Coronary artery bypass grafting (CABG) is one of the most common surgical procedures performed in the USA, with expenditures exceeding US$5 billion annually. The risks and highly invasive nature of CABG have driven the development of alternatives, such as percutaneous coronary intervention (PCI). Despite well-known limitations, PCI has grown steadily over the past decade while CABG volume has declined 40%, a success driven almost entirely by a dramatic difference in recovery time.

The Da Vinci robot is a US FDA approved device and is used in cardiac surgery to permit access of surgical instruments into the thorax through limited incisions. Proponents of robotics point to patients’ demand for better short-term outcomes and quicker recovery. Detractors suggest that the procedure compromises the long-term benefits of CABG and has benefits limited to cosmetics. There are two primary components: the surgeon’s console and the surgical arm unit that maneuvers the surgical instruments. The system is used for internal mammary artery (IMA) harvest, with subsequent coronary grafting performed by a hand-sewn technique via small thoracotomy (Figure 1), or with a totally endoscopic approach [1-3]. Hybrid revascularization utilizes PCI to extend minimally invasive CABG to a broader population of patients with multivessel disease. While there are a number of issues that remain to be clarified, the hybrid procedure has been proven to be feasible, safe and to provide equivalent clinical outcomes to conventional CABG [4]. Adding IMA grafting to PCI is likely to reduce the need for reintervention compared with multivessel PCI alone.

The robot is available in over 800 hospitals in the USA but is utilized for CABG in less than 20 medical centers. This stark fact underscores significant challenges blocking the adoption of robotics in cardiac surgery, which will be outlined in this report.

**Challenge 1: develop the team**

An often underestimated step in starting a robotic program is building a team. The transition to robotic CABG requires that carefully choreographed routines of the traditional procedure are replaced with a set of new and unfamiliar behaviors. The first 20–40 cases of robotic coronary artery bypass grafting are inevitably associated with longer operative times or an early cluster of surgical failures … the ‘learning curve’.

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8-month intervals during the study, surgical intensive care unit nurses (n = 57, 93% staff participation) were surveyed using the culture of safety tool with a 1–5 scale (1: strongly disagree to 5: strongly agree with safety of the program). Although the composite rates of adverse events did not significantly change during the first versus the second half of the study (p = 0.37), CUSUM analysis clearly illustrated a steep cumulative failure rate for the first 40 (out of 160) patients. The first survey, obtained after the completion of the learning curve, showed an average response of 2.55 out of 5 (ranked in the 35th percentile according to data-base hospitals). By the completion of the 150th case, the scores improved to 3.53 (56th percentile, p < 0.05).

“Robotic coronary artery bypass grafting avoids risk factors for cognitive dysfunction by reducing the need for cardiopulmonary bypass, aortic cross-clamping and cardiac manipulation.”

These findings highlight the need to complete the learning curve as quickly as possible. Case volume (i.e., ‘learning by doing’) is necessary but not sufficient to create rapid learning. A comparison of 16 different institutions adopting minimally invasive cardiac surgery found that some organizations seem to capitalize on their experience more effectively than others [9]. These investigators found that team learning did not correlate with standard predictors, such as volume of cases or prior experience of the surgeon. Instead, interviews with staff at the 16 programs elucidated that the most consistent characteristic of a successful team was a high level of motivation to learn. This motivation stemmed from leaders judged by staff to be willing to admit mistakes and elicit feedback. In addition, members of successful teams were deliberately selected based on competence and personality characteristics that suggest openness to change. These factors were absent at programs with prolonged learning curves.

**Challenge 2: develop a vision about why robotic CABG is being pursued**

Traditional CABG is a mature surgical product that yields lasting results at low rates of mortality and morbidity. Adverse outcomes associated with the robotic CABG learning curve mandate a clear vision about the rationale for the program. From the perspective of the patient, a primary reason is the potential to improve quality of life during the recovery period. Other than the demonstration of shorter hospital stays and time to return to work [2,10], recovery time after robotic CABG has not been compared with traditional CABG using objective measures (e.g., exercise testing or validated health surveys, such as the Duke Activity Status Index or Short Form Health Survey). Outcomes after an intervention using modern technology are influenced by the placebo effect. Therefore, a credible mechanism that explains how recovery is accelerated beyond merely the placebo effect is required to validate robotic CABG as an evidence-based practice.

