Chapter 253

Robotic CABG via Minithoracotomy—Advantages, Challenges and Pitfalls

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ABSTRACT

There are a variety of reasons for the poor adoption of robotics in cardiac surgery relative to other surgical specialities. First, the benefits of this procedure have not been widely reproduced. When employed at expert centers to facilitate minimally invasive CABG, the main advantages of robotics are better quality of the IMA conduit, less risk of postoperative complications and prolonged recovery. However, these benefits have been overshadowed by its risks at many surgical programs, which are mainly related to safety challenges from intraoperative adverse events. Bleeding, fibrillation and hemodynamic deterioration are common issues that happen during CABG and are managed using standardized protocols. Addressing these problems is more inefficient when the surgical team has to circumvent a robot and a closed chest.

Several strategies are used to mitigate these safety concerns. First is to emphasize team training prior to the first case and to brief and debrief before and after each case. Both tactics create a learning environment that enables rapid progress through the learning curve. Second, two way communication is enhanced by emphasizing closed loop communication and the SBAR tool. This is particularly helpful at improving performance during critical moments in the case, known as the sterile cockpit. Finally, the conditions for team learning also include using the same team members in every case, performing cases with a sufficient frequency to mitigate the "forgetting curve" and addressing systems issues that can sabotage success. With these strategies, the benefits of robotic CABG can exceed the risks.

KEYWORDS

253.1 Introduction

The procedure known as "Minimally Invasive Direct Coronary Artery Bypass Grafting" (MIDCAB) has multiple advantages compared to the open chest approach. At our center, we perform MIDCAB using robotic assistance while others complete the procedure manually (i.e. without a robot) using long, hand-held instruments via a minithoracotomy. Both methods avoid the median sternotomy. Since MIDCAB was first introduced, several expert cardiac surgical centers have proven it to be a safe and effective means of coronary revascularization that enables quicker patient recovery (1,2)

The main advantage of MIDCAB is reduced postoperative complications (1,3). First, MIDCAB uses one or both IMA as conduits for CABG without the need for any proximal anastomoses or cannulation of the ascending aorta, thereby reducing aortic manipulation and the risk for stroke (4, 5). After a mini-thoracotomy in the left chest, the distal coronary anastomosis is directly performed off pump on the beating heart using standard hand-held surgical instruments. With no sternotomy, the risk for blood loss and sternal infection are reduced. Less surgical trauma improves recovery time and return to function, resolution of wound pain, and provides cosmetically superior results (1).

Despite all these advantages, robotic CABG has not been widely adopted, largely due to two persistent concerns. The first is about its safety due the lengthy learning curve (6). The second is about its reproducibility given that high quality results from MIDCAB have been shown only by a few expert centers (5). Most heart surgeons have not overcome safety concerns of robotics, which is problematic in light of the strong safety record of the sternotomy approach.

There is nothing inherently unsafe about the technical aspects of robotic CABG. A comparison of successful vs. failed robotic heart programs showed that the technical capability of a surgical team or proficiency in utilizing the available technology was not a defining factor in success (7). Rather, the most important differentiator was a surgeon-

leader who had the skills needed to create the right operating environment for team learning. These nontechnical skills are not part of the standard curriculum for cardiothoracic surgery training.

The impact of leadership is often underappreciated in robotic CABG. It requires a highly effective communicator at the helm to make the team good at learning from and correcting mistakes. This leads to an excellent learning environment which turns team experience into team expertise. Without this environment, the team enters a state of arrested development where experience does not convert into learning, morale worsens and negative opinions about robotic CABG grow (8,9). The hallmark of an expert team is resilience in the face of unexpected adverse events due to skill at situational awareness and "sense-making," the ability to interpret, foresee, and resolve serious changes in patient status. It is this skill at sensemaking that enables the team to enact rapid responses to adverse events, before it impacts patient safety (10,11).

The purpose of this article is to outline the strengths of the robotic MIDCAB procedure and barriers in its adoption, both technical and institutional, and suggest useful strategies for overcoming them.

