25 Cardiac Surgery Advances: Do We Still Remember How to Do the Open Bypass?

Soroosh Kiani and Robert S. Poston

Strengths and Weakness of Traditional CABG

Traditional coronary artery bypass grafting (CABG), characterized by a full sternotomy and harvest of venous conduits, is one of the most thoroughly performed and investigated surgical procedures in medical history. CABG volume exceeds 200,000 cases/year only in the USA and has been the subject of multiple randomized controlled prospective clinical trials and retrospective analyses. Based on this extensive experience, this procedure has been continuously improved, optimized, and streamlined and now lends itself to rigorous statistical comparisons of outcomes against well-defined benchmarks from the Society of Thoracic Surgeons (STS) national database. CABG programs have followed methods analogous to those of efficient manufacturing [1] to exploit this strong evidence base in order to create detailed and reproducible management protocols that minimize error and reduce costs. At the same time, CABG has evolved into a fungible *commodity* capable of being provided with reproducible outcomes by most board-certified CT surgeons. Reproducibility enables quality to be tracked with credible metrics that are publically reported and linked to reimbursement through pay-for-performance initiatives. All these issues have been good for healthcare policy. Patients at rural settings that have limited ability to travel have been able to obtain CABG as safely at smaller facilities as the large-volume centers. Moreover, efficiency drives cost containment, which has major implications to our healthcare system given estimated annual expenditures for CABG that exceed $10 billion [2].

A strong value network has developed around CABG based on its stability and familiarity which, paradoxically, poses an important barrier to innovation. Significant changes in surgical technique obligate a learning curve that is associated with transient period of inefficiency. Surgeons have been reluctant to accept this learning period even in the face of competition with nonsurgical options to treat severe coronary diseases such as percutaneous interventions (PCI) [3, 4]. While it is estimated that at least 30 % of all heart surgeons have attempted less invasive approaches to CABG, most have not persisted long enough to get through the learning curve and these techniques are used in less than 0.5 % of all CABG cases in the USA [5]. Even modest innovations have failed to achieve wide-

S. Kiani, M.D., M.S., M.A.
Department of Internal Medicine, University of Virginia, Charlottesville, VA, USA
e-mail: soroosh@bu.edu

R.S. Poston, M.D. (✉)
Department of Cardiothoracic Surgery, St Francis Medical Center, Trenton, NJ, USA
e-mail: postonlab@gmail.com

