for patients with concomitant CAD and TAA. In aortic arch aneurysm in zone 1 requiring coverage of left common carotid artery and left subclavian artery, extra-anatomical bypass is available to maintain blood perfusion in these arteries with low invasiveness. Some investigators reported this debranching technique with feasible outcomes [19, 20]. By using the debranching technique, hybrid procedure combined OPCAB and TEVAR can be done. After complete coronary artery revascularization in off-pump fashion through full sternotomy, single- or two-staged debranching TEVAR is performed. The author and colleagues had some experience of this hybrid procedure in two-staged fashion with excellent clinical results. This hybrid procedure is not complicated and can be performed safely without perioperative stroke. However, this technique has a disadvantage that LIMA is hard to use because the left subclavian artery is covered with a stent graft and occluded to avoid end leak. When we use in situ LIMA graft to LAD in patients with complex disease, a right carotid to left carotid to left subclavian artery bypass or a right to left subclavian artery bypass is carried out to get its blood flow in consecutive TEVAR procedure (Fig. 27.2). Author et al. had a few experiences with combination of LIMA to LAD bypass and this extra-anatomical bypass. However, long-term blood flow of LIMA cannot be guaranteed; therefore, the use of LIMA should be considered carefully.

With aging of the patient in CAD, concomitant disease such as AS or TAA has been increasing. This frequent coincidence of cardiac and major vascular disease requires careful preoperative evaluation of these patients. Cardiovascular surgeons have to select optimal operative strategies carefully based on these evaluations. OPCAB has been a completely established technique with lower

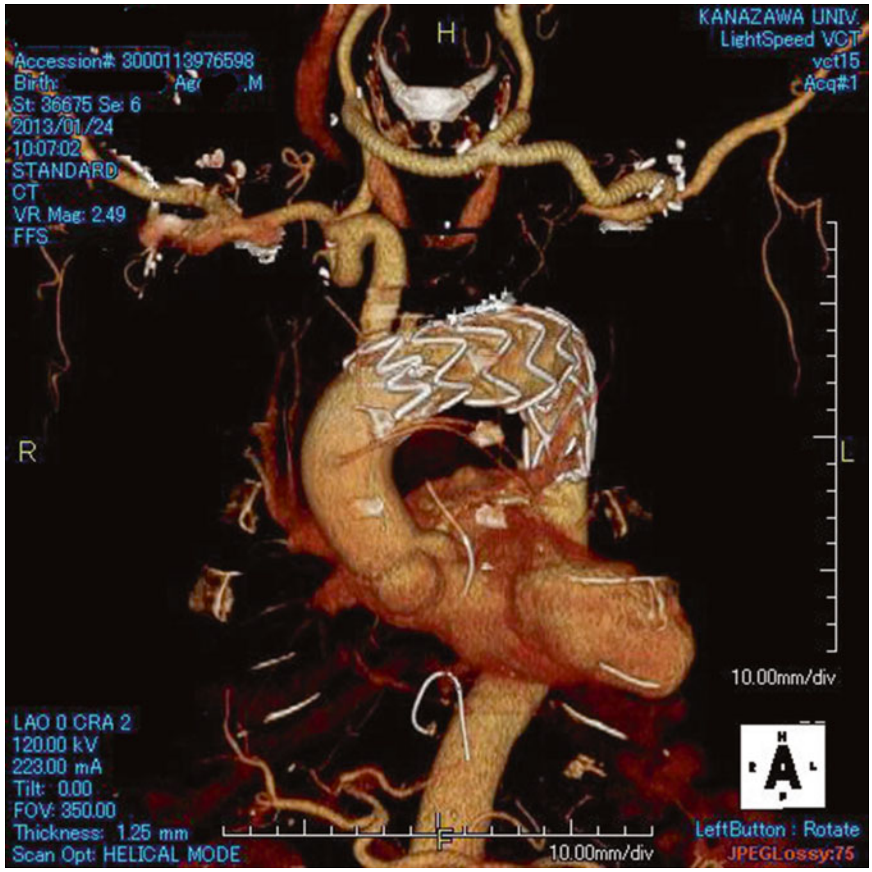

Fig. 27.2 3-dimensional computed tomography revealed a carotid to carotid and to left subclavian artery bypass with thoracic endovascular aortic stent graft. This patient underwent triple-vessel off-pump coronary artery bypass grafting including LIMA to LAD at 1 month before TEVAR procedure

complications and high patency rate, and TEVAR has evolved with technology of devices and improvement of surgeon's skill. Therefore, combination therapy of OPCAB and TEVAR may become an alternative hybrid procedure for complicated patients.

References

1. Angelini GD, Wilde P, Salerno TA, Bosco G, Calafiore AM (1996) Integrated left small thoracotomy and angioplasty for multivessel coronary artery revascularisation. Lancet 347:757
2. Murphy GJ, Bryan AJ, Angelini GD (2004) Hybrid coronary revascularization in the era of drug-eluting stents. Ann Thorac Surg 78:1861–1867
3. Verhaegh AJ, Accord RE, van Garsse L, Maessen JG (2013) Hybrid coronary revascularization as a safe, feasible, and viable alternative to conventional coronary artery bypass grafting: what is the current evidence? Minim Invasive Surg 2013:10 p
4. Green KD, Lynch DR Jr, Chen TP, Zhao D (2013) Combining PCI and CABG: the role of hybrid revascularization. Curr Cardiol Rep 15(4):351
5. Acuff TE, Landreneau RJ, Griffith BP, Mack MJ (1996) Minimally invasive coronary artery bypass grafting. Ann Thorac Surg 61(1):135–137
6. Vassiliades TA Jr, Douglas JS, Morris DC, Block PC, Ghazzal Z, Rab ST, Cates CU (2006) Integrated coronary revascularization with drug-eluting stents: immediate and seven-month outcome. J Thorac Cardiovasc Surg 131:956–962
7. Serruys PW, Onuma Y, Garg S, Vranckx P, De Bruyne B, Morice MC, Colombo A, Macaya C, Richardt G, Fajadet J, Hamm C, Schuijer M, Rademaker T, Wittebols K, Stoll HP, II ARTS Investigators (2010) 5-year clinical outcomes of the ARTS II (Arterial Revascularization Therapies Study II) of the sirolimus-eluting stent in the treatment of patients with multivessel de novo coronary artery lesions. J Am Coll Cardiol 55:1093–1101
8. Hu S, Li Q, Gao P, Xiong H, Zheng Z, Li L, Xu B, Gao R (2011) Simultaneous hybrid revascularization versus off-pump coronary artery bypass for multivessel coronary artery disease. Ann Thorac Surg 91:432–438
9. Halkos ME, Vassiliades TA, Douglas JS, Morris DC, Rab ST, Liberman HA, Samady H, Kilgo PD, Guyton RA, Puskas JD (2011) Hybrid coronary revascularization versus off-pump coronary artery bypass grafting for the treatment of multivessel coronary artery disease. Ann Thorac Surg 92:1695–1701
10. Bonatti JO, Zimrin D, Lehr EJ, Vesely M, Kon ZN, Wehman B, de Biasi AR, Hofauer B, Weidinger F, Schachner T, Bonaros N, Friedrich G (2012) Hybrid coronary revascularization using robotic totally endoscopic surgery: perioperative outcomes and 5-year results. Ann Thorac Surg 94(6):1920–1926. discussion 1926. doi:10.1016/j.athoracsur.2012.05.041
11. Shen L, Hu S, Wang H, Xiong H, Zheng Z, Li L, Xu B, Yan H, Gao R (2013) One-stop hybrid coronary revascularization versus coronary artery bypass grafting and percutaneous coronary intervention for the treatment of multivessel coronary artery disease: 3-year follow-up results from a single institution. J Am Coll Cardiol 61:2525–2533

12. Adams C, Burns DJ, Chu MW, Jones PM, Shridar K, Teefy P, Kostuk WJ, Dobkowski WB, Romsa J, Kiaii B (2014) Single-stage hybrid coronary revascularization with long-term follow-up. Eur J Cardiothorac Surg 45(3):438–442
13. Levine GN, Bates ER, Blankenship JC, Bailey SR, Bittl JA, Cercek B, Chambers CE, Ellis SG, Guyton RA, Hollenberg SM, Khot UN, Lange RA, Mauri L, Mehran R, Moussa ID, Mukherjee D, Nallamothu BK, Ting HH, American College of Cardiology Foundation, American Heart Association Task Force on Practice Guidelines, Society for Cardiovascular Angiography and Interventions (2011) ACCF/AHA/SCAI guideline for percutaneous coronary intervention. A report of the American College of Cardiology Foundation/American Heart Association Task Force on practice guidelines and the society for cardiovascular angiography and interventions. J Am Coll Cardiol 58:e44–e122
14. Conradi L, Treede H, Reichenspurner H (2013) Hybrid coronary revascularization: a task for the true heart team! Eur J Cardiothorac Surg 2013:30
15. Repossini A, Tespili M, Saino A, Kotelnikov I, Moggi A, Di Bacco L, Muneretto C (2013) Hybrid revascularization in multivessel coronary artery disease. Eur J Cardiothorac Surg 44:288–293
16. Bachinsky WB, Abdelsalam M, Boga G, Kiljanek L, Mumtaz M, McCarty C (2012) Comparative study of same sitting hybrid coronary artery revascularization versus off-pump coronary artery bypass in multivessel coronary artery disease. J Interv Cardiol 25:460–468
17. de Cannière D, Jansens JL, Goldschmidt-Clermont P, Barvais L, Decroly P, Stoupel E (2001) Combination of minimally invasive coronary bypass and percutaneous transluminal coronary angioplasty in the treatment of double-vessel coronary disease: two-year follow-up of a new hybrid procedure compared with "on-pump" double bypass grafting. Am Heart J 142:563–570
18. Gasparetto V, Fraccaro C, Tarantini G, Buja P, D'Onofrio A, Yzeiraj E, Pittarello D, Isabella G, Gerosa G, Iliceto S, Napodano M (2013) Safety and effectiveness of a selective strategy for coronary artery revascularization before transcatheter aortic valve implantation. Catheter Cardiovasc Interv 81(2):376–383. doi:10.1002/ccd.24434. Epub 2012 May 2
19. De Rango P, Cao P, Ferrer C, Simonte G, Coscarella C, Cieri E, Pogany G, Verzini F (2013) Aortic arch debranching and thoracic endovascular repair. J Vasc Surg. doi:10.1016/j.jvs.2013.07.010 pii: S0741-5214(13)01320-7. [Epub ahead of print]
20. Bavaria J, Vallabhajosyula P, Moeller P, Szeto W, Desai N, Pochettino A (2013) Hybrid approaches in the treatment of aortic arch aneurysms: postoperative and midterm outcomes. J Thorac Cardiovasc Surg 145(3 Suppl):S85–S90. Epub 2012 Dec 20

