28 Hybrid Revascularization

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Introduction

The standard approach to coronary artery bypass grafting (CABG) involves a full sternotomy with bypass grafts placed to all appropriate coronary targets. There are 200,000 cases/year in the United States that use this approach, making it one of the most thoroughly investigated, improved, optimized, and streamlined surgical procedures in all of medical history. The results of a given program can be risk stratified, compared to national norms using well-defined benchmarks established by the Society of Thoracic Surgeons (STS) National Database, which drives continuous improvement. These efforts have turned CABG into a *fungible commodity* that is reproducible in a cost-effective manner by most cardiothoracic surgeons. This cost efficiency has major implications for our healthcare system because the annual expenditures for CABG exceed $10 billion.

The technique for a CABG done today remains fundamentally unchanged since it was first developed decades ago via a full median sternotomy, with complete cardiopulmonary bypass (CPB) and an arrested heart, using saphenous vein conduits to create most of the bypass grafts. Less invasive approaches that avoid the sternotomy (e.g., MIDCAB) were developed in the 1990s but are currently limited to less than 0.5% of all CABG cases in the United States. Even more modest improvements aimed at avoiding the side effects of CPB such as off-pump CABG through a full sternotomy (OPCAB) machine (CPB) have failed to achieve widespread adoption.

Robotic-assisted CABG (rCABG) is a less invasive approach to CABG that avoids a median sternotomy. Single-center studies demonstrate that rCABG attenuates the bleeding and infection risk associated with large incisions, reduces postoperative recovery times and convalescence, and shortens the duration of time for pain to resolve. After multiple clinical trials, sternotomy OPCAB has shown no advantage for these endpoints compared to on-pump CABG. This suggests that the sternotomy is an important and underappreciated driver of morbidity and recovery time while the adverse effects of CPB may have been overestimated.

Performed only at selected centers, rCABG has none of the benchmarks, standards, or "best practice" recommendations available for traditional CABG. There is no clear consensus on the best approach to performing the distal anastomoses, either hand-sewn via a left-sided minithoracotomy or created totally endoscopically using the robotic instruments (i.e., TECAB). In addition, most centers only apply rCABG for grafting the left internal mammary artery (LIMA) to the left anterior descending (LAD) coronary artery. Those patients that require multiple bypass grafts for a complete revascularization are rarely grafted with bilateral IMA (BIMA) conduits during rCABG. However, there is a greater consensus among rCABG surgeons about the utility of staged combination of both percutaneous coronary intervention (PCI) and less invasive LIMA to LAD grafting, known as the "hybrid approach." Hybrid coronary artery revascularization is tailored in a patient-specific manner so that stenting is used to treat amenable non-LAD lesions while the gold standard IMA graft is used to revascularize the critical LAD. This approach necessitates real time collaboration of a multidisciplinary team, or the "heart-team" approach. The most recent ACC/AHA guidelines have recognized hybrid procedures are a reasonable and viable approach to achieve revascularization in appropriate patients.

INDICATIONS

Standard candidate

The standard of care for treating multivessel coronary artery disease is conventional CABG or PCI. The hybrid approach is often considered in patients with factors that would limit the success of these gold standards such as a heavily calcified aorta, lack of suitable conduits for grafting, or extensive CAD not amenable to stenting. In addition, some patients are more suitable for a less invasive approach, either due to personal preference or poor surgical candidacy. For patients with stable angina due to multivessel CAD, the target with the highest-grade lesion is addressed as "step one," of a staged hybrid approach and the remaining target(s) addressed afterward.

Acute coronary syndromes

Usually after gaining experience, use of a hybrid procedure can be safely extended to selected cases with acute coronary syndromes. This requires an understanding of the "culprit lesion," or the vessel causing the acute coronary ischemia. Most typically, the culprit is revascularized first and nonculprit lesions are addressed in a staged fashion afterward. If the culprit lesion is to be addressed by PCI, then the PCI is performed first followed by rCABG in a separate setting during active clopidogrel administration and the staging is reversed if the culprit is best addressed by LIMA grafting. In the case of acute, transmural myocardial infarction, the culprit lesion is usually clearly identifiable while with NSTEMI and unstable angina, the ability to identify the exact lesion is less precise. If the culprit lesion for an acute coronary syndrome is misidentified, the patient is placed at increased risk for myocardial ischemia by the culprit lesion remaining untreated during either surgery or PCI. The risks of CABG in the setting of acute myocardial infarction are known to be increased; whether rCABG reduces this risk remains to be clarified.

Patients at risk for bleeding

Evidence suggests that hybrid revascularization can be safely applied to patients that are actively treated with potent antiplatelet agents such as clopidogrel up to the day of surgery. Active clopidogrel use increases the risk of bleeding and transfusions after rCABG but the magnitude of risk is far less than is seen after conventional CABG. A unique aspect of the rCABG procedure is that it requires the placement of ports bluntly through the chest wall (Fig. 28.1). When removed, these ports create bleeding sites that can be difficult to detect and treat. We have demonstrated that routine use of a topical hemostatic agent placed locally within these port sites helps to reduce postoperative bleeding and blood product requirements. These findings suggest that undetected bleeding from chest wall sites used for port access has likely been an underappreciated source of morbidity after rCABG.