253.2 Benefits of Minimally Invasive Robotic-Assisted CABG

The advantage of using the surgical robot to perform CABG is that harvesting one or both internal mammary arteries is more effective and straightforward than manual harvest via a minithoracotomy (1). There are several reasons for this. First, long instruments can be accurately navigated through a small thoracic incision without robotic assistance in only a subset of patients that would otherwise be candidates for MIDCAB and can be quite technically challenging in obese patients (12). The robot helps to mitigate the impact of obesity and other challenges related to body habitus. Second, the manual method requires long instruments that cause a fulcrum effect. Dissecting the IMA is difficult when manual dexterity is compromised by this fulcrum effect (13). This alters haptic perception and increases the risk of error, particularly when attempting to reach intrathoracic points the

farthest away from the thoracotomy. For example, right IMA harvest using traditional thoracoscopic methods via a left sided ports is essentially impossible and not done. Robotics eliminates this fulcrum effect. Robotic harvest via left sided ports presents no difference in technical difficulty for the left vs. right IMA. Third, visualization of the entire IMA is limited when using manual techniques via a minithoracotomy. Robotics expands the field of view, which enables a longer length of IMA to be harvested. This reduces the chance that the LIMA is too short and the graft anastomosis is sewn under tension or unable to reach its target (14). The robotic camera provides a vast magnification of the visual field of up to 20-power, which is 7-times greater than with surgical Loupes alone, which reduces the chance for injury. The value of this benefit of robotics cannot be overstated because the quality of the conduit is critical to the long term results of CABG.

There are additional benefits of performing CABG using a closed vs. open chest approach. Intraoperatively, a robotic approach affords greater hemodynamic stability (15), lower ambient fluid and temperature loss than with an open chest. Convincing evidence shows that robotic CABG is not only safe but is superior to open CABG when applied to appropriate candidates. Data collected on nearly 10,000 patients undergoing robotic CABG in the US over the last decade have shown that it yields a length of stay that is 3 days shorter and a significantly lower major complication rate (10.2% vs 13.5%, $p < 0.0001$) than in the sternotomy cohort (4,5).

The core principle of minimally invasiveness is to reduce the incisions and their burden of wound healing (16). Small incisions require less time to complete the wound healing process. This benefit is especially useful in obese and/or diabetic patients in the setting of bilateral mammary harvest, where the risk of sternal non-union or dehiscence would be significantly higher when done via open sternotomy. A patient's return to normal function, to work and to a feeling of normalcy in society after surgery is directly related to the length of time it takes to heal their wounds, so it is logical that a minimally invasive approach would speed up these factors. This translates into a decreased length of stay and

lower need for costly postacute care, which decreases overall healthcare costs.

The financial benefits of less invasive cardiac surgery are captured by a quicker hospital recovery. This is illustrated in the tangible line items of decreased need for staff, decreased ventilator days, and quicker ICU bed turnover (1). Because these patients are eligible for fast track recovery protocols, they leave the ICU quicker which enables the safe expansion of nurse-to-patient ratios. A quick recovery leads to other benefits such as less risk for hospital acquired infections, shorter rehabilitation duration and lower loss of salary and societal productivity. These less tangible outcomes have had a strong influence on the "staying power" of laparoscopic programs in other fields but are often overlooked when evaluating robotic programs in cardiac surgery.

253.3 Safety Challenges in Minimally Invasive Robotic-Assisted CABG

More than any other issue, concerns about robotic CABG focus on safety. Operating with robotic instruments or via a mini-thoracotomy narrows the surgeon's field of view, which can hinder the ability to identify and react to sudden adverse events intraoperatively. Skills in situational awareness are needed to compensate for this limitation. This includes anticipation, early recognition and quick correction of potential safety hazards.

Complications like bleeding, myocardial ischemia or hemodynamic changes (11) occur in almost every heart surgical case. Traditional CABG via a full sternotomy provides maximal exposure of the entire operative field, which accelerates troubleshooting of these issues. Experienced surgeons resolve any potential threats by scanning the entire operative field so they may enact quick and decisive changes in the operative plan.