28 Robotic Surgery

Shigeyuki Tomita and Go Watanabe

Abstract

Robotic coronary artery surgery has progressed with the advancements of robotic surgical system and the passion of advanced surgeons over the last two decades. Technologies of robotic-assisted surgery have been developed to overcome the limitations of the conventional endoscopic surgery. A surgical robot available for cardiac surgery is only the da Vinci surgical system (Intuitive Surgical, Inc, Sunnyvale, CA, USA) in the world.

The patient's setting of standard totally endoscopic coronary artery bypass graft (TECAB) including a left internal mammary artery (LIMA) to left anterior descending artery (LAD) is as follows: (1) general anesthesia with double-lumen tube intubation for single-lung ventilation, (2) supine position with the left chest slightly elevated, and (3) three ports placed in the third, fifth, and seventh intercostal spaces to 1 cm medial on the anterior axillary line. After a surgical cart is docked to an endoscopic camera and the instrument ports, an operation is performed by order of LIMA harvesting, identification of LAD after opening of a pericardium, stabilization of a target vessel, and anastomosis of LIMA to LAD.

Short-term outcomes of TECAB with either beating or arrested heart were acceptable; however, mid- to long-term outcomes were reported in few studies. Patient selection is very important to perform TECAB with the reduction of operative risk and complications.

Keywords

Totally endoscopic coronary artery bypass graft • da Vinci surgical system • TECAB

28.1 Introduction

Minimally invasive surgery has developed with innovative progress in surgical instruments for the last 20 years. In the field of the coronary artery bypass grafting (CABG), an off-pump CABG (OPCAB) technique without cardiopulmonary bypass and minimally invasive direct coronary artery bypass (MIDCAB) without a full sternotomy have been introduced with shorter hospital stay, faster recovery, and cosmetic superiority [1–3]. Endoscopic surgeries in CABG also have been introduced to exclusively harvest a left internal mammary artery (LIMA) in initial period [2, 3]. Watanabe and colleagues reported the first totally endoscopic CABG on a beating heart in 1999 [4], in which the LIMA was totally endoscopically harvested and anastomosed to the left anterior descending artery (LAD) in closed chest (Fig. 28.1). This conventional endoscopic procedure without a robotic instrumentation system required very advanced skills and some special apparatuses. Robot-assisted endoscopic surgery has been developed and introduced to overcome the limitations of the conventional endoscopic surgery. In the cardiac surgery fields, the first use of robotic instruments for surgery was in mitral valve

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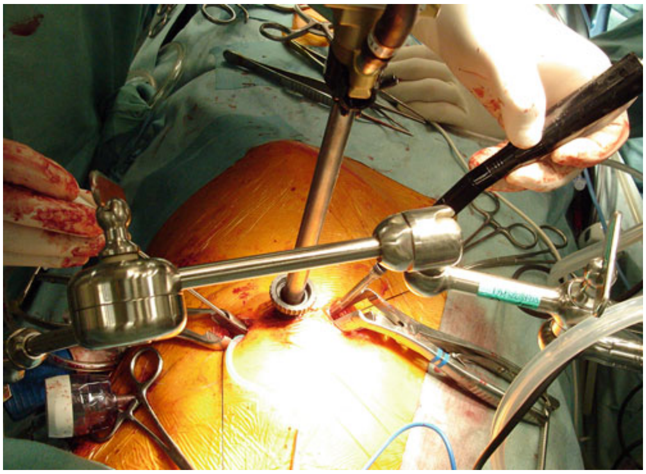

Fig. 28.1 Totally endoscopic coronary artery bypass grafting using endoscopic stabilizer without surgical robot

surgery. Loulmet and colleagues performed the first successful totally endoscopic coronary artery bypass graft (TECAB) on the arrested heart using robotic assist system [5]. In 2000, Falk and colleagues reported the first TECAB on the beating heart using robotic assist system, and subsequently, several robotic TECABs using da Vinci surgical system (Intuitive Surgical, Inc., Sunnyvale, CA, USA) on the either arrested or beating heart were reported to date [5–13]. In this chapter, we comment patient's selection, procedure, and outcome of the TECAB.

28.2 Patients' Selection

From the viewpoint of coronary lesions, the patients who have significant stenosis or total occlusion in LAD are most ideal candidates for single-vessel TECAB. The patients with double- or triple-vessel disease in which LAD involved total or subtotal occlusion and non-LAD lesions are amenable to percutaneous coronary intervention (PCI) can become candidates for double-vessel TECAB or hybrid procedure consisting of TECAB and PCI. A robotic TECAB including internal mammary artery (IMA) harvesting and coronary anastomosis is performed with intrathoracic robotic forceps and needle folder through the instrument ports. Therefore, the patients with small thoracic cavity or small space between the heart and the sternum which causes interference of forceps are not suitable for this procedure. Moreover, the patients with severe lung disease enable prolonged single-lung ventilation, or the patients with stenosis of IMA or stenosis of ipsilateral subclavian artery are contraindicated. The patients with hemodynamic instability, acute coronary syndrome, huge left ventricle with aneurysm after myocardial infarction, and redo surgery are also contraindication for this procedure.

Because the TECAB is an operation to require innovative technologies and special operative skills, surgeons have to select the eligible patients very carefully.

28.3 Operative Procedure

All operations are performed under general anesthesia with double-lumen tube intubation for single-lung ventilation. External defibrillator patches are placed on the chest preoperatively.

28.3.1 Patients' Position

In the case of using LIMA or both IMAs, the patients are placed in the supine position with the left chest slightly elevated with the lower position of their left arms. When it is difficult to harvest a right IMA (RIMA) through the left thoracic cavity, the patients are placed in the supine position, and a RIMA is harvested through the right thoracic cavity using a surgical bed rotation toward an opposite side following the LIMA harvesting through the left side.

In some female patients, it is useful to put the breast medially by adhesive tapes to make it easy to insert forceps ports.

28.3.2 Port Placement

Optimal port configuration is very important to perform full-length IMA harvesting and consecutively anastomosis of LIMA to LAD without the stress of arm collisions. Preoperative enhanced three-dimensional computed tomography (3DCT) is very useful to know precise anatomical relations of the intercostal spaces, LIMA, and LAD.

Three about 1.0-cm incisions are made in the third, fifth, and seventh intercostal spaces to 1 or 2 cm medial on the anterior axillary line. The places of right and left instrument ports can be sifted medially to camera port in some cases. After deflation of the left lung, a camera port is inserted through the middle incision, and carbon dioxide insufflation is initialed to make a space between the sternum and heart. A 30-degree angle upward camera is inserted firstly to examine the thoracic cavity, and the left and the right instrument ports are inserted into the third and seventh intercostal spaces under endoscopic confirming. The da Vinci surgical cart is moved to the surgical bed and docked to the camera and the instrument arm ports (Fig. 28.2.).

28.3.3 IMA Harvesting

Techniques of IMA harvesting with robotic instruments are desirable to cut small side branches using coagulation of

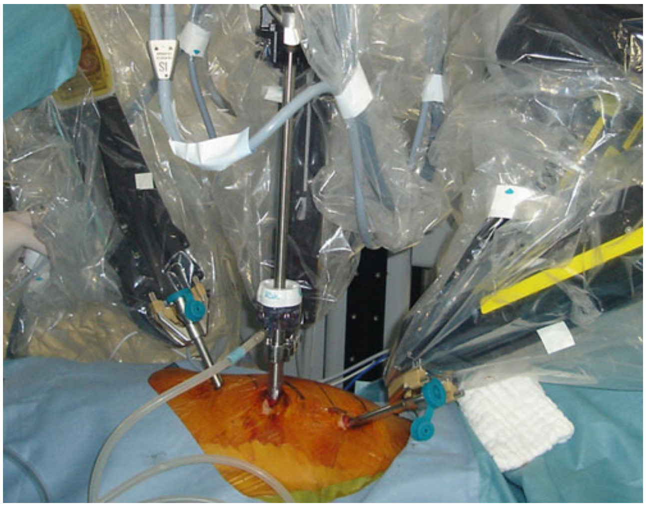

Fig. 28.2 The camera and the instrument arm ports are docked to a cart of a da Vinci surgical system. Three ports of a camera and both instruments are inserted into the third, fifth, and seventh intercostal spaces