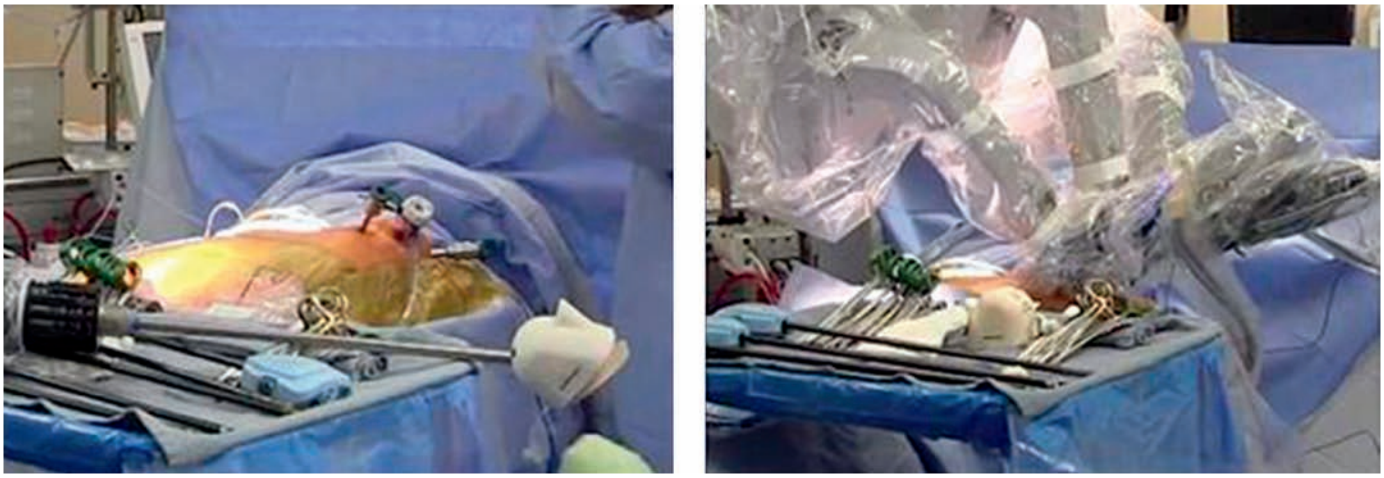

Figure 28.1 Ports with a diameter of 8 to 12 mm are introduced through intercostal spaces in a blunt fashion so that instruments and the 3D camera can be inserted into the thoracic cavity. At the completion of the case, the ports are removed and there is a potential for bleeding from any disrupted tissues. Treatment of these port sites with topical hemostatics can reduce postoperative bleeding after rCABG.

Redo surgery

As centers gain experience, candidacy for robotics can be broadened to include those that require reoperative cardiac surgery. Redo cardiac surgery via a repeat sternotomy poses unique risks that have been difficult to avoid, even at experienced centers. Sternal adhesions render the heart prone to injury during sternal reopening and when injury occurs it is associated with a remarkably high mortality rate. Cardiac manipulation to dissect these adhesions can trigger hemodynamic instability, result in prolonged CPB times, excessive bleeding, transfusions, and postoperative cardiac dysfunction. We have found that less invasive surgery helps circumvent many of these complications associated with reoperative sternotomy. Reoperation via a robotic approach improves access to the retrosternal space for precise dissection of adhesions (Fig. 28.2A) and is associated with improved safety of harvesting and grafting the right internal mammary artery (RIMA) (Fig. 28.2B). Reoperative CABG is frequently indicated in patients that have previously undergone harvest of the LIMA while the RIMA is often intact and available for harvest. Harvest of the only remaining IMA at the time of repeat sternotomy may present a risk factor for poor sternal healing and mediastinitis. However, using robotics to circumvent the sternotomy obviates any concerns for healing difficulties or mediastinitis that might otherwise follow procurement of both IMA.

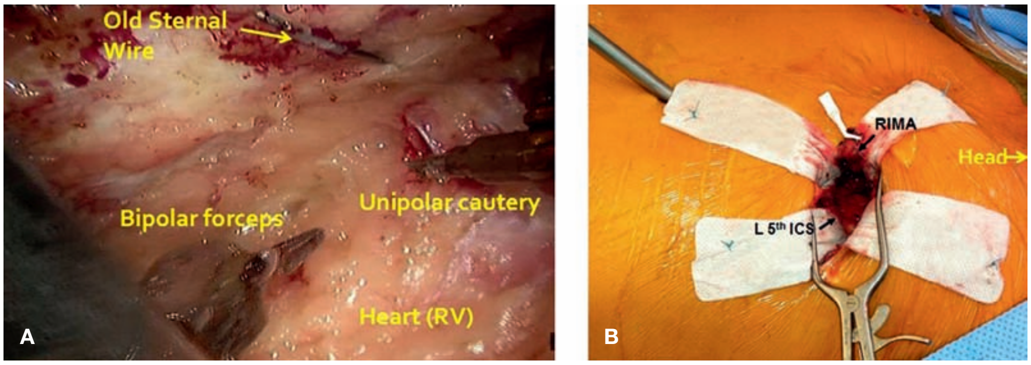

Figure 28.2 Robotic instruments and camera provide superior visualization and exposure of the retrosternal space (**A**) in comparison to the traditional approach through a repeat sternotomy. Adhesions between the heart and posterior sternum can then be precisely divided, minimizing the risks of bleeding and cardiac trauma that accompany redo sternotomy. Commonly, harvest of the right internal mammary artery (RIMA) is then followed by a hand-sewn anastomosis to the LAD coronary artery performed via a left minithoracotomy (**B**). Removal of both IMA vessels can lead to a devascularized sternum, but risk is avoided with this strategy because healing of the minithoracotomy wound is not affected.