An open chest facilitates the resolution of the three most common problems of heart surgery. First, is the issue of bleeding. Unencumbered visualization of surgical sites that are bleeding makes its diagnosis easier and enables treatment to be implemented before blood loss is great enough to cause clinical hypovolemia/hypotension. Second, the heart might develop fibrillation during surgery and require defibrillation. A full sternotomy makes the use of defibrillation paddles rapid and effective. Thirdly, sudden hemodynamic changes are

addressed quickly by aortic and atrial cannulation for the urgent initiation of cardiopulmonary bypass. All three of these interventions are highly efficient and reproducible processes for any experienced cardiac team when there is a sternotomy.

Rapid correction of each of these potential complications is more difficult in robotic CABG (17-19). In the case of bleeding, many of the surgical sites that are prone to bleeding, such as the internal mammary harvest site, robotic port sites and internal mammary branches, are outside of direct view provided by a mini-thoracotomy (20). This reduced ability to visually survey the entire surgical field increases the chance for a delay in the diagnosis of bleeding. Occult surgical bleeding might manifest only after enough blood volume is lost that it causes fluid accumulation in the left chest or pericardium to be detected on an intraoperative transesophageal echocardiogram (TEE). It may not be detected until clinical hypovolemia, which results in new hypotension, provokes a need for increased vasopressor support and/or the need for blood product transfusion.

Another example of a complication that is more difficult to manage robotically is ventricular fibrillation. Defibrillation of the heart is complicated in robotic cases. Internal defibrillation paddles used in sternotomy cases are a more awkward fit via the mini-thoracotomy. Instead, externally placed defibrillation pads placed on the surface of the chest are preferred, where an effective vector of electricity is paramount. Transthoracic impedance is altered by the non-conducting pocket of air within the thorax where the left lung has been deflated or the metal ports placed through the chest wall (21).

To successfully terminate fibrillation, the left lung must be fully re-inflated, the robot undocked, and the metal ports removed from the chest wall prior to delivering the shock. Completing these tasks involves a complex choreography of multiple team members working in concert, often while under duress (i.e. pulseless patient with the heart fibrillating). This magnitude of psychological stress can reduce performance for even simple technical tasks (22). If small details get missed, the heart can remain in fibrillation longer than it would in an open sternum. Since the length of time a heart remains in fibrillation

correlates negatively with survival, even a modest change in the efficiency of defibrillation can compromise patient safety (23).

A third complication that requires rapid identification is intraoperative myocardial ischemia and hemodynamic deterioration. The options used to diagnose and treat this problem during open CABG are direct visualization of ventricular performance, rapid cannulation of the heart and vasculature for initiating cardiopulmonary bypass support, and open cardiac massage. Each of these maneuvers benefit from direct visual and manual access to the intrathoracic cavity. Such techniques are compromised in a robotic case, particularly when robot in the docked position. Any delay in responding to reversible ischemia can progress to irreversible myocardial infarction, which in turn is associated with the risk of death and other major complications (24).

Sudden problems during robotic MIDCAB may demand the team to implement bailout maneuvers like the initiation of CPB support via peripheral cannulation or the emergency conversion to an open sternotomy. Teams with expertise in only open CABG can have difficulty executing unfamiliar maneuvers, particularly under conditions of extreme stress. The potential for the operative plan to employ a bailout maneuver makes robotic CABG inherently more complex than just starting out with open CABG. However, high reliability organizations have taught us that added complexity does not make a task inherently unsafe. When the appropriate bailout is implemented in a way that is efficient and timely, robotic CABG ends up being the same as open CABG. As with any skill, execution of bailouts can be accommodated through diligent practice and effective team communication.

An appropriate metaphor for the safety of robotic CABG is electricity from nuclear power compared to conventional methods. Nuclear energy has added hazards that are well known since Three Mile Island. However, the vigilance of teams that operate these plants have eliminated any impact on the US public from nuclear hazards in the 40 years since that accident (25). High reliability organizations use principles of high-performance teamwork to

make nuclear power plants, aircraft carriers and the military missions of US Special Forces as safe as their less complex alternatives. The same is true when appropriately trained and experienced teams perform a more complicated robotic CABG procedure.