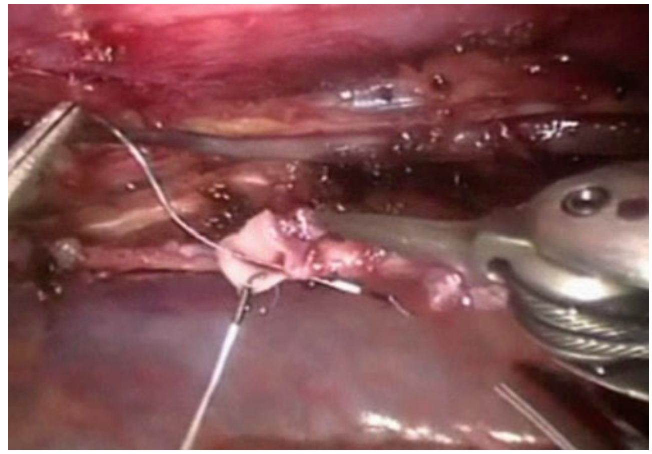

Fig. 28.3 The distal end of the IMA is partially transected leaving toe section attached, and five S18 U-Clips are passed outside-in to the LIMA in the far side

low-energy cautery and larger branches using hemoclips in a totally skeletonized fashion. Harmonic scalpel has been used for IMA harvesting in the skeletonized fashion in Japan, however, is still not available in the da Vinci surgical system. It is also recommended not to grasp the IMA directly, because the grasp force of robotic forceps is strong unexpectedly. When enough working space is not obtained, the intrathoracic pressure can be as long as the hemodynamics of the patient is unaffected, and lifting up the sternum by an electrical sternum lifting system is also useful [14]. Thanks to the various techniques mentioned above and the enhanced freedom of forceps tips, the full-length IMA from the subclavian artery bifurcation can be harvested comparatively easily with shorter learning curve [5]. When bilateral IMA has to be harvested through the left thoracic cavity, it is better to harvest RIMA first before LIMA through the fat tissue between the sternum and pericardium, because the harvested LIMA nearby interferes the forceps manipulation of RIMA harvesting.

28.3.4 LIMA to LAD Anastomosis

28.3.4.1 Beating Heart TECAB

After sysytemic heparinization to achieve an activated clotting time of more than 300 s, the pericardium is opened and the LAD is exposed. After setting of an operation field is completed, a stabilizer port is inserted in the subcostal region with endoscopic guidance. An EndoWrist stabilizer (Intuitive Surgical, Sunnyvale, CA, USA) mounted on the fourth arm of the da Vinci surgical system is used to fix an anastomotic region. This suction-type endostabilizer gives the console surgeon complete control while offering better exposure and stabilization, and these have led to highly complex endoscopic procedures such as triple and quadruple CABG on arrested and beating hearts. After the endostabilizer is placed just above on the anastomosis site of the LAD, the target coronary artery is dissected and occluded with two silastic saddle loops.

LIMA to LAD anastomosis techniques have two types: (1) intermittent sutures using S18 U-Clips (Medtronic, Minneapolis, MN, USA) and (2) running sutures using 7-0 polypropylene.

The intermittent suture technique with U-Clips was reported in details by Srivastava and colleagues [10]. This technique is as follows. The distal end of the IMA is partially transected leaving toe section attached, and five S18 U-Clips are passed outside-into the IMA in the far side (Fig. 28.3). The LIMA is completely dissected and led it to anastomotic site approximately. Previously placed five U-clips in LIMA are passed inside out sequentially in the far side of LAD, and the LIMA is parachuted down. Three additional U-clips are placed in the near side to complete the anastomosis (Fig. 28.4). Robotically achieved interrupted coronary anastomosis also reduces the possibility of purse-string continuous sutures with manageability and helps to overcome the lack of tactile feedback inherent with the da Vinci surgical system. However, U-clips are not universally available.

Another technique with running sutures using 7-0 polypropylene follows standard OPCAB techniques. However, the working space is limited in the TECAB; special needle and strings which Bonatti and colleagues reported may be useful [15]. After anastomosis and protamine administration, it is necessary to confirm all graft flows by transit-time Doppler assessment. Whenever all procedures of the TECAB are finished, surgeons have to check endoscopically the homeostasis of all camera and instrument ports. Bleeding from the ports is one cause of the revision for bleeding because intercostal artery or veins are injured by the force of robot arm.

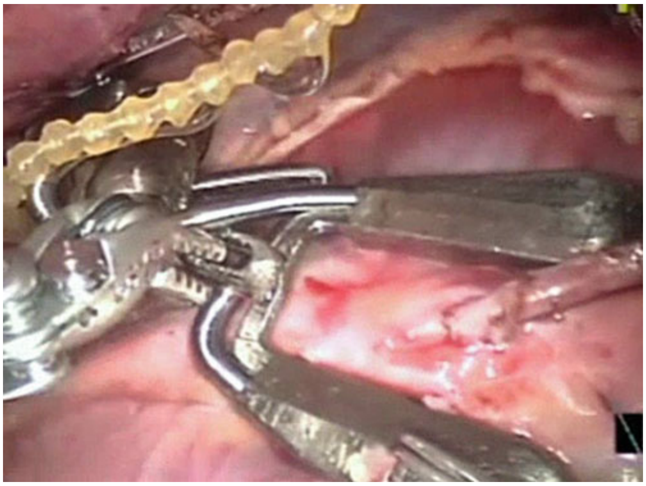

Fig. 28.4 A total of eight U-Clips are placed to complete the anastomosis using an EndoWrist stabilizer (Intuitive Surgical, Sunnyvale, CA, USA)

For the safe and precise anastomosis in the beating heart TECAB procedure, it is very important to obtain bloodless standstill operation field. Moreover, a preparation of cardiopulmonary assist is also important for unexpected arrhythmia or hemodynamic instability.

28.3.4.2 Arrested Heart TECAB

Bonatti and colleagues preferentially applied arrested heart TECAB with cannulation of the femoral vessels, a balloon-tipped device (Cardiovations, Edwards Lifesciences Inc., Irvine, CA, USA, or Estech, San Ramon, CA, USA) for aortic endo-occlusion, and anastomosis of the coronary artery using running 7-0 polypropylene sutures [15]. Patient's position and the ports' setting for an endoscopic camera and instruments are almost the same as in the beating heart TECAB. When constructing running suture, two-point fixation technique of heel and toe may be favorable to prevent a thread from getting tangle. Moreover, surgeons have to perform enough hemostasis from an anastomotic region, because the bleeding from heel is difficult to control endoscopically after the anastomosis is finished.

28.3.4.3 Alternative Anastomotic Device

Balkhy et al. used coronary anastomotic connectors in beating heart TECAB [16]. The C-Port Flex-A distal anastomotic device (Cardica, Redwood City, CA, USA) was approved for use in the USA in 2005 after a multicenter European trial had shown >95 % vein graft patency at 6 months [17]. The C-Port device creates an end-to-side anastomosis using multiple interrupted stainless steel clips. The flexible shaft of the C-Port device allows its introduction through a port and facilitates a truly endoscopic approach to coronary bypass. They concluded that the C-Port device leads to a safe and reproducible robotic endoscopic single- and multivessel coronary bypass under the beating heart with excellent short-term and midterm outcomes. This device needs some techniques for loading; however, it can be an alternative anastomotic method in the future.

28.3.5 Multivessel Robotic Totally Endoscopic Coronary Bypass Grafting

With application of robotic technology, single-vessel coronary artery bypass grafting procedures of LIMA to LAD were performed and reported by many institutions with feasible outcomes. Further technical progress in robotic surgery has to make multivessel coronary artery bypass grafting procedures possible. Some pioneers of TECAB procedures reported more than 100 cases of multivessel robotic totally endoscopic coronary artery bypass grafting [15, 18]. In multivessel TECAB, basic operative setting including anesthesia, position of patients, ports' placement, and preparation of cardiopulmonary bypass is the same as in single TECAB. The most important thing for the multivessel TECAB is to expose and stabilize the target coronary artery of either beating or arrested heart. An EndoWrist stabilizer mounted on the fourth arm of the da Vinci surgical system (available in da Vinci S or Si system) is very useful in this procedure. Bonatti and colleagues reported exposure techniques of the target coronary artery using this endostabilizer [19].

To perform multivessel TECAB, the use of both IMAs is indispensable, and Y-composite graft technique with LIMA and RIMA or sequential bypass technique is also required.

In the beating heart multivessel TECAB, the C-Port Flex-A distal anastomotic device mentioned above is available; however, another fifth port has to be created for the introduction and deployment of the device [17]. In any case, to perform multivessel TECAB, surgeons have to select patients very carefully from perioperative patient's risks and coronary lesions and have to raise their skills by training.

28.4 Outcomes of Robotic Surgery

28.4.1 Intraoperative Outcomes

In comparison with standard OPCAB, TECAB procedure is accompanied with various complications. Intraoperative exclusion criteria of TECAB are (1) pleural adhesion, (2) intramyocardial left anterior descending artery (LAD), (3) inadequate working space, and (4) severely calcified LAD. The most common causes for exclusion in both beating heart TECAB and arrested heart TECAB were intramyocardial LAD and an inadequate working space. In the case of intramyocardial LAD, a small skin incision on the intercostals' space has to be made to find out LAD. Using epicardial echo is available to find intramyocardial LAD. In some cases, operators mistake a diagonal branch for LAD. To avoid such a mistake, it is important to open the pericardium longitudinally from the pulmonary artery to the apex and to mark the target artery by a clip on the surrounding epicardial tissue. Inadequate working space limits a mobile range of robot forceps; therefore, TECAB procedure has to be converted to MIDCAB.