Neurocognitive dysfunction occurs in 10–70% of patients after cardiac surgery and adversely affects postoperative recovery and return to work. Robotic CABG avoids risk factors for cognitive dysfunction by reducing the need for cardiopulmonary bypass, aortic cross-clamping and cardiac manipulation. Abnormal cerebral tissue oxygenation, measured intraoperatively using near infrared spectroscopy, has been shown to predict postoperative cognitive decline [11]. We monitored intraoperative cerebral oxygenation in a matched group of patients undergoing robotic and sternotomy CABG, and found significantly better results with robotic cases. Ongoing testing of cognitive function in these patients will help determine if this issue helps to explain the quicker recovery of this patient cohort.

**Challenge 3: prove that the longevity of traditional CABG is not compromised**

Patency of bypass graft is the primary determinant of long-term success after CABG [12]. Critics of minimally invasive techniques question the ability to perform coronary anastomoses of equal quality compared with those performed on an arrested heart via a full sternotomy. Anastomotic quality influences patency, particularly during the learning curve; however, most studies suggest that the type of conduit (e.g., mammary artery vs vein) has
a much greater impact [12–14]. Saphenous vein grafts have a high failure rate (20–30% at 1 year), yet are chosen over a second IMA owing to concerns about sternal devascularization [15]. As a sternal sparing procedure, robotic CABG can provide the advantages of bilateral IMA conduits (i.e., freedom from major adverse cardio- and cerebro-vascular events) without concerns about healing/infection (Figure 1) [16]. In part because of a higher frequency of IMA grafting, robotic CABG was associated with significant reductions in major adverse cardio- and cerebro-vascular event rates, compared with sternotomy CABG at 1 year (4 vs 25%; p = 0.01) [2]. However, these studies are preliminary. Further investigation of long-term outcomes after robotic CABG has been called for by professional societies (e.g., American College of Cardiology and American Heart Association), regulatory bodies (e.g., NICE) and insurance carriers (e.g., Blue Cross/Blue Shield, United Healthcare/Oxford Health Plans). The stigma of robotic CABG as an ‘experimental’ procedure by these organizations will remain until the long-term efficacy and reproducibility is clearly demonstrated.

**Challenge 4: establish that robotic CABG is financially ‘viable’**

From the perspective of the hospital, a major obstacle for pursuing robotics is the cost. The acquisition costs of the robot and higher procedural costs, particularly during the learning curve, can be prohibitive for many organizations [2]. After the learning curve, robotic CABG consistently reduces hospital stay, need for blood transfusions and frequency of complications, all highly effective strategies for reducing costs [17]. These advantages prove greatest for patients at high risk for a prolonged hospital stay (e.g., the elderly or those who have an ejection fraction of 20%, poorly controlled diabetes and severe chronic obstructive pulmonary disease) [2]. The opportunity to market robotic CABG to low-risk patients further shortens average hospital stay for CABG and can produce a shift in the payer mix for the hospital, with a favorable impact on revenue and receivables. On balance, for most patients robotic CABG proved to be cost-neutral if the acquisition costs of the robot are excluded.

Robotic CABG has intangible advantages, not accounted for in standard cost–benefit analyses. Faster return to work after robotic CABG (44 vs 91 days; p = 0.016) has a significant economic impact on loss of wages and productivity. Also, recent changes in healthcare financing designate mediastinal infection as a ‘never event’ that is not reimbursable by Medicare [18]. Robotic CABG eliminates the risk of mediastinal infection, even in those at extreme risk (Figure 1). This is in contrast to a 1–5% risk after traditional CABG, which can be associated hospital costs in excess of US$50,000 per case.

**Future**

Familiarity, concerns about the safety and efficacy of alternatives, and acceptable intermediate-term results have led to established practice patterns for CABG, such as the routine use of a full sternotomy, even for patients otherwise suitable for a less invasive approach. There is a clear clinical and economic mandate to find the most effective and durable method for coronary artery revascularization. Numerous clinical trials have compared surgery versus PCI, yet none have considered the hybrid method that combines both techniques. The growing adoption of less invasive methods for CABG makes it increasingly apparent that the best revascularization technique should draw upon the strengths of both. The National Heart Lung and Blood Institute recently funded a pathway to help establish hybrid coronary revascularization as a new, scientifically validated approach for coronary artery disease. Success with this promising collaborative effort would be a major advance in cardiovascular medicine and would probably have a profound impact on patient care in the future.

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