CONTRAINDICATIONS

Although the hybrid approach is appropriate for a broad population of patients, careful patient selection is paramount. Patients with unstable hemodynamics or active coronary ischemia (e.g., ST elevations on arrival to the OR) benefit from the full cardiac exposure AQ2 and access provided by a sternotomy, making them poor candidates for the limited exposure of rCABG. Patients with pulmonary hypertension or significant lung disease that are not likely to tolerate the period of single-lung ventilation required during rCABG. Relative contraindications include those with unfavorable anatomy or lesions not amenable to complete revascularization through a less invasive approach. Given the impact that the specialized team has on the success of this procedure, rCABG is often not used in patients that present for urgent revascularization "off hours" when the robotic team is not available. Multiple grafts done using the rCABG technique are challenging in those with low left ventricular ejection fraction because surgical access to posterior or lateral wall targets is difficult, even while the heart is decompressed on peripheral CPB support. During the informed consent process, the surgeon should try to determine if the patient might prefer a more stereotyped procedure with a longer "track record" than rCABG. A patient who seems reluctant to accept the often unforeseen risks of innovation or has unrealistic expectations are at increased risk of postoperative decisional regret after rCABG and should be steered toward a traditional approach.

SURGERY

Surgical strategy for single versus multiarterial grafting for hybrid cases

Multivessel CABG via a sternotomy can be performed off-pump as long as the hemodynamics tolerate the cardiac subluxation required to expose coronary targets that are not on the anterior surface. When cardiac manipulation compromises hemodynamics, it can lead to complications related to poor tissue perfusion. The inconsistent ability to manage hemodynamics has been an important reason for the lack of widespread adoption of sternotomy OPCAB. In contrast, the heart maintains normal positioning during the typical hybrid treatment of multivessel CAD because LIMA to LAD grafting during rCABG and PCI require minimal cardiac manipulation (Fig. 28.3). As a result,

AQ9 **Figure 28.3** A minithoracotomy incision is made anterior to the mid to distal portion of the LAD, often in the fourth or fifth intercostal space. This enables the distal end of the LIMA conduit to be anastomosed to the LAD with very minimal need to manipulate the heart, thereby maintaining more stable hemodynamics during the case compared to traditional, open chest CABG.

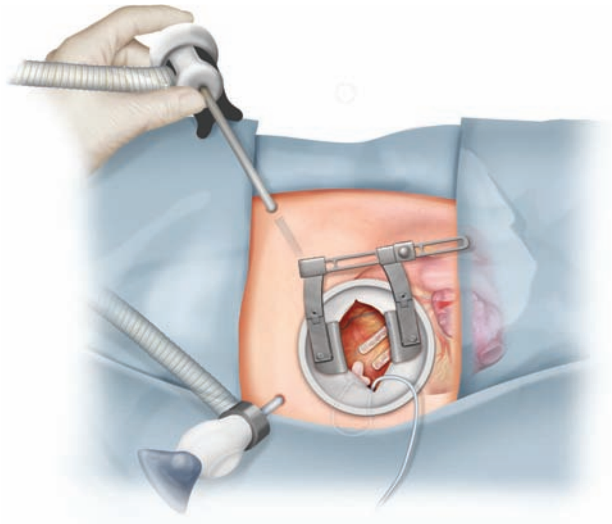

Figure 28.4 Multivessel coronary artery grafting can be achieved through a minimally invasive approach using port access exposure and stabilization devices. These devices attach to the heart using suction so it can be rotated as needed to expose and stabilize the necessary coronary targets.

hemodynamics remain more stable than either on- or off-pump CABG, thereby making hybrid cases a more reliable way to avoid intraoperative hypotension and reap the advantages of off-pump CABG.

Several centers have established the feasibility of multivessel CABG to targets other than the LAD. In contrast to isolated LIMA to LAD grafting, maintaining hemodynamics during less invasive multiarterial grafting has proven challenging, particularly when posterolateral coronary targets are planned for grafting. The technical complexity leads to prolonged operative times, and therefore long periods in which single-lung ventilation and CO_2 insufflation can provoke hemodynamic hazards while manipulating the heart off-pump. For this reason, we routinely initiate CPB via peripheral access before starting the distal anastomoses onto targets outside the anterolateral wall. Coronary artery grafting is then completed on the unloaded heart while hemodynamics and exposure of coronary targets are optimized. Depending on the quality of the distal targets, the heart can be arrested using an aortic endoclamp (HeartPort, Cardiovations) or allowed to remain beating while it is unloaded using port access exposure devices and stabilizer to facilitate the anastomoses (Fig. 28.4). CPB support enables multiarterial grafting to be accomplished less invasively with better overall hemodynamics than when attempted completely off-pump.

A potential downside of femoral artery cannulation for CPB access is a higher risk of cerebral embolism and aortic retrograde dissection. A sensitive method to predict this risk is to screen for descending aortic atherosclerosis in selected high cases using preoperative CT aortic angiography and routine screening with intraoperative transesophageal echocardiography (Fig. 28.5).

In patients contraindicated for femoral cannulation (Grade III and IV disease), we use axillary artery cannulation via an 8-mm Dacron graft sewn end-to-side to the artery (Fig. 28.6). Patients with a prior history of IVC filter placement for PE prophylaxis are contraindicated for femoral venous cannulation. In these cases, venous cannulation can be achieved via the internal jugular and/or axillary vein.

Conduit harvest

Because of the superior visualization, robotic IMA harvesting is often done with a full skeletonization technique. Unlike the use of this method in open cases, robotic skeletonization may be associated with a greater tendency to use electrocautery instead of sharp dissection (sutures, clips, scissors, etc.) when stripping off surrounding tissues from the vessel and dividing side branches (Fig. 28.7).