253.4 Training Challenges in Minimally Invasive Robotic-Assisted CABG

There are two critical lessons for new teams to learn about robotic CABG—how to get past their early novice phase and how to optimize case selection. Regarding team training, there is no generally accepted and established curriculum designed to help train heart teams wishing to introduce robotics into surgical programs. Early efforts have focused on developing technical skills through computer and cadaver simulation (26). The major limitation with these methods is that they only teach the basics and don't seem to impact the clinical outcomes of early-phase cases performed by teams who have completed the training (27). Most programs have included clinical proctors in their first three to five cases. However, this neglects to support the team through its entire novice phase, which can last up to 200 cases.

In total, the training and proctorship amounts to approximately 15–20 hours of prerequisite training prior to gaining credentials to perform unsupervised operations. In stark contrast, the pilot of a commercial airline is credentialed to fly unsupervised only after 1500 hours of supervised training. The lack of emphasis on prerequisite training has shifted the burden of proficiency onto the individual operating teams who gain skills through their initial clinical cases in a "learn by doing approach."

With no formal postgraduate training program in place, the default is for staff to train experientially in the OR. In other words, we expose unwitting patients to the risks of on-the-job training. Although this is standard of care and the most commonly used strategy, it is inappropriate. It puts excessive pressure on the team to develop skills quickly in order to avoid excess patient hazards. It leads to a risk of postoperative complications during early phases of robotic CABG programs that is in many cases higher than the traditional, well-honed open CABG procedure (2). While 100 to 200 cases is necessary for gaining

proficiency, it is not sufficient. Many robotic CABG teams enter a state of arrested development where proficiency fails to ever develop, often due to the following: 1) the same exact team members were not present to perform each of these early cases, 2) the frequency of cases during the learning curve is too low for the team members to remember the lessons learned (i.e. "forgetting curve" (28)), 3) there is no strategy for deliberate practice to accelerate and amplify learning in its early phase (e.g. no routine and formal "debriefing" sessions, surgeon not provided coaching to improve performance), 4) team members become demoralized and disgruntled about the new procedure, which creates a poor learning environment and 5) systems issues that compromise the safety of this program are not identified and addressed rapidly.

When on-the-job training is applied to learning robotic CABG, patients are exposed to a risk of this harm that continues until the team becomes proficient. This heightens the risk phase compared to a robotic CABG center with more experience. "Learning by doing" is an effective strategy for learning surgical procedures that do not place a patient at risk for harm but it creates a moral dilemma when it provokes preventable harm. Each adverse event during this period can have a measurable psychological impact on providers, lower team morale and promote a poor learning environment, further lengthening the time to proficiency. Naturally risk averse hospital administrators view this period as particularly problematic.

The focus of training is to enable the robotic team to learn from their experience fast. An important side effect of the "learn by doing" approach is that it creates an impression in stakeholders that some of complications of this procedure might have been prevented if the team stuck with the well-established open approach. This impression, coupled with the fact that its benefits are appreciated mainly after discharge and therefore not as well documented, means that complications after robotic CABG are framed as losses while its benefits are framed as gains. This difference in framing poses a problem for the robotics because the subjective weight of loses loom larger than that of potential gains, a

cognitive bias attributed to the "loss aversion" principle described by Kahneman & Tversky. This inevitably leads someone on the robotic team to question whether the benefits of robotics are worth the risk.

A separate way to accelerate team learning is by optimal case selection. This underappreciated skill is more difficult to acquire than most surgeons realize but is mandatory for the program to succeed. Case selection is often oversimplified to the notion that the only safe way to get through the learning curve is to select low risk, straightforward cases. However, this can lead to too few initial referrals. Team learning of technically complex procedures like robotic CABG is hindered by the forgetting curve when the cases are done at low frequency (28). There is a subset of patients referred for CABG that poorly tolerate the more traumatic open CABG. On the other hand, there are some CABG candidates that are at high risk for having to convert from a robotic to an open approach. These patients would fare better if an open approach was chosen at the outset, because conversion is well-recognized as a risk factor for postoperative mortality and stroke (29). Appreciating the difference between these two groups is the hallmark of proficiency and expertise in this area. Diligence in performing an independent, comprehensive surgical consult that identifies the scope and severity of present co-morbidities is crucial to patient selection. A multidisciplinary committee of advisors, known as the Heart Team, can provide invaluable input on case selection. Ultimately, experience is the best guide.