R. Latifi et al. (eds.), *Technological Advances in Surgery, Trauma and Critical Care*,
DOI 10.1007/978-1-4939-2671-8_25

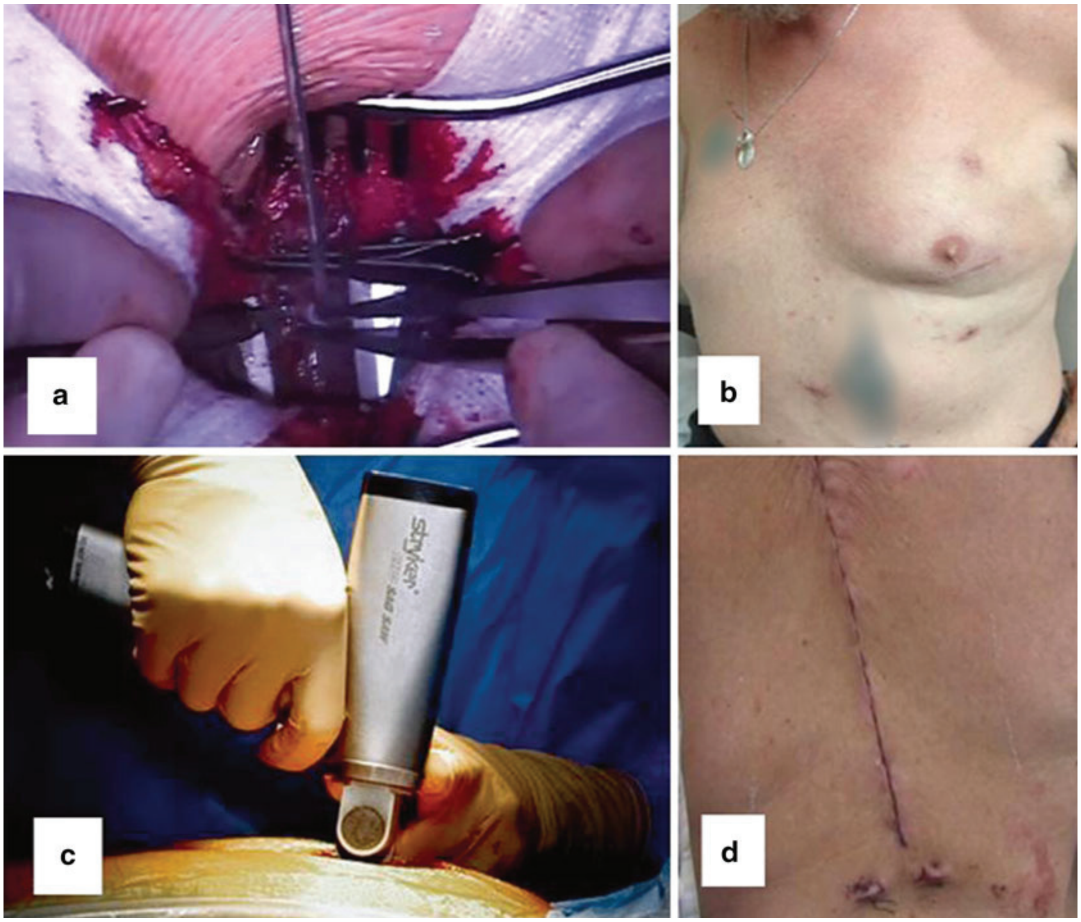

Fig. 25.1 In the less invasive approach, the surgeon can perform a direct, hand-sewn anastomosis of the LIMA to the LAD via a minithoracotomy using the same surgical instruments that would be used in the standard approach (**a**). A sternotomy is avoided by inserting robotic instruments through incisions in the left chest (**b**). In contrast, the standard incision for CABG utilizes a sternal saw (Stryker, Kalamazoo, MI) to widely open the chest cavity via a sternotomy (**c**, **d**)

spread adoption. For example, off-pump CABG via full sternotomy (OPCAB) to avoid side effects from cardiopulmonary bypass (CPB) is done by less than 20 % of surgeons [6]. As of 2014, the mainstay of surgical therapy for coronary heart disease remains fundamentally the same approach to CABG developed 20 years ago: complete CPB, an arrested heart, full median sternotomy, and grafts mainly consisting of saphenous veins.

Strengths and Weaknesses of Less Invasive Surgical Alternatives

Robotic assistance enables less invasive CABG without a median sternotomy (rCABG). Distal anastomoses during rCABG are performed by hand (i.e., minimally invasive direct coronary artery bypass grafting, MIDCAB) or totally endoscopically (TECAB) (Fig. 25.1a–d). Single-center reports about rCABG suggest attenuation of the bleeding and infection risk, reduced postoperative recovery times and convalescence, and shortening of the duration required for pain to resolve [7]. Many of these advantages were anticipated from the sternotomy OPCAB approach, but did not materialize. This suggests that the surgical incision is a more important (and previously underappreciated) driver of morbidity and recovery time than the use of CPB.

An important advantage of rCABG is the ability of this approach to interface with and take advantage of rapidly advancing technology in the field of computers and robotics to further improve surgical outcomes. For example, surgical loupes are used during standard CABG to enhance visualization of the microvascular anastomoses. Loupes provide limited magnification and ability to integrate visual data and represent relatively terminal technology with diminished prospects for future advances. On the other hand, a robotic workstation enables the surgeon to zoom in and out on the relevant anatomy, enhance magnification, and optimize lighting and resolution without sacrificing three-dimensional vision. Dexterity and tremor can be improved by translating larger, choppier movements of the human hand in smaller, better controlled movements of the instruments that interact at the patient end. While learning to perform the entire less invasive procedure is complex, the skills required to use robotic technology itself are acquired far quicker than those required for laparoscopy. This difference from laparoscopy has given robotics the reputation as a "democratizing tool" because it provides a wider range of surgeons with the ability to complete the technical tasks of less invasive procedures.