In addition, reduced tactile feedback while using the robot can result in greater traction during the division of side branches. Using a high-resolution imaging catheter

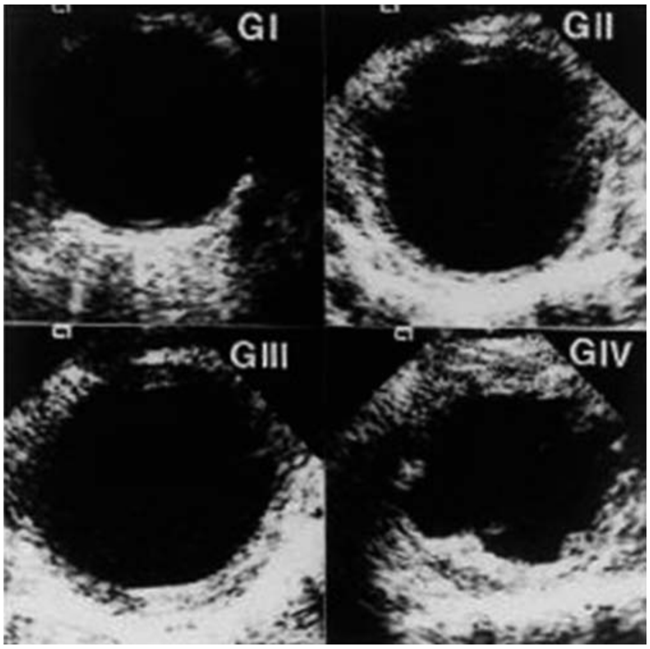

Figure 28.5 The severity of atherosclerosis in the descending aorta can be quantified by transesophageal echocardiography, which is used as a routine monitoring device for all cardiac surgical cases in most centers. Finding high-grade atherosclerosis on this examination provides a sensitive screen for patients who are at higher risk for femoral artery cannulation and would be better served by using alternate sites (e.g., axillary artery).

(optical coherence tomography, OCT, Fig. 28.8) to compare open versus robotic IMA harvest, we noted that the ostia of branches from IMA harvested robotically were a common site of intimal injury due to thermal and/or mechanical energy. While these alterations in conduit quality have not been related to long-term patency, we feel that it is prudent to enact strategies to minimize injury in the conduit to be grafted in the absence of data confirming that these abnormalities we detected are *not* clinically significant.

Grafting strategy

Several groups have demonstrated that BIMA grafting increases survival and freedom from revascularization in young patients undergoing CABG. Few sternotomy patients

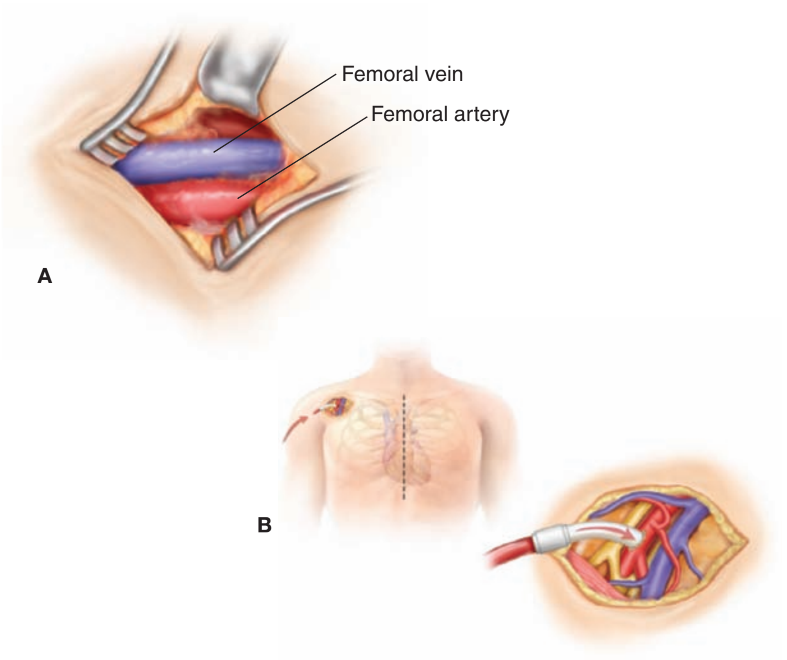

Figure 28.6 The femoral artery and vein provide most straightforward peripheral sites for acquiring the arterial and venous access needed for initiating cardiopulmonary bypass. In those patients that are not candidates for femoral cannulation, the axillary artery provides an acceptable alternative. Access to this artery requires a subclavicular incision near the deltopectoral groove and a Dacron “chimney” graft that is sewn end-to-side onto the axillary artery.