In beating heart TECAB, the most common causes for conversion to minithoracotomy are (1) injury of the LAD, (2) hemodynamic instability, (3) intolerance to single-lung ventilation, (4) bleeding from epicardium or anastomotic lesion, and (5) inadequate stabilization of the heart. On-pump beating anastomosis with cardiopulmonary support through femoral artery and vein is very safe and available in the case of hemodynamic instability. Authors experienced one conversion case of bleeding from epicardium which was caused by suction of heart stabilizer. A conversion rate was 4–24 % in the reported literatures [7–13].

On the other hand, majority of conversions in arrested heart TECAB are due to the difficulty with the cardiopulmonary bypass circuit including endoaortic balloon rupture or severe iliofemoral artery disease preventing guidewire placement.

28.4.2 Short-Term Outcomes

There are some reports about short-term outcomes over the past 10 years (Table 28.1). Incidence of conversion to larger thoracic incision, stroke, mortality, and myocardial infarction after operation were similar to both beating and arrested heart TECABs [7–13].

This value does not have inferiority in comparison with values which Japanese Association for Coronary Artery Surgery reported in 2013. Revision for bleeding rate was higher in the arrested heart TECAB group. These results may be influenced by using a cardiopulmonary bypass with prolonged operation time.

Operation time was significantly longer in multivessel TECAB than in single-vessel TECAB.

Bonatti and colleagues reported that double-vessel TECAB required a longer operative time (median 375 min) compared with singe-vessel TECAB (median 240 min) [19].

Table 28.1 Outcomes of TECAB with beating or arrested heart

Paper and year (reference)	n	Conversion	Revision for bleeding (%)	Mortality (%)	Stroke (%)	MI (%)	New-onset AF (%)	Reintervention rate (%)	Hospital length of stay (day)
Beating heart TECAB									
Srivastava 2012 [18]	164	0 (0 %)	2.4	0.6	0.6	0.6	7.9	2.4	NR
Dhawan 2012 [13]	106	4 (3.8 %)	3.8	3.8	1.9	NR	16.0	2.8	5.2 ± 3.1
Gao 2011 [12]	60	2 (3.3 %)	1.7	NR	NR	NR	NR	0.0	5.0 ± 1.5
Jegaden 2011 [11]	78	19 (24 %)	8.5	1.7	0.0	3.4	NR	10.2	5.5 ± 1.6
Balkhy 2011 [16]	120	3 (2.5 %)	1.6	0.8	0.8	0.8	NR	0.0	3.3 ± 2.2
Srivastava 2010 [10]	241	27 (11 %)	0.9	0.0	0.5	0.0	10.3	1.4	NR
de Canniere 2007 [9]	111	37 (33 %)	NR	2.2	NR	1.2	NR	4.1	NR
Weighted mean	880[a]	92[a] (10 %)	2.6	1.2	0.7	0.8	10.7	2.6	
Arrested heart TECAB									
Bonatti 2012 [19] Single vessel	334	31 (9.3 %)	6.3	0.3	1.8	0.0	15.0	NR	6.0
Bonatti 2012 [19] Double vessel	150	31 (21.7 %)	4.7	2.0	0.7	2.0	13.8	NR	6.0
de Canniere 2007 [9]	117	27 (23 %)	NR	1.1	NR	1.1	NR	2.2	NR
Argenziano 2006 [8]	98	5 (5.1 %)	3.5	0.0	0.0	1.2	1.2	4.7	5.1 ± 3.4
Dogan 2002 [7]	45	10 (22.2 %)	5.7	NR	2.2	2.2	NR	NR	8.6 ± 2.7[b]
Weighted mean	744[a]	104[a] (14.0 %)	5.8	0.9	1.2	1.8	5.1	3.5	

TECAB totally endoscopic coronary artery bypass graft, *MI* myocardial infarction, *AF* atrial fibrillation
[a] total
[b] for their one-vessel patients

Fig. 28.5 Single TECAB patient at 3 months postoperatively

Srivastava and colleagues had a similar report including longer operation time in multivessel TECAB [18]. In the cosmetic outcome, TECAB is a very satisfying procedure for the patient (Fig. 28.5).

28.4.3 Mid to Long-Term Outcomes

A few studies reported the mid- to long-term outcomes for greater than 1 year (range 3–8 years) with 94.5 % survival rate. Bonatti and colleagues reported the largest and most reliable mid- to long-term data in robotic TECAB [15]. In intraoperative outcomes, compared with the single-vessel procedure, double-vessel TECAB required a longer operative time (median 375 min vs. 240 min; $P<.001$) and had an increased conversion rate to a larger thoracic incision (20.7 % vs. 9.3 %; $P<.001$). In postoperative outcomes, hospital stay of 6 days and mortality were comparable in both single- and double-vessel TECAB groups. Cumulative survival of 95.8 and 93.9 %, freedom from major adverse cardiac and cerebral events of 83.1 and 73.5 %, and freedom from angina of 91.1 and 85.1 % at 5 years were similar after double- and single-vessel TECAB. These long-term outcomes are comparable to standard CABG [20]. In this way, there are few reports of long-term outcomes in TECAB procedure, and therefore, it is necessary to accumulate a case whether there is reproducibility for data of few reports.

28.5 Future of Robotic Surgery

Over the last two decades, robotic coronary surgery has progressed with the evolution of robotic surgical system and the passion of advanced surgeons. With their efforts and idea, the third-generation da Vinci surgical system is able to cope with multivessel coronary artery bypass. However, there are some problems to impregnate this robotic operative procedure. The first point is that there are any evidences with excellent outcomes based on a randomized control trial with standard OPCAB which has been performed to 60 % of all CABG in JAPAN. Therefore, advanced surgeons must accumulate cases of TECAB with lower operative complications and acceptable outcomes. The second point is that a learning curve is present to perform TECAB, and special and rigorous training with experienced surgeons is necessary to master robotic surgical skills. Implementation of a training program taken in some institutions is very important to spread this operative procedure worldwide [21]. On that account, it may be necessary to select a limited institution with many candidates for TECAB. The TECAB is not a completely established operative procedure and, therefore, has to be primarily performed by an entire surgical team which took training. The third point is that there are no strict criteria for patient selection. The criteria are the same in most institutions in single-vessel TECAB; however, there are no criteria in the multivessel TECAB. Following this, hybrid procedure combining single-vessel TECAB of LIMA to LAD and PCI is an ideal alternative coronary revascularization therapy. In the future, the criteria for multivessel TECAB have to be made with accumulations of those cases.

To create a further elegant operation with shorter operating time and improvement of patient outcomes, new technical developments including miniaturized instruments or new small anastomotic devices are required.

References

1. Benetti FJ, Ballester C (1995) Use of thoracoscopy and a minimal thoracotomy, in mammary-coronary bypass to left anterior descending artery, without extracorporeal circulation: experience in 2 cases. J Cardiovasc Surg (Torino) 36(2):159–161
2. Calafiore AM, Giammarco GD, Teodori G, Bosco G, D'Annunzio E, Barsotti A, Maddestra N, Paloscia L, Vitolla G, Sciarra A, Fino C, Contini M (1996) Left anterior descending coronary artery grafting via left anterior small thoracotomy without cardiopulmonary bypass. Ann Thorac Surg 61(6):1658–1663; discussion 1664–5
3. Acuff TE, Landreneau RJ, Griffith BP, Mack MJ (1996) Minimally invasive coronary artery bypass grafting. Ann Thorac Surg 61(1):135–137
4. Watanabe G, Takahashi M, Misaki T, Kotoh K, Doi Y (1999) Beating-heart endoscopic coronary artery surgery. Lancet 354(9196):2131–2132
5. Loulmet D, Carpentier A, d'Attellis N, Berrebi A, Cardon C, Ponzio O, Aupècle B, Relland JY (1999) Endoscopic coronary artery bypass grafting with the aid of robotic assisted instruments. J Thorac Cardiovasc Surg 118(1):4–10
6. Falk V, Diegeler A, Walther T, Banusch J, Brucerius J, Raumans J, Autschbach R, Mohr FW (2000) Total endoscopic computer enhanced coronary artery bypass grafting. Eur J Cardiothorac Surg 17(1):38–45
7. Dogan S, Aybek T, Andressen E, Byhahn C, Mierdl S, Westphal K, Matheis G, Moritz A, Wimmer-Greinecker G (2002) Totally