Further developments in imaging technologies may one day offer the surgeon the ability to detail surgical anatomy or identify other problems beyond what is visible to the human eye. While the existing surgical robot lacks tactile feedback—as subsequent advances in robotics are made, technology is under development that will actually *enhance* tactile feedback when using robotics compared to the human hand. Moreover, as new and competitive companies generating technologies for robotics emerge, the rate of further technological advancement is expected to grow as well. A potential caveat of all these advances is that surgeons may become too accustomed to having these new tools available, making it possible to forget how to do the open approach.

Strength: Patient Satisfaction

Regardless of the surgical approach that predominates, a successful CABG program drives patient traffic and acceptable levels of patient satisfaction because of the impact of this procedure on patient quality of life. Nevertheless, patients have shown a strong preference to know about less invasive surgery. Oftentimes, patients that require referral to a cardiac surgeon learn about their options from their medical providers and the surgeons to whom they are referred. Wide variability in the use of less invasive techniques suggests that centers only offering the traditional approach may not notify patients about all surgical alternatives [1, 2]. This lack of disclosure may result because physicians are unable to provide confident advice about a procedure for which they have no personal experience. Alternatively, the perceived advantages of r-CABG may be less meaningful to physicians than they are to patients. In either case, the assumption that a physician's rank order of priorities to be achieved from surgery is always the same as the patient's undermines patient decision making for preference-sensitive conditions. Instead, preferences of the surgeon and their referral sources have led r-CABG to be underutilized compared to what patients would otherwise demand [8, 9].

Because most patients referred for elective CABG have sufficient time to participate in the decision about where they receive their care [4], knowledge about r-CABG drives patients into programs offering this distinctive service that otherwise would not have come. As a result, these patients appreciate the clinical benefits derived from the procedure itself and that they were provided with information that might not have been discussed at other centers. Such a discussion is meaningful because it alleviates their vulnerability caused by asymmetry of information and empowers them with alternatives relevant to their personal needs, principles on which patient-centered care is based [5]. Patients and their families often become engaged in the idea that success for these novel programs helps foster transparency and beneficial competition in healthcare. For all these reasons, initiating a robotic cardiac surgical program drives up patient satisfaction scores and creates loyal advocates of the program. Supplemental strategies are also effective at improving satisfaction scores such as communicating with respect, sitting instead of standing at the bedside, the AIDET tool, face cards given to patients that describe the members of their care team, and follow-up phone calls. While these tools enhance the patient experience, none have the same fundamental impact of providing patients with a distinctive option that they highly value but cannot get elsewhere.

Patient satisfaction scores have become increasingly relevant because these data are publically reported [10] and influence pay-for-performance programs. Moreover, high scores have been shown to reduce legal exposure to malpractice suits [11]. Patient have demonstrated strong preferences for less invasive surgery [12], underscoring the role for surgical innovation as key part of a strategy for achieving patient-centered care [7, 13–17]. In addition to technical aspects of care (such as whether surgery is performed less invasively), overall patient satisfaction is also driven by ambiguous issues such as hospital experience, access to care, personality of the physician, and honest communication and other. Because ambiguous issues are difficult for the patient to judge, many patients will assimilate their opinions on these other issues to fit with their favorable first impressions about a distinctive service like rCABG, driving up satisfaction scores across the board.

Weakness: The Learning Curve

A prolonged period of inefficiency that must be endured before the team establishes proficiency at r-CABG is known as the "learning curve." A major weakness of rCABG is that difficulties with the learning curve can translate into more risk for the cardiac surgical patient than in other surgical specialties. Complications during the learning curve that occur often could have been prevented by more experience with technique and/or communication. This creates a stark contrast to the incumbent procedure where few are deemed to be preventable [18]. Despite the inherent bias from comparing a nascent r-CABG program in its early stages against a mature sternotomy CABG program, such comparisons often occur and lead critics to conclude that the challenges of r-CABG are not safely surmountable.

Because of the vulnerability that the learning curve causes for patients and the program, an important focus for the r-CABG team is to make rapid progress during this period. There are many examples of complex cardiovascular procedures that have endured lengthy learning curves to become accepted alternatives that compare quite favorably with the incumbent procedure. However, current training paradigms require at least 100 cases of experience that accumulate within time frames often exceeding a year in order to demonstrate proficiency [13]. The predominant training strategy has been experiential learning, or "learning by doing" on actual clinical cases. Under normal circumstances, educational theory suggests that experiential learning is more effective than other formal methods of training [19]. But team morale can be affected by preventable complications during the learning curve, which creates a poor learning environment [19]. Ineffective team learning aggravates the risks of the new rCABG program and limits the chances for sustainable success.