Several considerations influence who is appropriate for robotic CABG. A period of one-lung ventilation ranging between 2–5 hours can cause some patients to develop hypoxia and/or hypercapnia. Usually, this has no hemodynamic consequences but those with preexisting RV dysfunction, pulmonary hypertension, or active myocardial ischemia/infarction can become hemodynamic instable. Those with hemodynamics changes after one lung ventilation require immediate conversion to an open approach.

On the other hand, some patients tolerate robotic CABG better than open sternotomy such as those with renal insufficiency, neurologic deficit or chronic LV dysfunction. Open

CABG can provoke transient or prolonged periods of hypotension which may require the use of vasopressors. It can cause inflammation from surgical trauma or embolic debris from aortic manipulation. One or more of these effects can exacerbate pre-existing organ dysfunction. Hemodynamics are often more stable for robotic CABG because less cardiac subluxation is required to obtain surgical access to distal coronary targets than compared to a full sternotomy. If the heart is manipulated less, systemic perfusion is improved during the sewing of the anastomosis, thereby reducing the risk for conversion to a bailout approach.

Bailouts are lifesaving maneuvers but increase the risk of serious complications, so reducing the risk for a bailout is an important benefit of robotic CABG. Two large databases (STS database and the National Inpatient Sample) have demonstrated that the average rate of stroke after robotic CABG is less than 0.5%, which is far lower than conventional CABG at 1.8% (4,5). Given this accumulating evidence in support of less complications, the AHA/ACC guidelines for coronary revascularization indicate that robotic hybrid procedures "improve the risk/benefit ratio of surgery" for high risk patients (class IIb recommendation). (30)

253.4.1 Embracing the Early Learning Curve

In order to succeed, the team must accept that the problems encountered in the early learning curve phase for robotic CABG resolve with experience and that the procedure itself is not inherently unsafe. The value proposition of less invasive procedures has been well established in other surgical specialties. It applies to cardiac surgery as well.

The state of the art method for training is known as "deliberate practice," a purposeful and systematic approach that mandates the team learn as much as possible from each case. It requires continuous guidance and feedback from a robotic cardiac expert serving as a coach who is present throughout the entire learning phase. "Deliberate practice" is facilitated through organized and regularly scheduled post-operative debriefing with the entire surgical team present (31). Root-cause analyses of most cardiac surgical mortalities reveal communication failures as a primary cause of error (32). Even the best

teams typically have limited capacity to learn lessons during high tempo periods or high stress periods. Team debriefings outside of the heat of the moment can optimize learning in an atmosphere of "psychological safety." Each member of the team can learn from their mistakes and those of others, and actively engage in troubleshooting.

A strong OR team should be set up well before the first case. Every member of the team must be comfortable with what needs to happen and what their role will be during the initial procedure. Teams that communicate well establish a clear understanding of the surgeon's plan and goals for the case well ahead of the first procedure.

Limited thoracotomy access means that internal defibrillator paddles are not easy to use and should not be relied upon as the sole strategy for cardiac fibrillation. Thus external defibrillator pads must be placed on the patient for every case, in a way that avoids the surgical field while still maintaining an effective vector across the heart. Prior to incision, the pads should be hooked up to the defibrillator and the presence of an ECG trace on the monitor should be confirmed as part of the time out safety check.