endoscopic coronary artery bypass grafting on cardiopulmonary bypass with robotically enhanced telemanipulation: report of forty-five cases. J Thorac Cardiovasc Surg 123(6):1125–1131
8. Argenziano M, Katz M, Bonatti J, Srivastava S, Murphy D, Poirier R, Loulmet D, Siwek L, Kreaden U, Ligon D, TECAB Trial Investigators (2006) Results of the prospective multicenter trial of robotically assisted totally endoscopic coronary artery bypass grafting. Ann Thorac Surg 81(5):1666–1674; discussion 1674–5
9. de Cannière D, Wimmer-Greinecker G, Cichon R, Gulielmos V, Van Praet F, Seshadri-Kreaden U, Falk V (2007) Feasibility, safety, and efficacy of totally endoscopic coronary artery bypass grafting: multicenter European experience. J Thorac Cardiovasc Surg 134(3):710–716
10. Srivastava S, Gadasalli S, Agusala M, Kolluru R, Barrera R, Quismundo S, Kreaden U, Jeevanandam V (2010) Beating heart totally endoscopic coronary artery bypass. Ann Thorac Surg 89(6):1873–1879. doi:10.1016/j.athoracsur.2010.03.014; discussion 1879–80
11. Jegaden O, Wautot F, Sassard T, Szymanik I, Shafy A, Lapeze J, Farhat F (2011) Is there an optimal minimally invasive technique for left anterior descending coronary artery bypass?. J Cardiothorac Surg 6:37. doi:10.1186/1749-8090-6-37
12. Gao C, Yang M, Wu Y, Wang G, Xiao C, Zhao Y, Wang J (2011) Early and midterm results of totally endoscopic coronary artery bypass grafting on the beating heart. J Thorac Cardiovasc Surg 142(4):843–849. doi:10.1016/j.jtcvs.2011.01.051. Epub 2011 Mar 8
13. Dhawan R, Roberts JD, Wroblewski K, Katz JA, Raman J, Chaney MA (2011) Multivessel beating heart robotic myocardial revascularization increases morbidity and mortality. J Thorac Cardiovasc Surg 143(5):1056–1061. doi:10.1016/j.jtcvs.2011.06.023. Epub 2011 Dec 14
14. Watanabe G, Matsumoto I, Kiuchi R (2013) Novel sternum lifting technique for robotic internal thoracic artery graft harvesting. Innovations (Phila) 8(1):76–79. doi:10.1097/IMI.0b013e31828d90ee
15. Bonatti J, Lehr EJ, Schachner T, Wiedemann D, Weidinger F, Wehman B, de Biasi AR, Bonaros N, Griffith B (2012) Robotic total endoscopic double-vessel coronary artery bypass grafting–state of procedure development. J Thorac Cardiovasc Surg 144(5):1061–1066. doi:10.1016/j.jtcvs.2012.08.023
16. Balkhy HH, Wann LS, Krienbring D, Arnsdorf SE (2011) Integrating coronary anastomotic connectors and robotics toward a totally endoscopic beating heart approach: review of 120 cases. Ann Thorac Surg 92(3):821–827. doi:10.1016/j.athoracsur.2011.04.103
17. Matschke KE, Gummert JF, Demertzis S, Kappert U, Anssar MB, Siclari F, Falk V, Alderman EL, Detter C, Reichenspurner H, Harringer W (2005) The Cardica C-Port System: clinical and angiographic evaluation of a new device for automated, compliant distal anastomoses in coronary artery bypass grafting surgery–a multicenter prospective clinical trial. J Thorac Cardiovasc Surg 130(6):1645–1652
18. Srivastava S, Barrera R, Quismundo S (2012) One hundred sixty-four consecutive beating heart totally endoscopic coronary artery bypass cases without intraoperative conversion. Ann Thorac Surg 94(5):1463–1468. doi:10.1016/j.athoracsur.2012.05.028. Epub 2012 Jul 7
19. Bonatti J, Wehman B, de Biasi AR, Jeudy J, Griffith B, Lehr EJ (2012) Totally endoscopic quadruple coronary artery bypass grafting is feasible using robotic technology. Ann Thorac Surg 93(5):e111–e112. doi:10.1016/j.athoracsur.2011.11.049
20. ElBardissi AW, Aranki SF, Sheng S, O'Brien SM, Greenberg CC, Gammie JS (2012) Trends in isolated coronary artery bypass grafting: an analysis of the Society of Thoracic Surgeons adult cardiac surgery database. J Thorac Cardiovasc Surg 143(2):273–281. doi:10.1016/j.jtcvs.2011.10.029
21. Schachner T, Bonaros N, Wiedemann D, Weidinger F, Feuchtner G, Friedrich G, Laufer G, Bonatti J (2009) Training surgeons to perform robotically assisted totally endoscopic coronary surgery. Ann Thorac Surg 88:523–527

OPCAB Combined Regenerative Surgery

29

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Abstract

Patients with chorionic ischemic heart disease including irreversible myocardial damage cannot be completely restored by conventional coronary artery revascularization including coronary artery bypass grafting (CABG) or percutaneous coronary intervention (PCI).

Cell transplantation therapy for these patients has advantageous potential to improve left ventricle function with preventing ventricular remodeling and contractility of ventricle reduction. A number of animal studies have shown that intramyocardial cell transplantation in ischemic cardiomyopathy is associated with an improvement in ventricle function and consequently several clinical trials have evaluated clinical effectiveness of these therapies.

Various type of cell and methods have been used for intramyocardial cell transplantation; however, cell types with clinical utilization are bone marrow stem cell and skeletal myoblast.

Especially, intramyocardial bone marrow stem cell transplantation combined with CABG is a safe and available procedure with evidence of improving the left ventricle function in patients with chorionic ischemic heart disease. Furthermore, using off-pump CABG (OPCAB) technique may reduce intra- and postoperative complications in patients who have low cardiac function caused by prior myocardial infarction. Although the selection of patients is carefully treated, this combination therapy of cell transplantation and OPCAB can be advantageous option for ischemic heart disease.

Keywords

OPCAB • Bone marrow stem cell • Myoblast • $CD34^+$

29.1 Introduction

Myocardial infarction (MI) is associated with an irreversible loss of cardiomyocytes which leads to progress of ventricular remodeling with enlargement and reduced contractility of the ventricle. Coronary artery revascularization including coronary artery bypass grafting (CABG) or percutaneous coronary intervention (PCI) can treat angina pectoris and myocardial infarction with the restoration of blood flow in viable myocardium, however, cannot rescue non-viability infarcted myocardium.

Myocardial regeneration and angiogenesis have been suggested to have therapeutic potential in such ischemic heart disease. The different cell types have been used for these regenerative therapies, such as embryonic stem cell, cultured skeletal myoblasts, and bone marrow stem cell. Embryonic cell has a potential of differentiating various cell types including cardiomyocytes; however, clinical application is a little difficult from a graft-versus-host disease and an ethical problems. On the other hand, skeletal myoblast and bone marrow stem cell have been investigated in animal model and clinically introduced with excellent results of animal studies [1, 2].

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Especially, bone marrow contains multipotent adult stem cells with a high capacity for differentiation. Various mechanisms of the bone marrow stem cell action in the human heart are thought such as cell differentiation, activation of cardiac stem cells, and cytokine-mediated effects. Since the first intramyocardial bone marrow stem cell transplantation with CABG by Stamm and colleagues in 2003, many early-phase clinical trials using direct injection of bone marrow cells into the coronary arteries or the intramyocardium have reported to improve postinfarction left ventricle (LV) function [1, 3–10]. Subsequently, several prospective randomized controlled trials (RCTs) were performed to evaluate the safety and efficacy of bone marrow stem cell transplantation therapy with CABG for the patients with chronic ischemic heart disease in comparison with CABG alone. Meta-analysis of the RCTs in these studies has given clinical evidences with the improvement of LV function.

Autologous skeletal myoblast cell transplantation is another cell type in myocardial regeneration therapy for the patients with chronic ischemic heart disease. The first clinical trial of myoblast transplantation in addition to CABG was performed by Menasche and colleagues in 2001 [2]. Several clinical studies of skeletal myoblast transplantation were performed to evaluate the efficacy of this therapy [3, 11–13]. Current opinion of this therapy concluded direct myoblast injections combined with CABG in patients with depressed LV function fail to improve echocardiographic heart function, because the proportion of injected cells surviving to engraft the infarcted myocardium is very low [14]. Therefore, various delivery methods of myoblast into myocardium have been developed instead of direct injection. In current understanding, bone marrow cell and myoblast cell transplantation therapy with CABG have reasonable utilization clinically with effective midterm outcomes.

29.2 Bone Marrow Cell Therapy Combined with OPCAB

29.2.1 Patient Population

The patient selection is very important to perform bone marrow cell implantation therapy combined with CABG for ischemic heart disease. General indications and contraindications in this treatment are as follows based on past several clinical investigations. Patients are eligible if they had have all the following conditions: (1) at least 2 months since the last MI, (2) planned CABG with graftable native coronary arteries for multivessel disease, (3) existence of transmural old myocardial infarction with akinesis or dyskinesis of the left ventricle on two imaging studies (echocardiography and cardiac catheterization), (4) evidence of fixed perfusion defect area shown by single photon emission computed tomography (SPECT), (5) left ventricular ejection fraction less than 30 %, (6) without LV aneurysm requiring surgical intervention, (7) NYHA heart failure functional class III or IV.

Patients are excluded if they had (1) a current or prior malignancy, (2) primary hematologic disorder, (3) renal failure with dialysis, (4) concomitant valve surgery, (5) prior cardiac surgery, and (6) ventricular arrhythmia. Preoperative baseline investigations are (1) echocardiography, (2) Holter ECG, (3) technetium-99 m sestamibi or thallous chloride Tl 201 SPECT, and (4) standard hematologic laboratory tests. Furthermore, this procedure has to be approved by each enforcement institutional ethical review board. All patients have to be given extensive information and give written informed consent.

29.2.2 Operation Methods

Operative techniques of bone marrow transplantation procedures combined with CABG are similar in several clinical reports [3–8]. Bone marrow cell is firstly harvested from iliac bone followed by either arrested heart CABG or off-pump CABG (OPCAB). The harvested bone marrow cells are diluted and prepared for transplantation during CABG procedure, and after CABG, the prepared stem cells are injected with by using a small-gauge needle apparatus in the preselected sites of myocardial dyskinesis.

Our specific techniques of bone marrow cells transplantation with combined OPCAB are as follows [15]. Under general anesthesia, a patient is placed prone, and bone marrow is harvested from the iliac crest in a sterile fashion by an experienced hematologist and a cardiac surgeon for 1 h (Fig. 29.1).

The harvested bone marrow cells are diluted with RPMI 1640 (Gibco, Invitrogen, Carlsbad, CA, USA) containing

Fig. 29.1 Under general anesthesia, patient is in prone position and bone marrow cells are collected from the iliac crest for about 1 h

Fig. 29.2 Isolex300i magnetic cell selection system separates $CD34^+$ cells from the fraction of mononuclear bone marrow cells for about 3 h

heparin, and about 750 mL is saved in a sterile pack from the bone marrow collection kit (Baxter, Chicago, IL, USA). The mononuclear cell fraction is sorted and concentrated to a final volume of 100 mL with a COBE Spectra Apheresis System (Gambro, Stockholm, Sweden). The total count of mononuclear cells is $3.5–6.5 \times 10^9$ cells. Next, we use the Isolex 300i Magnetic Cell Selection System (Nexell Therapeutics, Irvine, CA, USA) to separate $CD34^+$ cells from the fraction of mononuclear bone marrow cells (Fig. 29.2). The final count of isolated $CD34^+$ cells is $2.0–3.0 \times 10^7$ cells.