Evidence that programs have been able to shorten the learning curve has revealed some strategies that consistently work. The process starts with articulating how progress during this learning period will be measured, i.e., metrics of success. Standard quality assurance tools of conventional cardiac surgery include the review of incident reports, chart audits, autopsy findings, morbidity and mortality conferences, administrative data, and patient complaints. These are insensitive measures of progress with the learning curve of r-CABG. Successful programs use a much broader array of metrics that reflect performance of the surgeon (e.g., prolonged operative times, markers of myocardial injury), perioperative team (e.g., rates of postoperative morbidity or re-intubation, poor pain control, excess transfusions), and hospital (e.g., prolonged hospital stay, higher costs). Review of these data will likely reveal that the learning curve is impacted by stakeholders that extend well beyond the OR team. These team members are not passive observers of the robotic surgeon but actively influence the learning curve by accommodating their tasks to the new program. Evidence from the US Military has demonstrated that even the best teams typically have limited capacity to address the burdens of change during high tempo periods and require team debriefings to optimize learning [20]. Emulating this model with regular, multidisciplinary review of the data outside the OR is required to identify areas that need improvement and create specific action plans. These meetings signal to the team that there is the "psychological safety" needed for members to learn from mistakes and actively engage in troubleshooting [17].

Based on the irreplaceable role of the lead surgeon, it is tempting to conclude that the technical ability and experience of the surgeon are sufficient for the success of rCABG programs. However, Dhawan et al. showed that a lead surgeon with >300 cases of prior r-CABG experience at the outset when he initiated a new program was unable to avoid a substantial de novo learning curve [21]. Surrogates of the technical skill of a surgeon such as dexterity on simulators or how quickly their procedure times decline over time have not been found to correlate with the sustainability of robotic programs [21]. Instead, there are many nontechnical skills required to manage and lead change at the level of the organization that appear to be critical for success [22].

An often overlooked challenge posed by rCABG is a significant "forgetting curve." Early cases are often scheduled infrequently until the procedure becomes recognized and popularized among those that are appropriate candidates. If the frequency of scheduling early cases is too long, skills acquired from previous cases lapse and the learning curve becomes longer than it would with higher caseloads. This leaves surgical programs in a conundrum—the requirement of up-front volume in order to solidify training in a program that is new and requires time to ramp up its volume of referrals. The forgetting curve may be mitigated to some degree by training programs, including virtual reality simulator and cadaveric training. One benefit of the robotic console is the ability to use it to create "virtual environments." Utilizing available virtual simulators, as well as animal and human cadaveric training labs can be helpful to improve surgeon and team skill without exposing clinical patients to additional risk [23, 24]. Despite the promise of this approach and demonstrated utility in other surgical specialties, a validated curriculum for rCABG training has not been established and funding for these programs can be a challenge.

Weakness: Additional Safety Concerns

Likewise, the technical complexity of operating on the heart within the relatively tight and constrained chest cavity has given rise to safety concerns. The potential for sudden bleeding, either from the heart or vascular sources such as the IMA, cardiac fibrillation, ischemia, and hemodynamic collapse, is difficult to address when working in a closed chest and with the bulky arms of the robot hindering patient access (Fig. 25.2a, b). 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