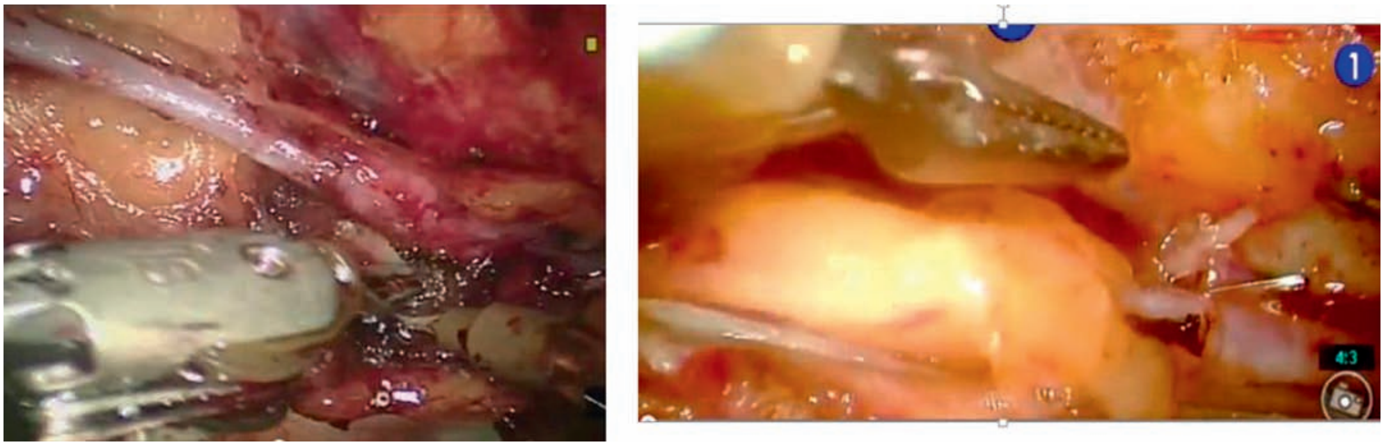

Figure 28.7 There is a tendency for surgeons that utilize robotics to harvest of IMA vessels using a full skeletonization technique because the enhanced visualization and precision provided by robotics make this method more straightforward than with an open harvesting technique (image on left). Alternatively, a pedicled technique can be used which involves retaining the concomitant veins and fatty tissue that surround the IMA.

are offered BIMA grafting due to the risk of sternal devascularization and associated postoperative sternal complications (i.e., poor wound healing and increased risk of infection). Moreover, sternal infection is considered a “never event” (i.e., Medicare will not reimburse the additional costs of care associated with this complication). Given that the added hospital costs of these unfortunate events often exceed $50K, it is apparent why the use of BIMA has been rare. Robotics facilitates the use of BIMA grafting while avoiding median sternotomy and, therefore, without the increased risks of sternal infection or poor wound healing. In patients with multivessel coronary artery disease, the use of BIMA grafting enables two targets to be addressed with gold standard conduits while the remaining lesions are addressed via PCI. The most common way to utilize BIMA conduits for grafting is as a composite “y-graft” with the LIMA grafted onto the LAD and the RIMA grafted onto a separate left-sided coronary target (Fig. 28.9). This grafting strategy avoids the limitations in length that are common when using the in situ RIMA as the conduit to be anastomosed to the LAD.

Surgical incision used to expose the distal targets

After completing the harvest of one or both IMA, the next steps are to expose the distal targets and create the graft anastomoses. A totally endoscopic approach (i.e., TECAB) accomplishes this via the same ports that were used for the IMA harvest and robotic instruments to stabilize the site and suture the distal anastomoses. Alternatively, the fifth intercostal port can be extended into a minithoracotomy in the region of the LAD.

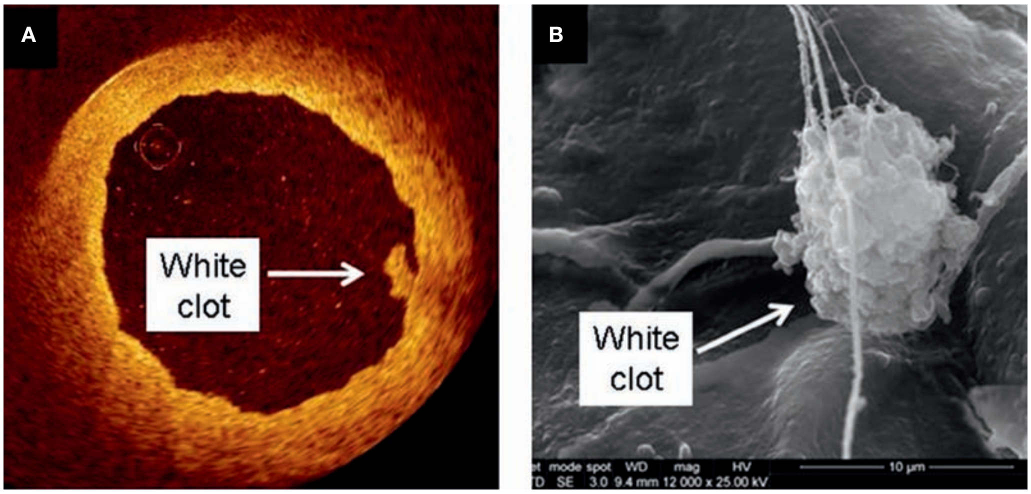

Figure 28.8 We used high-resolution OCT imaging to analyze the quality of IMA conduits harvested using a robotic skeletonized technique. As illustrated in the OCT image and scanning electron microscopic image from a registered biopsy, we noted an increased frequency of injury to the IMA intimal layer near the ostium of branches. This suggests that excessive use of cautery to divide these branches with robotics could translate into reduced conduit quality and patency. AQ10

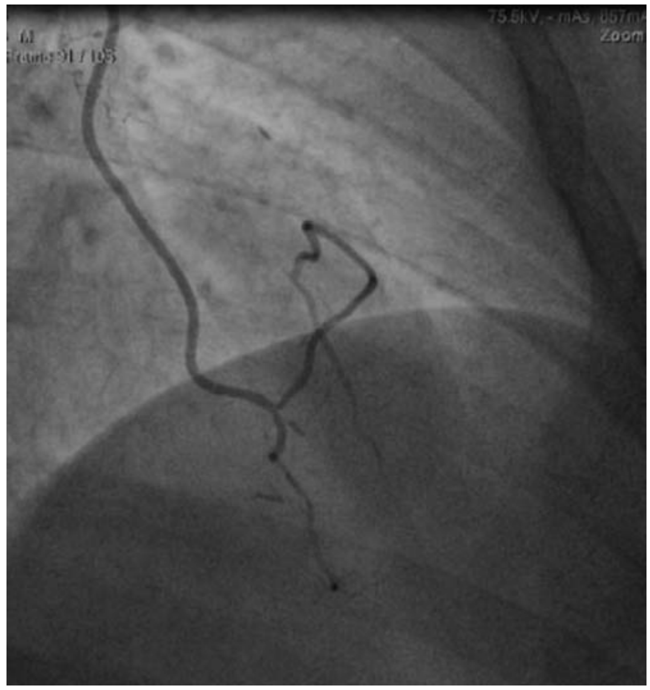

Figure 28.9 A LIMA–RIMA “y-graft” is created by anastomosing the end of the RIMA onto the side of the LIMA. The distal ends of this composite conduit are then anastomosed to the left-sided coronary targets to enable multiarterial grafting.