Coronary artery bypass is performed in our standard off-pump fashion. When the OPCAB procedure is completed, implantation of $CD34^+$ cells into the infarction site is performed while the beating heart is stabilized with a heart net (Vital, Tokyo, Japan) (Fig. 29.3). This heart net can provide precise and equal injection of cells on the beating heart. The injection placement is based on preoperative echocardiography and SPECT viewing.

A 5-mL cell suspension containing $2.0–3.0 \times 10^7$ $CD34^+$ cells is injected into 25–30 sites (0.2 mL to each site) with a 1 × 1-cm grid and a 26-gauge needle apparatus (6 mm deep). Using small needle can prevent bleeding at the puncture sites. After implantation, ventricular pacing wires and drainage tubes are put in place, and the chest wall is closed in standard fashion.

In our clinical study, we used $CD34^+$ cells separated from bone marrow cells using an automatic mononuclear separating system. Other clinical studies of this therapy have used original bone marrow stem cell, bone marrow mononuclear cell, and $CD133^+$ cell. Techniques of bone marrow collection are almost the same by all studies. Although methods of cell transplantation varied in each study, a direct intramyocardial injection of bone marrow cells is a most popular technique in

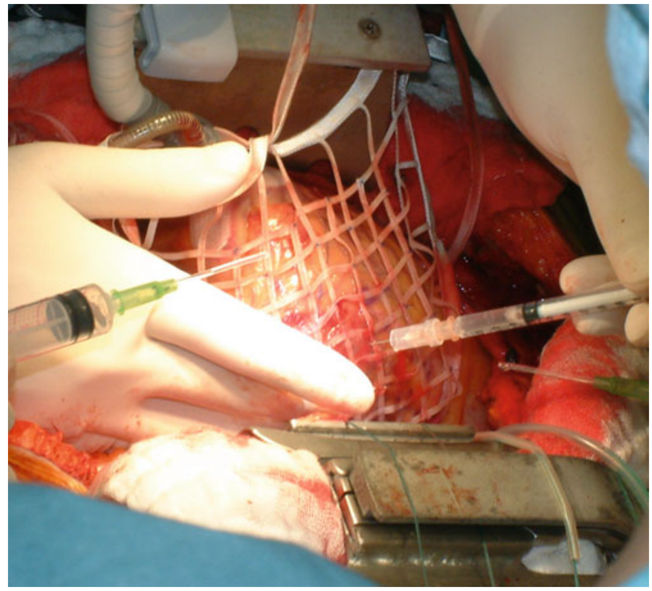

Fig. 29.3 A 5-mL cell suspension containing $2.0–3.0 \times 10^7$ $CD34^+$ cells is injected into 25–30 sites (0.2 mL to each site) with a 1 × 1-cm grid and a 26-gauge needle apparatus (6 mm deep)

the combination therapy of bone marrow cell transplantation and CABG. Some studies reported a method to inject bone marrow cells from a bypass graft; however, from the view point of cell delivery into insufficient vascular area, intramyocardial stem cell direct injection during surgery seems better. Furthermore, this therapy can accomplish all procedures on beating heart, at one operation room and in a day even if we take either methods of cell transplantation.

29.2.3 Follow-Up

After operation, patients are transferred to the intensive care unit for monitoring. Especially, it is very important to pay careful attention to new developing polymorphic premature ventricular contraction or ventricular tachycardia caused by cell transplantation. Before discharge, routine blood examination including cardiac enzymes and chest roentgenogram is taken. To evaluate short-term safety and feasibility of this therapy, electrocardiogram (ECG), transthoracic echocardiography, SPECT study, and cardiac catheterization including coronary artery assessment are routinely performed on the 1 month postoperative day. In our experiences, echocardiography and SPECT study are assessed on the 6, 12, 24, and 36 months compared with baseline values to evaluate mid- or long-term effectiveness of this therapy. The values (infarction wall thickness, LV end-systolic diameter, LV end-diastolic diameter) measured by M-mode echocardiograph are mostly available to assess the improvement of LV function.

Many papers which investigated the clinical effectiveness of this therapy also used echocardiography and SPECT study as evaluation methods of midterm outcomes [3–8]. Regarding SPECT study, we used stress ATP SPECT-sestamibi perfusion scans to determine myocardial perfusion during follow-up compared with baseline control. A few investigations used thallous chloride Tl-201 SPECT to assess the improvement in myocardial perfusion viability after intervention. Even if either radio nuclides are used, SPECT study is available methods to evaluate myocardial blood perfusion, distribution, and viability.

In current studies of this therapy, utilization of cardiac magnetic resonance imaging (MRI) and fluorine 18-fluorodeoxyglucose (^{18}F-FDG) positron emission tomography (PET) has been reported. These methods may become useful in the future to evaluate a true effectiveness of postoperative cell transplantation except the influence of CABG [8, 9].

29.2.4 Outcomes

For the past 10 years, a large number of clinical studies in this bone marrow cell transplantation therapy have demonstrated their clinical benefits. Some RCTs compared with the combination therapy of cell transplantation and CABG with CABG alone also have showed their safety and effectiveness with excellent outcomes [3–9].

29.2.4.1 Intraoperative and Early Postoperative Outcomes

Regarding cell collection methods, there are some differences in each manipulation, but the number of harvested bone marrow stem cells is almost the same. In a few studies, there were the cases that required an intra-aortic balloon pump or a left ventricular assist device postoperatively, because these studies treated severe cases with low cardiac function. Few complications including fatal arrhythmia due to injection of cell transplantation did not present.

29.2.4.2 Echocardiography

Most studies of this therapy have demonstrated the significant improvement of LV function with echocardiography compared with their baseline data [3–9]. In RCTs, the improvement of cardiac function by echocardiography has been described as an increase in left ventricle ejection fraction (LVEF) of approximately 10 % in patients of combined therapy with CABG (Table 29.1). A few studies of combining cell transplantation with OPCAB reported similar results which implicates that cardiac arrest is not necessarily to perform safe and efficient cell implantation [3]. Moreover, this therapy showed a trend toward reduction in left ventricular end-diastolic volume (LVEDV) compared with control group. Yerebakan and colleagues reported that patients with LVEF not greater than 40 % had a possibility of improvement in LV function than patients with LVEF greater than 40 % in a mean follow-up of 65 months [9]. Our small study also presents an increase in LVEF of approximately 10 % in patients with cell transplantation within 1 month. It is very interesting knowledge from most clinical studies that the cardiac function in cell therapy patients significantly improves within 1 month in comparison with the baseline data [3–8].

29.2.4.3 SPECT

In the SPECT study, many studies reported that the infarcted area was decreased compared with the baseline and the control with no significant difference. In addition, it is one of the characteristics of SPECT study that the improvement of myocardial blood perfusion appears about 6 months later. Furthermore, it is other character of SPECT study that it is little difficult to universally evaluate the improvement of SPECT viewing using number values.

29.2.4.4 New York Heart Association Functional Class

A few studies reported that New York Heart Association (NYHA) functional class and physical activity has improved in cell plantation group compared with control group. However, NYAHA class also improved in control group, and there was no clear significant difference.

29.2.4.5 Others

In the follow-up, computed tomography was taken to investigate adverse epicardial tissue changes by some studies including authors [9, 15]. No myocardial calcification or tumor formation was detected in the cell implantation area.

29.2.5 Future of Bone Marrow Cell Transplantation Therapy Combined with OPCAB

Many studies have demonstrated the safety and effectiveness of cell transplantation therapy with CABG. In contrast with intracoronary application, local intramyocardial surgical injection of bone marrow cell will be more effective, because transplanted cell is delivered directly into the target area of the myocardium across the endothelial barrier and is hard to be washed away. However, the past clinical studies have some limitations. The number of these studies was very small and the subject patient varied by each study. Concerning these problems, the recently launched PERFECT (intramyocardial transPlantation of bonE maRrow stem cells For improvEment of post-inFarct myoCardial regeneraTion in addition to CABG surgery) study is the first placebo-con-

Table 29.1 Treatment results of randomized controlled studies in bone marrow cell transplantation combined with coronary artery bypass grafting

Study author (ref) (year)	Sample size	Study design	Treatment group	Control group	Follow-up (mo)	LVRF/LVEDV evaluation	Change of LVEF (%)		Change of LVEDV (ml)	
							Treatment	Control	Treatment	Control
Patel et al. [3] (2005)	20	RCT	CD34 BMSC 22×10^6	CABG only[a]	6	Echocardiography	16.7 ± 3.2	6.5 ± 1.8	−22 ± 27.6	−5 ± 12.4
Hendrikx et al. [4] (2006)	20	RCT	BMC-MN $60.25 \pm 31.35 \times 10^6$	CABG only	4	Cardiac MRI	6.1 ± 8.6	3.6 ± 9.1	–	–
Stamm et al. [5] (2007)	40	RCT	CD133 BMSC 5.8×10^6	CABG only	6	Echocardiography	9.7 ± 8.8	3.4 ± 5.5	−11.1 ± 38.6	−4.4 ± 19.2
Ang et al. [6] (2008) (IC)	63	RCT	BMSC $84 \pm 56 \times 10^6$	CABG only	6	Cardiac MRI	−0.5 ± 1.8	0.7 ± 1.9	9.9 ± 14.64	17.9 ± 15.2
Ang et al. [6] (2008) (IM)	63	RCT	BMSC $115 \pm 73 \times 10^6$	CABG only	6	Cardiac MRI	4.3 ± 1.58	0.7 ± 1.9	−19.3 ± 14.82	17.9 ± 15.2
Zhao et al. [7] (2008)	36	RCT	BMC-MN 22.0×10^8	CABG only	6	Echocardiography	13.3 ± 9.2	3.9 ± 4.9	–	–
Hu et al. [8] (2011)	60	RCT	BMC-MN $13.17 \pm 10.66 \times 10^7$	CABG only	6	Cardiac MRI	10.62 ± 11.98	5.69 ± 6.87		