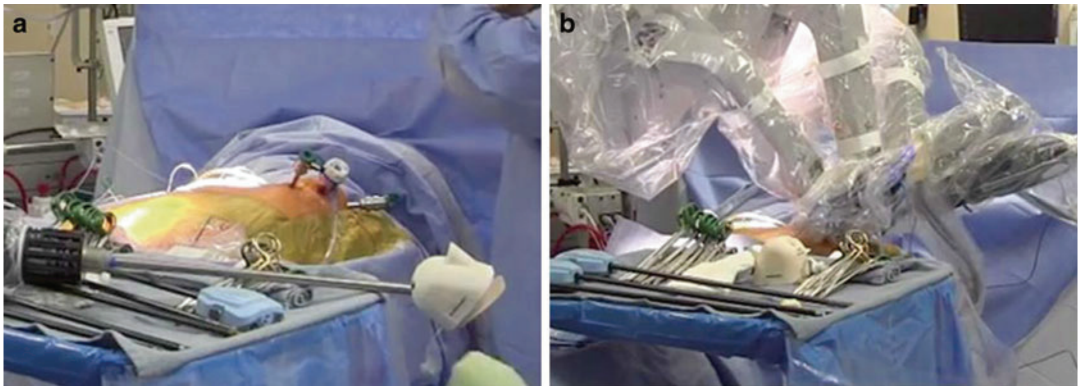

Fig. 25.2 Robotic cases are initiated by inserting ports (diameter 8–12 mm) in between the ribs in the left chest (**a**). The robot is then brought into the field, covered by sterile drapes, and docked to these ports. Docking enables the robotic instruments and camera to be inserted into the ports and controlled by the surgeon sitting at the console. An important risk of this setup is that access to the patient is limited after docking (**b**). If a patient were to develop the type of catastrophe that can happen during CABG (e.g., fibrillation or sudden hemodynamic collapse), the rapid access required to deal with these circumstances is hindered after docking

better utilizing TEE data, hemodynamics, better team communication, heightened "situational awareness," and standardized and reliable protocols to respond to those changes. While a learning curve for physicians performing the procedure has been clearly identified, staff must also undergo technically complex training. It is often argued that the inherent complexity of the robotic approach will never afford the surgical team the ability to achieve results equivalent to those seen with a sternotomy, leading to a fixed higher risk of error. The associated learning curve and concerns about overall safety may also be demoralizing to the team which can be a latent risk factor for preventable complications. Team morale, therefore, is a critical focus of improving the safety of the procedure. Developing and validating strategies for rapid progress through the learning curve and gaining "buy-in" about the benefits of less invasive surgery will be critical in enabling programmatic success.

Weakness: Cost Concerns

The added costs of less invasive CABG are widely perceived to be a disadvantage that limits its adoption. The additional time and expertise required for preparing the robotic apparatus prolong operating room times and alter the efficiency of the OR staff. Even after the learning curve is complete, multivessel revascularization by rCABG usually takes longer than sternotomy CABG. This may pose a significant hurdle to success at those hospitals where OR capacity is already a bottleneck for revenue generation and would be understandably reluctant to use this precious resource inefficiently.

The literature has demonstrated the cost-effectiveness of surgical robotics versus the standard approach for multiple cardiothoracic procedures. Most of these analyses have shown higher variable costs in the OR (e.g., longer operative times, more costs for disposable supplies) offset by less postoperative costs (e.g., shorter length of stay, less blood loss, less postoperative complications). However, any technically complex new procedure will have a learning curve period that reduces cost efficiency. Costs per case during the learning curve are dynamic—initial cost/case is high but declines as experience accrues for the surgeon and staff. In addition, case volumes increase as the robotic program becomes recognized, which reduces fixed costs/case by an effect known as economies of scale. Therefore, innovation in surgery must be met with innovation in accounting practices such as the designation of costs from capital expenses and the learning curve as sunk costs. This designation is rational because it eliminates the use of these costs to influence forecasts of future profitability of the r-CABG program after the learning curve is completed.

Much of the value created by rCABG is not directly measured by the hospital. For instance, a quick convalescence might a minimal impact on patients' hospital recovery but substantial impact on their need to take leave from work, request sick pay and return to work underemployed [19]. These are benefits to society but do not influence hospital costs or profitability. Other advantages become apparent when assessing the incremental cost-effectiveness of rCABG relative to conventional CABG. Unfortunately these advantages are often overlooked. This is because standard profit-loss statements that provide the basis for most hospital's strategic decision making do not often include an assessment of opportunity costs. The following are examples of these relative advantages of r-CABG:

1. *Reduce* "*never events*": A sternal infection has been designated as a "never event" by Medicare [25]. This offers a strong incentive for developing non-sternal splitting procedures for cardiac surgery in order to reduce the risk of this complication. Many patients referred for cardiac surgery often have diabetes, obesity, lung disease, and other risk factors for sternal infection and mediastinitis. This "never event" in a patient with Medicare, regardless of preexisting conditions, leads to unreimbursed costs that range from $50,000 to 100,000 per case of sternal infection.
2. *Improved performance on quality rating scores*: By avoiding aortic manipulation and the sternotomy, r-CABG consistently reduces the risk of stroke and mediastinitis. These major complications are publically reported as part of the composite quality rating score from the STS. In addition, less invasive surgery improves patient satisfaction, which is a metric of the quality measurement program called value-based purchasing. Many insurance plans (UnitedHealth, Blue Cross/Blue Shield) designate CT surgery programs as a "center of excellence" (COE) based on their ratings from these quality scores. COE designation can be leveraged by the hospital to negotiate higher reimbursement rates for other cardiac procedures.
3. *Improved operational efficiencies*: Shorter recovery time after less invasive surgery allows the hospital to leverage operational efficiencies in bed utilization and ICU resources, thereby capturing a larger share of DRG reimbursements as revenue. In a hospital that is near or at full capacity, an early discharge also frees up an available bed so that another patient can be admitted that might not otherwise been able to in the case of a bed shortage. Many hospitals find this enhanced efficiency particularly valuable for their cardiac and telemetry units.
4. *Improved payer mix*: Less invasive cardiac surgery is a distinctive program that is able to recruit patients via word of mouth and other social media that are outside the primary service area of the hospital. These patients are characterized by having more education, higher incomes, and commercial rather than public insurance coverage. The influx of these types of patients can improve the payer mix, allowing the hospital to capture a greater proportion of charges as revenue.

Weakness: Competitive Landscape

A common roadblock to widespread adoption of rCABG is a lack of acceptance by local stakeholders. On one hand, a new rCABG is controversial because it challenges a well-entrenched status quo. On the other hand, new rCABG programs are competitively positioned compared to the sternotomy option because of strong patient demand. In addition, introduction of an rCABG program creates a "first-mover" advantage that heightens barrier to entry from local competitors. First movers can capitalize on lower risk cases necessary for gaining the high volume of initial experience required for successful team learning. In contrast, later entrants are forced to accept a

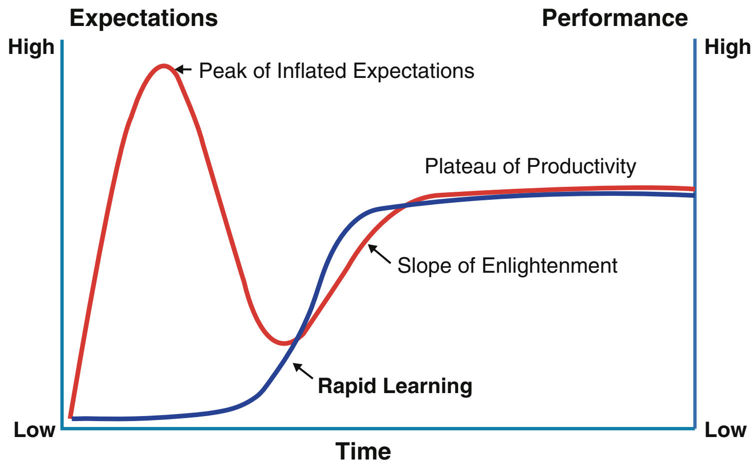

Fig. 25.3 A comparison of the change over time in local expectations about r-CABG (*red curve*) versus actual performance (*blue curve*) demonstrates an early phase where a large gap develops between expectations and performance. After this early phase, there is a period in which performance and expectations become aligned ("slope of enlightenment")

smaller subset of potential candidates. Incorporating rCABG with other less invasive revascularization procedures offered by interventional cardiologists (i.e., "hybrid procedure") avoids the typical "zero-sum" competition that exists between these specialties. In terms of the competitive landscape, this collaborative approach can alter the bargaining power of an influential supplier of patients.

The community response to a new rCABG program often occurs in a predictable manner similar to a pattern seen with other disruptive technologies [26]. There is often initial excitement surrounding any new technology after its introduction that peaks very early in its adoption. The timing of this heightened (or "hyped") expectation coincides with the learning curve period when performance tends to be lowest (Fig. 25.3). This combination of high expectations during a learning curve results in a very vulnerable period when the innovation is often criticized on the basis of this large gap between expectations and reality. Indeed, much of the criticism of rCABG that exists today was generated by the results of its early adoption in the late 1990s when both the field and practitioners were still in their learning phase and equipment in its initial versions. Subsequently, rCABG has been demonstrated to be safe and effective in expert hands, but the perceptions of these early experiences have been difficult to change and remain a persistent hindrance to widespread acceptance of this approach.