A soft tissue spreader is inserted so that the distal anastomoses can be created by hand
AQ3 through the minithoracotomy wound (Fig. 28.3).

Exposure and stabilization of the target sites are accomplished with port access
AQ4 devices described above (Fig. 28.4). We advocate the minithoracotomy approach for a variety of reasons:

1. Acceptability of the learning (and forgetting) curve

   TECAB places a higher technical demand on the surgeon owing to the lack of tactile feedback while performing IMA–LAD anastomosis and the necessity to precisely visualize appropriate targets for grafting. Likewise, this technique also places greater demands on the anesthesiologist to manage hemodynamics. Compared to the minithoracotomy approach, TECAB requires a longer period of CO_2 insufflation in order to expose the coronary targets, which can create a tamponade effect and lead to hypercarbia. The technical complexity of TECAB prolongs the learning curve for multiple members of the surgical team, and also increases the slope of the so-called “forgetting curve.” The forgetting curve can be described as the phenomenon of technical attrition during intervals between initial cases that result in forgetting the many lessons learned during the learning curve. The team may feel pressure to accept marginal and, perhaps, less appropriate cases to punctuate the respite between early cases that can result in poorer outcomes. Those outcomes may then lead to marginalization of the program, poorer team morale, and serve as an overall barrier to programmatic success.
2. Ease of distal anastomoses

   TECAB affords the distinct advantage of allowing the surgeon to place the anastomosis at the most optimal target site anywhere on the heart (Fig. 28.10). In contrast, target sites for the minithoracotomy approach are limited to those that are accessible via the surgical wound, which can result in suboptimal placement of the distal anastomosis. On the other hand, there is the lack of tactile feedback during TECAB but not when a graft is hand-sewn via a minithoracotomy. Therefore, TECAB may not be suitable in those cases where the distal coronary disease burden makes the tactile feedback necessary for a safe anastomosis.
3. Operative times

   The longer learning curve for TECAB is associated with longer case times for cases that are early in the team's experience than would be expected for the minithoracotomy

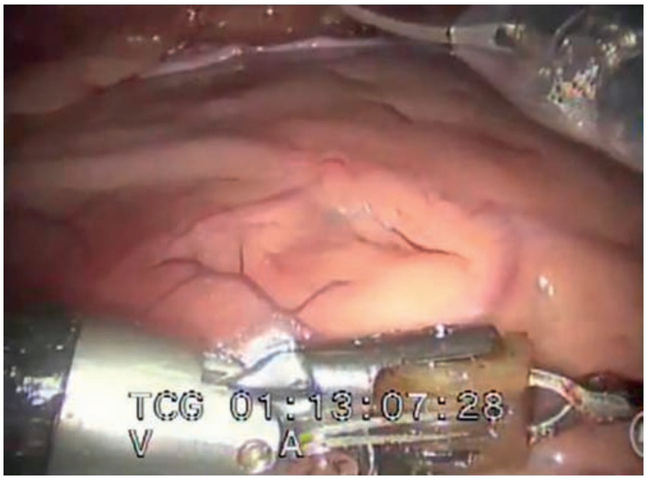

Figure 28.10 Visualization of the epicardial surface of the heart is excellent when the robotic camera and instruments are still within the left chest cavity. This allows for the coronary anatomy to be investigated and the appropriate targets to be identified far easier than when the robotic instruments are removed and the only visualization is through the minithoracotomy wound.

approach. Even in experienced hands, operative times to complete a single-vessel TECAB exceed single-vessel revascularization via minithoracotomy by approximately 1 hour, even after the team's learning curve is surmounted. This difference can create safety and fiscal concerns and is a major hurdle for hospitals with limited capacity in their operating rooms.

4. Concerns about safety

   There is a higher risk for complications due to poor hemodynamics during TECAB when compared to the minithoracotomy approach. TECAB requires increased operating times and periods of single-lung ventilation and CO_2 insufflation in order to be able to suture the distal anastomosis of the graft using robotics versus a hand-sewn method. During the period the robot is docked to instruments in the chest, the robotic arms create a barrier to patient access that could make it more difficult to resuscitate an unstable patient (Fig. 28.11). Because distal anastomoses during off-pump CABG require coronary occlusion, TECAB increases the risk of pulmonary hypertension and cardiac tamponade caused by prolonged CO_2 insufflation at a critical portion of the case. Placement of femoral arterial and venous wires a priori helps mitigate (but not eliminate) this risk by facilitating rapid access for CPB support.

5. Ability to increase hospital revenue

   Less invasive surgery has proven to be a highly marketable product that resonates with its target audience of patients who demand the least possible invasiveness for

Figure 28.11 After placing the ports into the left chest, the robotic arms are docked to these ports, enabling the instruments and camera to be manipulated by the robot. Docking the robot significantly reduces access to the patient compared to what is the norm for a traditional cardiac surgery case. This restricted working environment often raises concerns about patient safety when events occur that demand quick access for an effective response (e.g., bleeding, hemodynamic problems).