Planning the relative positions of the OR table, the anesthesia ventilator, the echocardiogram and the perfusion pump, as the robot itself must be well thought out in advance. "Acting out" a routine case with the robot can help everyone see how the room is set up and what needs to be done for the case to proceed smoothly. At that time, a dress rehearsal of an emergency bail out procedure is done so that everyone knows their role in such an emergency. During the time out prior to every case, the team is reminded of what they did during that drill. Once these two steps are taken—rehearsal followed by reminder of the rehearsal—evidence suggests that the actual performance of a bailout will be more efficient and controlled when the moment of need arrives. (33)

As for all surgical cases, the circulating nurse initiates a time out that follows the protocol described by the World Health Organization. During a robotic CABG, the patient's overall baseline state of stability after the induction of anesthesia is discussed. The time out checklist assures the proper access and functioning of the necessary equipment and

supplies. In addition, three discussions, led by the Anesthesiologist, the Surgeon and the Perfusionist will help improve the safety of robotic CABG:

253.4.1.1 Anesthesia

The purpose of anesthesiologist's report is to discuss the patient's stability from first contact with the patient up until the time out, including the results of the TEE exam, hemodynamics, and the patient's tolerance of one lung ventilation. All of these topics can influence the safety of proceeding with a minimally invasive plan. Other factors of importance include preoperative anticoagulation or antiplatelet, preoperative medication usage, cessation of specific medications with rebound tendencies such as beta-blockers, and comorbidities. Sharing this information before committing to a less invasive approach enables a shared mental model to be created about whether it is safe to proceed with the planned approach.

253.4.1.2 Surgery

After the anesthesia report, the Surgeon summarizes how the less invasive approach to the case might increase the risk of difficulty and complications. The Surgeon should have a thorough knowledge about how the patient is likely to respond to the proposed surgery. It is the job of the Cardiac Surgeon to share that knowledge and make sure that all staff in the room understand the unique risks posed by this procedure in the case being performed on that day. This type of information allows everyone to anticipate the equipment needs of the case, reducing the need for the circulating nurse to leave the room and scramble for it later during a crisis.

253.4.1.3 Perfusion

Finally, the Perfusionist's report covers bypass strategies, cannula sizes for central or peripheral cannulation if cardiopulmonary bypass or intra-aortic balloon pump support is needed. The Perfusionist serves a valuable cross-checking role by clearly articulating his/her understanding of the Surgeon's plan for cardiopulmonary bypass and cardiac protection. For instance, if the Surgeon proposed femoral artery/venous cannulation and there is evidence

of severe peripheral artery disease or a previously placed vena caval filter, the Perfusionist cross-checks that idea by suggesting an alternative approach. This reinforces the need for the Perfusionist to be assertive on the basis having done their own complete medical history and physical exam prior to surgery.

253.4.2 Managing the Unique Challenges of Robotic CABG

Robotic CABG creates set of risks that are new compared to open CABG but the risks are predictable. They are commonly due to things that are unique about robotic CABG, e.g. a more limited visual field and its unfamiliar nature for novice teams. Intraoperative imaging compensates for the field of view and therefore takes on a more important role for these cases. Timely and accurate transesophageal echocardiographic imaging is useful to diagnose new onset right and left ventricular dysfunction that are more difficult to detect with a closed chest. Information from TEE exams is shared in real time and might be used to revise the surgical plans such as a conversion from an off-pump approach to cardiopulmonary bypass support via peripheral cannulation (34). More extreme deterioration in ventricular ejection fraction or valve dysfunction might prompt immediate conversion to an open sternotomy.

It is more difficult for the operative team to follow the surgical progress of a minimally invasive case, which means that situational awareness can more easily be compromised (35). Intraoperative video imaging that is viewable to the entire team enables them can watch the procedure and anticipate what equipment or treatment will be needed next. When the Surgeon returns table-side and after the mini-thoracotomy incision has been made, a head camera attached to the Surgeon's headlight allows the team to observe progress in the operative field that would otherwise be out of their field of view.

Robotic surgery also introduces novel problems with communication (36). Most team members in the cardiac surgery OR are very familiar with the standard techniques and potential hazards of conventional open-heart surgery. It is a mature procedure which fosters the development of intuitive or tacit knowledge in the team. Everyone is "on the same

page" with little effort. For a team with no prior experience, robotics is a stark contrast from open CABG. In order to introduce this procedure safely, frequent and explicit communication from the surgeon is mandatory. Echocardiographic and video camera imaging do not substitute for excellent communication skills from the lead surgeon.