Values are given as mean ± SD
IC intracoronary transplantation, *IM* intramyocardium transplantation, *RCT* randomized controlled trial, *BMSC* bone marrow stem cell, *BMC-MN* bone marrow mononuclear cell, *CABG* coronary artery bypass grafting, *MRI* magnetic resonance imaging, *LVEF* left ventricular ejection fraction, *LVEDV* left ventricular end-diastolic volume
[a]Off-pump coronary artery bypass grafting

trolled, double-blinded, multicenter Phase III trial investigating the effects of intramyocardial bone marrow stem cell injection combined with CABG surgery [16]. Second limitation is that it is very difficult to correctly evaluate the effect of implantation of autologous bone marrow cells into the infarcted area, because there is some possibility that bypass grafting to the not infarcted areas may increase blood supply to the infarcted area through collateral circulation. Therefore, in order to conduct a strict evaluation, it is necessary to perform cell transplantation alone without any other coronary revascularization. But in the actual treatment of patients with severe ischemic heart disease, it is very rare that cell transplantation alone is required. Therefore, it is certain that the future cell transplantation therapy will come to be performed in combination with bypass surgery. Furthermore, off-pump bypass techniques with cell transplantation therapy may provide excellent results with fewer complications and mortality.

29.3 Skeletal Myoblast Cell Transplantation Combined with OPCAB

Skeletal myoblasts are other potential cells which have several advantages of autologous origin and the feasibility of ex vivo expansion of progenitor cells. Since the first clinical trial of myoblast transplantation combined with CABG was reported by Menasche and colleagues in 2001, several clinical studies were performed to evaluate the effectiveness of this therapy [2, 11–13].

29.3.1 Patient Population

The patient selection and preoperative baseline investigations follow bone marrow cell transplantation with CABG fundamentally. Transthoracic echocardiography and SPECT are also performed to assess global LV function, ischemia, and viability.

29.3.2 Operation Methods

Operative methods including techniques of cell injection into intramyocardium and CABG are similar to bone marrow cell transplantation. An only difference of this therapy is that the days incubating myoblast cells are necessary. Three to 5 weeks before the scheduled CABG procedure, a muscle biopsy is obtained from the vastus lateralis under sterile conditions with the patients under local anesthesia and processed immediately to obtain muscle progenitor cells. The methods of myoblast cell culture and purification are expressed in First Randomized Placebo-Controlled Study of Myoblast Transplantation (MAGIC trials) by Menasche and colleagues in detail [14]. Because the initial clinical trials in myoblast cell transplantation with CABG have developed postoperative arrhythmia including ventricular tachycardia or ventricular fibrillation, implantation of an implantable cardioverter -defibrillator (ICD) in all patients at the time of muscle biopsy or before post CABG according to local practices and amiodarone therapy starting at the time of biopsy and continued for 3 months postoperatively is strongly recommended.

29.3.3 Follow-Up and Outcomes

Postoperative follow-up is the same as bone marrow cell transplantation therapy. Effectiveness and safety of this therapy are evaluated with echocardiography and SPECT at the 30 days and 6 months postoperatively.

In short- and midterm outcomes, Dib and colleagues reported that follow-up SPECT showed new areas of glucose uptake within the infarct scar in CABG patients and echocardiography measured an average change in LVEF from 28 to 35 % at 1 year and of 36 % at 2 years. Moreover, they commented the survival and engraftment of the skeletal myoblasts expressed within the infarcted myocardium [11].

However, Menasche and colleagues recently concluded in their large prospective randomized study that myoblast injections combined with coronary surgery in patients with depressed LV function fail to improve echocardiographic heart function and the increased number of early postoperative arrhythmic events after myoblast transplantation, as well as the capability of high-dose injections to revert LV remodeling, warrants further investigation [14]. Furthermore, they commented that the potential for myoblast-induced arrhythmias remains a concern. In this way, the outcomes vary by studies; therefore further clinical research is necessary to confirm the effects of this therapy.

29.3.4 Future of Myoblast Cell Transplantation Therapy Combined with CABG

Though this therapy is performed with equal technique of cell direct injection of bone marrow cell, myoblast cell is not stable in infarcted area, and it is thought that one of the causes is poor retention and survival of the injected cell. However, the true reason of differences in both therapies remains unknown. Shudo and colleagues reported new cell delivery system using cell-sheet techniques to supplement a weak point of direct cell injection method in animal model [17]. Future clinical research is necessary, but it seems a promising cell transplantation therapy in the future.

29.4 Other Regenerative Therapy Combined with OPCAB

In cell transplantation therapy, blood supply with regard to both oxygen and nutrients into infarcted area is needed so that the transplanted cell survives. In the treatment area, natural blood flow decreases, and if sufficient blood flow is not supplied in this area into where transplanted cells are injected, cells cannot survive rightly.

Historically, cardio-omentopexy had been demonstrated as a surgical technique for myocardial revascularization for ischemic heart disease induced by autologous outside tissue. Omentum frap is a potential organ as new extra blood source to the infarcted area.

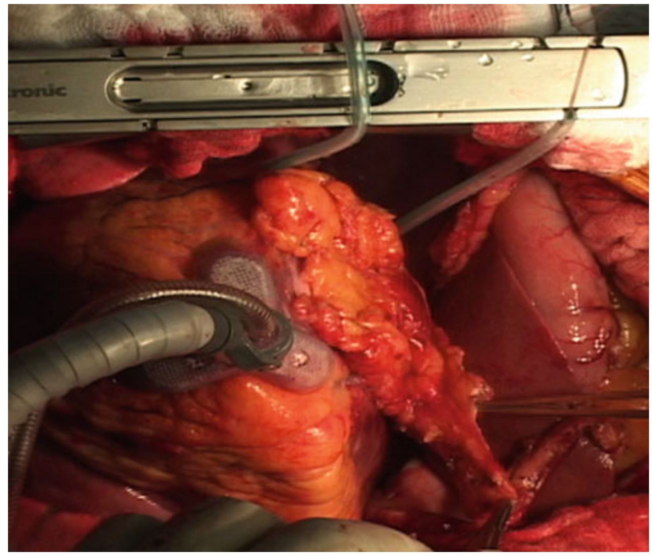

Fig. 29.4 After bone-derived mononuclear cells were injected into the myocardium including the infarcted area, epicardiectomy was performed, and the omental flap passed through the diaphragm was wrapped directly around the injected area

Authors' group investigated a new hybrid surgical angiogenesis procedure induced by transplantation of autologous bone marrow-derived mononuclear cells combined with omentopexy and evaluated the effectiveness of cell transplantation with or without omentopexy in a large animal model [18]. After having confirmed availability in animal experiment, we performed clinical application of several examples (Fig. 29.4). Clinical study of this hybrid therapy with small cases has shown the improvements of LV function. Reentry, new regenerative therapy using cell sheet with omentum, has been reported with the evidence of increased angiogenesis [19]. Further clinical research is necessary; however, this cell transplantation with cardio-omentopexy combined with CABG is another method with magnitude potential in the future.

References

1. Stamm C, Westphal B, Kleine HD, Petzsch M, Kittner C, Klinge H, Schümichen C, Nienaber CA, Freund M, Steinhoff G (2003) Autologous bone-marrow stem-cell transplantation for myocardial regeneration. Lancet 361(9351):45–46
2. Menasché P, Hagège AA, Scorsin M, Pouzet B, Desnos M, Duboc D, Schwartz K, Vilquin JT, Marolleau JP (2001) Myoblast transplantation for heart failure. Lancet 357(9252):279–280
3. Patel AN, Geffner L, Vina RF, Saslavsky J, Urschel HC Jr, Kormos R, Benetti F (2005) Surgical treatment for congestive heart failure with autologous adult stem cell transplantation: a prospective