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any therapeutic procedure. Usually, patient satisfaction is not driven by technical performance of a distinctive service like rCABG but instead it is about subjective factors such as the hospital experience, access to care, and physician communication. However, rCABG creates high expectations that often drive up patient satisfaction with all aspects of their care. Using "word of mouth," many patients become advocates that help address the unmet information needs of potential candidates about this option. Combined with other modes of effective outreach, many robotic cardiac programs have been able to recruit prospective patients from outside the primary service area of the hospital.

It is uncertain if the advantages of TECAB over minithoracotomy are likely to translate into more referrals, but based on the principle that patients ultimately tend to endorse the option that requires the least possible invasiveness, TECAB is likely to have an edge on patient recruitment. As web-based marketing increases the public's understanding of the technical nuances of these two methods, it is possible that motivated customers may drive the adoption of TECAB even further.

6. Hospital Costs

   Greater technical demands of TECAB lead to a more protracted learning curve than expected during the adoption of the minithoracotomy approach. Therefore, more TECAB cases are likely to have prolonged operative times and heightened risks of complications, thereby increasing labor costs and hospital length of stay. Even after the learning curve period, TECAB has fixed higher average costs than the minithoracotomy approach due to significantly higher disposable costs and consistently longer operative times. There are approximately $10K/case of additional costs for
AQ5 TECAB including the robotic endoscopic stabilizer, percutaneous endoclamp for cardiac arrest, and use of distal anastomotic devices. None of these devices tend to be
AQ6 used in the minithoracotomy cases.

7. Broad acceptance among stakeholders

There is a tendency for the public media to promote new technologies as "the next big thing" prematurely during their early adoption before any experience has accrued. For a high-risk procedure like rCABG, this timing coincides with the learning curve phase and a heightened risk of adverse events. The combination of excessive fanfare and unforeseen problems during this phase can create gaps between expectations and perceived quality, triggering dissatisfaction among patients, the team, and other "internal customers." Problems during this early adoption phase are further compounded when support for the new program must be gained by leaders within the organization. Stakeholders can become disillusioned about rCABG, take action and lock others into a collective choice against the new procedure. The shorter learning curve associated with the minithoracotomy approach has a greater chance for acceptance, at least initially until this "hype effect" subsides.

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Nontechnical Skills

Train the Team

Marketing data from Intuitive Surgical has documented that at least 90% of the approximately 400 cardiac surgeons that have been to robotic training have failed to develop sustainable programs in robotic CT surgery. This dismal track record has led many surgeons to conclude that the technical complexities of robotic heart surgery are not safely surmountable. First and foremost, achieving a successful program requires a team that is able to rapidly progress through the vulnerable learning curve phase. Because there is no validated training strategy, the current default path is "learning by doing" during the early cases. With this approach, most teams require at least 100 cases of experience done over the span of a year to complete the learning curve. While educational theory suggests this type of experiential learning is often effective, long OR times and adverse events in patients can compromise team morale and create a poor learning environment. Shortening the learning curve starts with articulating how progress with learning will be measured. The standard quality improvement tools used to monitor conventional cardiac surgery—review of incident reports, chart audits, autopsy findings, morbidity and mortality conferences, administrative data, and patient complaints—are insensitive measures of the learning curve. Instead, a broader array of metrics are needed that reflect performance of the surgeon (i.e., prolonged operative times, markers of myocardial injury), perioperative team (i.e., rates of postoperative morbidity or reintubation, poor pain control, excess transfusions), and hospital (i.e., prolonged hospital stay, higher costs). Regular, multidisciplinary review of the data outside the OR is required to identify areas that need improvement and create specific action plans. This transparency signals to the team that there is the "psychological safety" needed for members to learn from mistakes and actively engage in troubleshooting.

Improve the safety of rCABG

The technical complexity of operating on the heart within the relatively tight and constrained chest cavity yields important safety concerns. The potential for sudden bleeding, either from the heart or vascular sources such as the IMA, cardiac fibrillation, ischemia, and hemodynamic collapse are difficult to address when working in a closed chest with bulky robotic arms blocking access to the patient. Indeed, to adequately address these concerns, best practices must be developed that facilitate early identification and appropriate responses to impending decompensation in the absence of direct inspection of the heart. This may include better utilizing TEE data, hemodynamics, better team communication, heightened "situational awareness," and standardized and reliable bail out strategies to respond to those changes. Similar to the learning curve for surgeons engaged in performing the technical aspects of this procedure, the nursing and anesthesia staff must also undergo complex training in order to complete their learning curve. The timeout period prior to skin incision is an excellent time for a verbal "rehearsal" of all the potential complications that could occur intraop and the proposed strategies to deal with them (Fig. 28.12). This improves team morale, if nothing else, which is a critical focus of improving the safety of the procedure. Developing and validating additional strategies for improving progress through the learning curve is critical for programmatic success.

Establish strategic accounting

The added costs of less invasive CABG are widely perceived to be a disadvantage that has limited its adoption. In fact, most literature on this topic has demonstrated that less postoperative costs (e.g., shorter length of stay, less blood loss, less postoperative complications) are able to offset the higher variable costs in the OR (e.g., longer operative times, more costs for disposable supplies). An underappreciated issue regarding cost-effectiveness is the learning curve period that can have a substantial impact on costs. These costs are dynamic with initial costs higher but later decline as experience accrues for the surgeon and staff. As the robotic program grows, there also is a reduction in

Figure 28.12 Formal briefing/timeout with the team at the beginning of the case provides a chance to verbally "rehearse" the bailout options to be used in response to any anticipated complications. Because these bailouts are not part of the routine in a standard cardiac surgery OR, this is an ideal opportunity to confirm that the necessary expertise and resources are available if needed. AQ12

costs amortized on a per case basis such as the learning curve and capital acquisition. Surgical innovation requires new, strategic accounting practices that define these early inefficiencies as sunk costs and therefore unhelpful in forecasts of program profitability.