It is helpful for the surgeon to communicate in a preoperative briefing just prior to skin incision the challenges that can be predicted for the specific patient that day. In general, this includes problems from one lung ventilation, the limited ability to detect bleeding, the risks of cardiac ectopy or fibrillation and the treatment of it, and the emergence of myocardial ischemia intraoperatively. The OR team acquires situational awareness about what to expect by thorough prebriefing of these risks and by clear announcements of "sterile cockpit" moments when these events can occur. These include one-lung ventilation, C02 insufflation into the thorax, use of instruments/cautery near the heart, LAD occlusion for bypass grafting and left chest suction of retained blood at the completion of the case.

Excellent communication occurs in two directions, meaning that the surgeon must be good at listening to and understanding the concerns of the Anesthesia and OR team. There are tools that are proven to improve the effectiveness of communication in environments that can be intimidating and not conducive to productive conversations. Our team and others have developed a preoperative checklist which empowers the circulating nurse to question details of the proposed operative plan and preoperative workup prior to skin incision (37). Staff communications during a critical moment of the case—the sterile cockpit—is improved by training on the importance of closed loop communication. In addition, the SBAR tool (situation, background, assessment, recommendation) guides the staff to make their point clearly and concisely, particularly during the critical moments (38). It is important to emphasize the "R"—the recommendation of the person presenting a message. The culture of many nurses and hospital staff dictates deferring to physicians regarding any recommendations for treatment. However, a clear recommendation for action

greatly clarifies the importance of message that is being relayed. Staff are trained on conflict resolution techniques so they don't get distracted by comments or attitudes that might otherwise cause their message to be derailed. The goal of these training efforts is the same goal of crew resource management training in other high reliability organizations: flatten the hierarchy and improve staff assertiveness.

Each patient has underlying comorbidities or other issues that will influence the risk for harm caused by the robotic method. Patients can be sensitive to transient hypoxia and/or hypercarbia during one-lung ventilation and chest insufflation. Evidence of problems with venous return or cardiac output should be communicated openly and should prompt minor adjustments, such as decreasing the insufflation pressure or starting to partially reventilate the deflated lung. Pulmonary hypertension may signal intolerance to one-lung ventilation. On occasion, inhaled nitric oxide can be used to improve stability. The TEE exam is helpful in monitoring right heart function during the lung isolation period. Right heart dysfunction and a drop in cerebral oxygenation readings despite aggressive efforts to manage this issue indicate a patient that is doing poorly with one lung ventilation and requires a change to open sternotomy.

Mechanically induced cardiac ectopy can occur when robotic ports are placed through the ribs at the start of robotic cases. This event is usually benign and should not prompt the same diagnostic work-up and/or anti-arrhythmic use when compared to unprovoked ectopy that might occur.

The differential diagnosis of a pathologic arrhythmia includes myocardial ischemia, C02 embolism from sewing the distal anastomosis or accidentally touching the heart with the cautery at any point. These different etiologies all have a major difference in prognosis and treatment. Fibrillation from myocardial ischemia from native unstable coronary disease or during the distal coronary anastomosis is often a dire situation that requires an aggressive response. Defibrillation may be successful only temporarily if the underlying ischemic etiology is not resolved and therefore fibrillation recurs. Major changes in the

operative plan may be required, possibly including initiating cardiopulmonary bypass emergently. In contrast, fibrillation can result from CO_2 embolism during a distal anastomosis off-pump and/or accidental injury from electrocautery. These events are not associated with underlying myocardial ischemia and are usually benign if effective defibrillation is quickly performed.

There are some keys to effective defibrillation during the period of one lung ventilation:

1. It must happen quickly. External defib pads should already have been placed while the patient was positioned preoperatively. If external pads don't work after 1 or 2 attempts, then the left lung should be inflated prior to a repeat attempt. This will fill the empty space within the thorax and change intrathoracic impedance between the defibrillator pads.