Weakness: Marketing of rCABG

Robotic heart surgery is a highly marketable topic. However, any form of advertising for innovative surgical procedures, particularly a complex one like robotic heart surgery, has been universally greeted with great skepticism and concern. It must be remembered that many patients that are appropriate candidates for r-CABG undergo traditional CABG because they either are not informed or learn about the robotic alternative at a stage that is too late in their work-up. 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 is often based on preferences of the surgeon and their referral sources rather than those of the patient [8, 9]. In this context, marketing of rCABG can serve an important information

Table 25.1 Minithoracotomy over TECAB: based on the consensus from a discussion group of eight experienced rCABG surgeons who utilized either approach

Evaluation criteria	Rank	Weight	Minithoracotomy	TECAB
Acceptable "learning curve"; risk of forgetting	1	30	70 % = 21	30 % = 9
Ease of distal anastomoses	2	20	50 % = 10	50 % = 10
Safety (CO_2 insufflation, access)	3	15	70 % = 10.5	30 % = 4.5
Operative times	4	15	80 % = 12	20 % = 3
Increase revenue	5	5	35 % = 1.75	65 % = 3.25
Reduce costs	6	5	80 % = 4	20 % = 1
Patient satisfaction	7	5	10 % = 0.5	90 % = 4.5
Broad acceptance among stakeholders	8	5	60 % = 3	40 % = 2
Total	–	100	57 % = 62.75	43 % = 37.25

purpose to the community. Patient surveys have been consistently favorable about the usefulness of direct-to-consumer advertising towards 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 efforts as a response to a new robotic, less invasive program. Their "campaign" is not directed to consumers but instead 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 [27].

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.

Future Directions

While rCABG has already been demonstrated to be safe and effective, it remains novel with many "best practices" recommendations that have not yet been established. To date, there is no clear consensus on the best approach to performing the distal anastomoses, whether by minithoracotomy or totally endoscopic, TECAB. We have utilized a multicriteria decision analysis tool that allows practitioners to rank multiple criteria to achieve a weighted score to the overall influence that each criteria would have on the sustainable success of an rCABG program. The distribution of points between the minithoracotomy approach versus TECAB was based on the consensus from a discussion group of eight experienced rCABG surgeons who utilized either approach. This analysis favored minithoracotomy over TECAB (Table 25.1). However, further developments in technology to facilitate TECAB are likely to change many of these calculations.

Many systematic roadblocks need to be overcome in order for rCABG to succeed. A concerted effort is required to allow patients and institutions to take full advantage of rCABG.

The combination of shared decision making for patients, strategic accounting practices for administrators, and team development strategies for OR and ICU staff has been helpful. Ultimately, a leader with experience and skill with dynamics of change at the level of the organization is critical for sustainable success.