randomized study. J Thorac Cardiovasc Surg 130(6):1631–1638. Epub 2005 Oct 26

4. Hendrikx M, Hensen K, Clijsters C, Jongen H, Koninckx R, Bijnens E, Ingels M, Jacobs A, Geukens R, Dendale P, Vijgen J, Dilling D, Steels P, Mees U, Rummens JL (2006) Recovery of regional but not global contractile function by the direct intramyocardial autologousbone marrow transplantation: results from a randomized controlled clinical trial. Circulation 114(1 Suppl):I101–I107
5. Stamm C, Kleine HD, Choi YH, Dunkelmann S, Lauffs JA, Lorenzen B, David A, Liebold A, Nienaber C, Zurakowski D, Freund M, Steinhoff G (2007) Intramyocardial delivery of CD133+bone marrow cells and coronary artery bypass grafting for chronic ischemic heart disease: safety and efficacy studies. J Thorac Cardiovasc Surg 133(3):717–725. Epub 2007 Feb 1
6. Ang KL, Chin D, Leyva F, Foley P, Kubal C, Chalil S, Srinivasan L, Bernhardt L, Stevens S, Shenje LT, Galiñanes M (2008) Randomized, controlled trial of intramuscular or intracoronary injection of autologous bone marrow cells into scarred myocardium during CABG versus CABG alone. Nat Clin Pract Cardiovasc Med 5(10):663–670. doi:10.1038/ncpcardio1321. Epub 2008 Aug 19
7. Zhao Q, Sun Y, Xia L, Chen A, Wang Z (2008) Randomized study of mononuclear bone marrow cell transplantation in patients with coronary surgery. Ann Thorac Surg 86(6):1833–1840. doi:10.1016/j.athoracsur.2008.08.068
8. Hu S, Liu S, Zheng Z, Yuan X, Li L, Lu M, Shen R, Duan F, Zhang X, Li J, Liu X, Song Y, Wang W, Zhao S, He Z, Zhang H, Yang K, Feng W, Wang X (2011) Isolated coronary artery bypass graft combined with bone marrow mononuclear cells delivered through a graft vessel for patients with previous myocardial infarction and chronic heart failure: a single-center, randomized, double-blind, placebo-controlled clinical trial. J Am Coll Cardiol 57(24):2409–2415. doi:10.1016/j.jacc.2011.01.037
9. Yerebakan C, Kaminski A, Westphal B, Donndorf P, Glass A, Liebold A, Stamm C, Steinhoff G (2011) Impact of preoperative left ventricular function and time from infarction on the long-term benefits after intramyocardial CD133(+)bone marrow stem cell transplant. J Thorac Cardiovasc Surg 142(6):1530–1539.e3. doi: 10.1016/j.jtcvs.2011.05.002. Epub 2011 Jun 12
10. Strauer BE, Steinhoff G (2011) 10 years of intracoronary and intramyocardial bone marrow stem cell therapy of the heart: from the methodological origin to clinical practice. J Am Coll Cardiol 58(11):1095–1104. doi:10.1016/j.jacc.2011.06.016. Review
11. Dib N, Michler RE, Pagani FD, Wright S, Kereiakes DJ, Lengerich R, Binkley P, Buchele D, Anand I, Swingen C, Di Carli MF, Thomas JD, Jaber WA, Opie SR, Campbell A, McCarthy P, Yeager M, Dilsizian V, Griffith BP, Korn R, Kreuger SK, Ghazoul M, MacLellan WR, Fonarow G, Eisen HJ, Dinsmore J, Diethrich E (2005) Safety and feasibility of autologous myoblast transplantation in patients with ischemic cardiomyopathy: four-year follow-up. Circulation 112(12):1748–1755
12. Gavira JJ, Herreros J, Perez A, Garcia-Velloso MJ, Barba J, Martin-Herrero F, Cañizo C, Martin-Arnau A, Martí-Climent JM, Hernández M, López-Holgado N, González-Santos JM, Martín-Luengo C, Alegria E, Prósper F (2006) Autologous skeletal myoblast transplantation in patients with nonacute myocardial infarction: 1-year follow-up. J Thorac Cardiovasc Surg 131(4):799–804
13. Zhang D, Wang L, Zhang F, Li C, Zhu T, Cao K, Ma W, Yang Z (2013) Nine-year follow-up of local implantation of autologous skeletal myoblasts in a patient with coronary heart disease. Am J Case Rep 14:139–142. doi:10.12659/AJCR.883903. Print 2013
14. Menasché P, Alfieri O, Janssens S, McKenna W, Reichenspurner H, Trinquart L, Vilquin JT, Marolleau JP, Seymour B, Larghero J, Lake S, Chatellier G, Solomon S, Desnos M, Hagège AA (2008) The Myoblast Autologous Grafting in Ischemic Cardiomyopathy (MAGIC) trial: first randomized placebo-controlled study of myoblast transplantation. Circulation 117(9):1189–1200. doi:10.1161/CIRCULATIONAHA.107.734103. Epub 2008 Feb 19
15. Nagamine H, Watanabe G, Shiobara S, Takemura H, Arai S, Tomita S (2004) Intramyocardial CD34+cell transplantation combined with off-pump coronary artery bypass grafting. Heart Surg Forum 7(4):E285–E287
16. Donndorf P, Kundt G, Kaminski A, Yerebakan C, Liebold A, Steinhoff G, Glass A (2011) Intramyocardial bone marrow stem cell transplantation during coronary artery bypass surgery: ametaanalysis. J Thorac Cardiovasc Surg 142(4):911–920. doi:10.1016/j.jtcvs.2010.12.013. Epub 2011 Mar 3. Review
17. Shudo Y, Miyagawa S, Fukushima S, Saito A, Shimizu T, Okano T, Sawa Y (2011) Novel regenerative therapy using cell-sheet covered with omentum flap delivers a huge number of cells in a porcine myocardial infarction model. J Thorac Cardiovasc Surg 142(5):1188–1196. doi:10.1016/j.jtcvs.2011.07.002. Epub 2011 Sep 14
18. Kanamori T, Watanabe G, Yasuda T, Nagamine H, Kamiya H, Koshida Y (2006) Hybrid surgical angiogenesis: omentopexy can enhance myocardial angiogenesis induced by cell therapy. Ann Thorac Surg 81(1):160–167
19. Kawamura M, Miyagawa S, Fukushima S, Saito A, Miki K, Ito E, Sougawa N, Kawamura T, Daimon T, Shimizu T, Okano T, Toda K, Sawa Y (2013) Enhanced survival of transplanted human induced pluripotent stem cell-derived cardiomyocytes by the combination of cell sheets with the pedicled omental flap technique in a porcine heart. Circulation 128(11 Suppl 1):S87–S94. doi: 10.1161/CIRCULATIONAHA.112.000366

ERRATUM

Graft–Coronary Anastomosis in Off-Pump CABG

15

Masami Ochi

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In chapter titled "***Graft–Coronary Anastomosis in Off-Pump CABG***" figure 15.14 and 15.15 are interchanged. The correct version is given below:

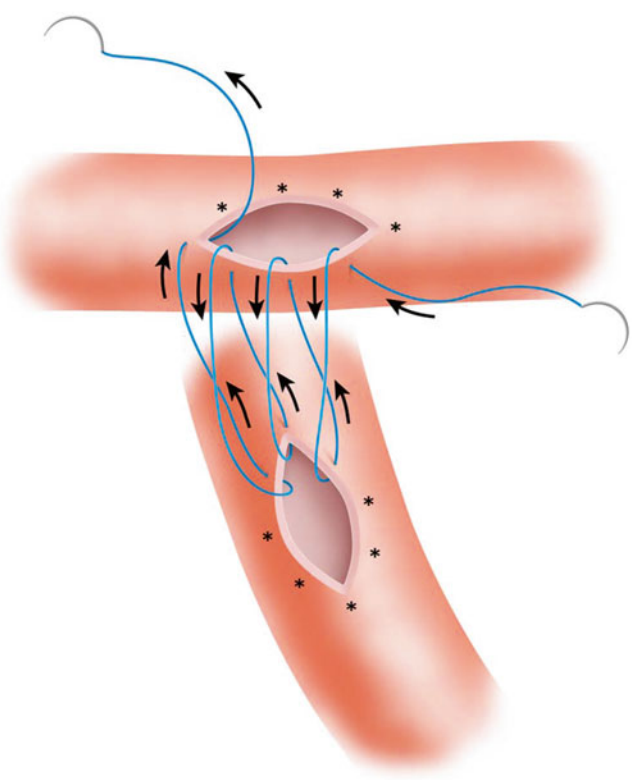

Fig. 15.14 Diamond side-to-side anastomosis

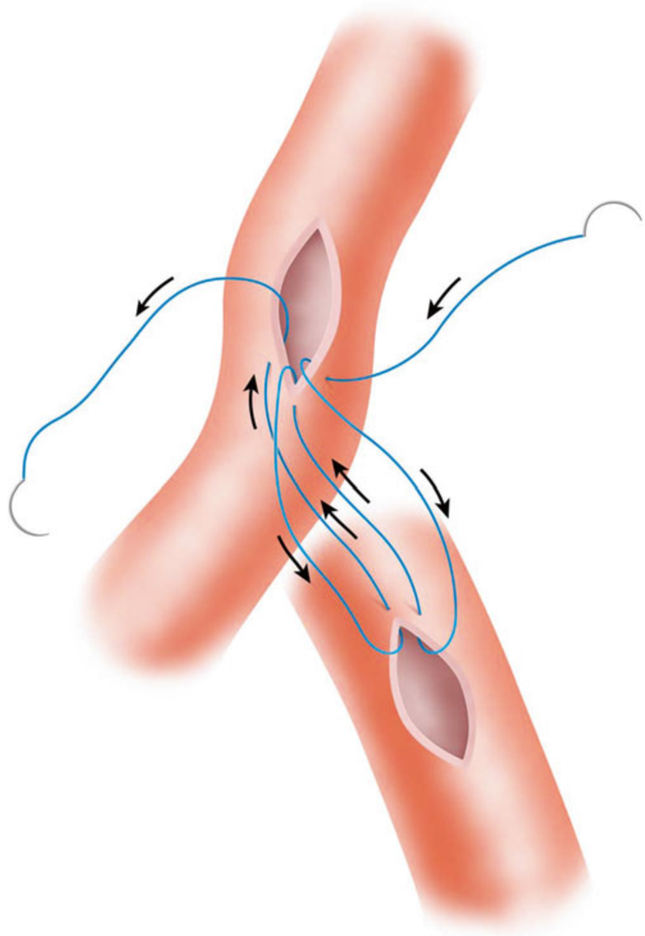

Fig. 15.15 Parallel side-to-side anastomosis

The online version of the original chapter can be found at
http://dx.doi.org/10.1007/978-4-431-54986-4_15

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