A "value framework" accounts for incremental costs in relation to incremental benefits. Some of these benefits are seen from the perspective of society such as a quicker convalescence that reduces leave from work, lost salary or utilization of sick pay, and less risk of underemployment when returning to work after a lengthy recuperation. While these benefits are difficult to quantify from the perspective of the hospital, the following issues can be demonstrated to impact profitability using an opportunity cost analysis:

1. *Improve performance on P4P programs.* Designating a sternal infection as a "never event" by Medicare means that each sternal infection leads to unreimbursed costs that range from $50,000 to 100,000/case. This strongly incentivizes nonsternotomy approaches for cardiac surgical referrals with diabetes, obesity, lung disease, and other risk factors for sternal infection. Also, improvement in patient satisfaction from robotics helps performance in the Medicare P4P program called value-based purchasing.
2. *Improved performance on STS composite quality rating.* Stroke and mediastinitis are complications after CABG that are monitored and publically reported as part of the STS star rating. Many insurance plans (UnitedHealth, Blue Cross/Blue Shield) designate CT surgery programs as a "center of excellence" (COE) based on achieving the highest (3 star) rating. Robotic cases avoid aortic manipulation and the sternotomy, increasing the chance for a COE designation that can be leveraged to negotiate higher reimbursement rates for CT surgical procedures.
3. *Improved operational efficiencies.* Shorter recovery time after less invasive surgery allows the hospital to leverage operational efficiencies in bed utilization. Earlier discharge after less invasive procedures allows hospitals to capture a larger share of DRG reimbursements as revenue and admit another patient that might not otherwise been able to in the case of a bed shortage.
4. *Improved payer mix.* A less invasive, distinctive program is able to recruit patients via word of mouth and other marketing media that often are more educated, have higher incomes, and covered by private insurance instead of Medicare/Medicaid. A change in the payer mix allows the hospital to capture a greater proportion of charges as revenue.

Manage the Competitive Landscape

While rCABG is highly attractive to patients, it is controversial because it challenges a well-entrenched *status quo.* The response provoked by a new rCABG program occurs in a predictable manner similar to a pattern seen with other disruptive technologies. The combination of high expectations about the program and the unforeseen risk of the learning curve can create a large gap between expectations and reality. After the learning curve rCABG can become safe and effective, yet perceptions of early experiences are difficult to change and can remain a persistent hindrance to its widespread acceptance.

Any form of advertising for an innovative surgical procedure, particularly robotic heart surgery, has been universally greeted with great skepticism and concern. However, many patients that would be appropriate candidates undergo traditional CABG because they either are not informed or learn about rCABG at relatively late stages in their work-ups. While the exact reasons why such information would not be shared are unclear, oftentimes it is merely because patients' healthcare providers are unable to provide confident advice about a novel procedure for which they have no personal experience. Extensive research has documented that variation in the use of "preference sensitive" therapies are often based on preferences of the surgeon and their referral sources rather than those of the patient. In this context, marketing of rCABG can serve an important information purpose to the community. Patient surveys have been consistently favorable about the usefulness of DTCA toward mitigating the adverse effects of information asymmetry. Ads are particularly empowering when they include a "call to action" that engages patients to become more involved in obtaining a second opinion or visiting a website with credible information about rCABG.

It must be pointed out that, at least in the experience of the authors, members of the *status quo* usually initiate their own marketing as a response to a new robotic, less invasive program, albeit directed to internal stakeholders in cardiac surgery (e.g., cardiologists, administrators, nurses). Absent unambiguous evidence that the traditional CABG is superior, cardiac surgeons faced with competition from rCABG develop defensive strategies designed to discourage patients and their providers to investigate this alternative. A surgeon cannot prevent consumers from hearing claims about rCABG, but can stress the logic of "why change if it works" and emphasize the risks of experimentation. Incidentally, this is a classic marketing strategy used in the past by general surgeons objecting to laparoscopic cholecystectomy in the early 1990s and many market leaders responding to new entrants in industries outside of healthcare.

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While effective, this defensive strategy deserves reconsideration and possibly revision in light of growing interest in patient empowerment and shared decision making. At a minimum, the notion of shared decision making requires practitioners to discuss all therapeutic options that a "reasonable patient" would want to know. It is clear based on the growth of PCI that patients have a strong interest in less invasive means of coronary revascularization.

Recommended References and Readings

Christensen CM. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail.* Boston, MA: Harvard Business Review Press; 2013.

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Levine GN, Bates ER, Blankenship JC, et al. 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.* 2011;58(24):e44–e122.

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AQ1: Please note that there is only one author mentioned in the TOC whereas three are in the document.
AQ2: Please check the sentence "Patients with pulmonary hypertension.... ventilation required during rCABG", for clarity.
AQ3: (Reviewer comment) Please verify this is correct figure reference
AQ4: (Reviewer comment) Please verify this is correct figure reference
AQ5: (Reviewer comment) Can we delete?
AQ6: (Reviewer comment) Can we delete?
AQ7: Please check the sentence "Absent unambiguous evidence .... this alternative" for clarity.
AQ8: Please note that "28" and "29" in the sentence "Incidentally, this is a classic ...... industries outside of health-care are deleted as these are reference numbers, please check.
AQ9: Please note that there are two figures (left and right) in art pdf for figure 28.3, but is not mentioned in the figure caption.
AQ10: Please note that there are two figures (A and B) in art pdf for figure 28.8, but is not mentioned in the figure caption.
AQ11: Please note that there are two figures in art pdf for figure 28.11, but is not differentiated in the figure caption.
AQ12: (Reviewer comment) Finalize figure number after issue resolved above re: hospital costs section