References

1. Womack JP, Jones DT. Lean thinking: banish waste and create wealth in your corporation. 1st ed. New York: Free Press; 2003.
2. Members WC, Hillis LD, Smith PK, et al. ACCF/AHA guideline for coronary artery bypass graft surgery: a report of the American College of Cardiology Foundation/American Heart Association Task Force on practice guidelines. Circulation. 2011;124(23):e652–735.
3. Molina JA, Heng BH. Global trends in cardiology and cardiothoracic surgery—an opportunity or a threat? Ann Acad Med Singapore. 2009;38(6):541–5.
4. Wilson CT, Fisher ES, Welch HG, Siewers AE, Lucas FL. U.S. trends in CABG hospital volume: the effect of adding cardiac surgery programs. Health Aff. 2007;26(1):162–8.
5. Harskamp RE, Brennan JM, Xian Y, et al. Practice patterns and clinical outcomes after hybrid coronary revascularization in the United States: an analysis from the society of thoracic surgeons adult cardiac database. Circulation. 2014;130(11):872–9.
6. Lazar HL. Should off-pump coronary artery bypass grafting be abandoned? Circulation. 2013;128(4):406–13.
7. Poston RS, Tran R, Collins M, et al. Comparison of economic and patient outcomes with minimally invasive versus traditional off-pump coronary artery bypass grafting techniques. Ann Surg. 2008;248(4):638–46.
8. Nattinger AB, Gottlieb MS, Veum J, Yahnke D, Goodwin JS. Geographic variation in the use of breast-conserving treatment for breast cancer. New Engl J Med. 1992;326(17):1102–7.
9. Wilson CT, Woloshin S, Schwartz LM. Choosing where to have major surgery: who makes the decision? Arch Surg. 2007;142(3):242–6.
10. Rowland C. Hospitals blitz airwaves with ad campaigns. Stiff competition as consumers gain more say in care. The Boston Globe. February 21, 2006.
11. Hickson GB, Federspiel CF, Pichert JW, Miller CS, Gauld-Jaeger J, Bost P. Patient complaints and malpractice risk. JAMA. 2002;287(22):2951–7.
12. Hornberger J, Bloch DA, Hlatky MA, Baumgartner W. Patient preferences in coronary revascularization. Am Heart J. 1999;137(6):1153–62.
13. Bonatti J, Schachner T, Bonaros N, et al. Effectiveness and safety of total endoscopic left internal mammary artery bypass graft to the left anterior descending artery. Am J Cardiol. 2009;104(12):1684–8.
14. Jones B, Desai P, Poston R. Establishing the case for minimally invasive, robotic-assisted CABG in the treatment of multivessel coronary artery disease. Heart Surg Forum. 2009;12(3):E147–9.
15. de Canniere D, Wimmer-Greinecker G, Cichon R, et al. Feasibility, safety, and efficacy of totally endoscopic coronary artery bypass grafting: multicenter European experience. J Thorac Cardiovasc Surg. 2007;134(3):710–6.
16. Damiano Jr RJ, Tabaie HA, Mack MJ, et al. Initial prospective multicenter clinical trial of robotically-assisted coronary artery bypass grafting. Ann Thorac Surg. 2001;72(4):1263–8. discussion 1268–1269.
17. Argenziano M, Katz M, Bonatti J, et al. Results of the prospective multicenter trial of robotically assisted totally endoscopic coronary artery bypass grafting. Ann Thorac Surg. 2006;81(5):1666–74. discussion 1674-1665.
18. Guru V, Tu JV, Etchells E, et al. Relationship between preventability of death after coronary artery bypass graft surgery and all-cause risk-adjusted mortality rates. Circulation. 2008;117(23):2969–76.
19. Cook RI, Woods DD. Adapting to new technology in the operating room. Hum Factors. 1996;38(4):593–613.
20. Rochlin GI, La Porte TR, Roberts KH. The self-designing high-reliability organization: aircraft carrier flight operations at sea. Nav War Coll Rev. 1987;40(4):76–90.
21. Dhawan R, Roberts JD, Wroblewski K, Katz JA, Raman J, Chaney MA. Multivessel beating heart robotic myocardial revascularization increases morbidity and mortality. J Thorac Cardiovasc Surg. 2012;143(5):1056–61.
22. Pisano GP, Bohmer RMJ, Edmondson AC. Organizational differences in rates of learning: evidence from the adoption of minimally invasive cardiac surgery. Manag Sci. 2001;47(6):752–68.
23. Aggarwal R, Ward J, Balasundaram I, Sains P, Athanasiou T, Darzi A. Proving the effectiveness of virtual reality simulation for training in laparoscopic surgery. Ann Surg. 2007;246(5):771–9.
24. Kanumuri P, Ganai S, Wohaibi EM, Bush RW, Grow DR, Seymour NE. Virtual reality and computer-enhanced training devices equally improve laparoscopic surgical skill in novices. JSLS. 2008;12(3):219–26.
25. Centers for M, Medicaid Services HHS. Medicaid program; payment adjustment for provider-preventable conditions including health care-acquired conditions Final rule. Fed Regist. 2011;76(108):32816–38.
26. Christensen CM. The innovator's dilemma: when new technologies cause great firms to fail. Boston: Harvard Business Review Press; 2013.
27. Alford BL. Affect, attribution, and disconfirmation: their impact on health care services evaluation. Health Mark Q. 1998;15(4):55–74.