2. If the external pads don't work after the lung is re-inflated, then internal paddles must be used. The defibrillator monitor will require changing the cords from the external to the internal paddles and changing the setting to 20 Joules. A thoracotomy needs to be rapidly made so that pediatric paddles can be inserted through the mini-thoracotomy incision. These paddles should be present on the sterile field prior to the start of any minimally invasive procedure.

3. If the internal paddles don't work, then cardiopulmonary bypass should be initiated in order to decompress the heart. Defibrillation is often more effective on an unloaded heart. At this point, amiodarone and/or lidocaine may be utilized. A metabolic cause can be investigated as well, and any acidosis or electrolyte problem should be corrected.

Intraoperative ischemia carries a significant mortality. Monitoring for ST changes using the chest EKG leads provide a sensitive measure of coronary ischemia in robotic CABG. Additionally, monitoring for regional wall motion abnormalities on TEE is a more specific finding. If ischemic EKG changes don't resolve after the bypass graft is placed and it is associated with wall motion abnormality on TEE, it is a serious situation that often requires a rapid change in the operative approach to avoid a major intraoperative MI. These are the type of events that should be anticipated and choreographed in order to facilitate rapid corrective action when the clinical need arises.

Since the double-lumen endotracheal tube is removed at the completion of the case,

a natural goal for many robotic CABG cases is extubation in the OR suite. The anesthetic regimen that allows for quick extubation is different from the standard used for open cases. Short acting anesthetics can wear off too soon and increase the risk of diaphragm movement during the sewing of the distal anastomosis or while the robot is still docked. If there is diaphragm movement, there is a risk of serious tissue damage by instruments that are in a fixed position within the chest (e.g. docked robotic instruments).

253.4.3 Sustaining the Robotic Program

Nearly 400 cardiac surgery programs have attended robotic training and obtained credentials to perform these minimally invasive surgeries (4). However, around 20 of them have established sustainable programs, as defined by annual volumes of more than 50 cases per year. Of the many factors contributing to problems with sustainability, a major one is cost. It should be expected that costs of robotic surgery will initially be high during the learning curve phase due to extended operative times and the use of disposable equipment. Over time operative times shorten and the use of disposable equipment and supplies becomes streamlined. If they don't, hospital leadership is unlikely to commit to the major capital and personnel investments that are required. Therefore, careful consideration of how to reduce costs will help maximize the financial value delivered by any new program and improve the chances of sustainability.

Robotic CABG helps to mitigate complications in a subset of patients that are high risk for post-operative complications. These adverse events drive up the need for healthcare resources and costs. Reduction in stroke, sternal infection, bleeding, length of stay and blood product usage will translate into substantial financial value. A financial analysis of robotic CABG applied to the high-risk subset revealed a hospital margin that was 65% greater than the open method (1), a finding corroborated in larger studies.

A supportive, open work environment where well-recruited and well-trained team members can feel valued and empowered enhances retention and promotes institutional memory. Less turnover in a highly coordinated and effective OR team inherently lowers both

hospital cost and patient risk.

253.5 Conclusion

While there are similarities to traditional open-sternotomy cases, minimally invasive robotic assisted CABG introduces several challenges that are unique. The OR team must be aware that the small incision and/or robot itself hinders the surgeon's ability to react to sudden adverse events and must develop efficient strategies for circumventing these limitations. Staff are obligated to accelerate "learning by doing" in the early cases using formal methods of debriefing. The Heart Team must acquire the skill of differentiating between the high-risk patient that is favorable for robotic CABG versus one that is unfavorable. Expert coaches who can provide feedback enable novice teams to get through their learning curve period quickly and improve the safety of robotic CABG. By selecting a small dedicated team that performs every case, the team can gain expertise and reduce both cost and patient risk. Gaining the support of the institution by demonstrating patient benefit, community benefit and down-trending costs can promote sustained acceptance of a new program. Supporting team members with training, open communication and emotional support fosters staff retention and the formation of institutional memory on how to achieve safe and effective adoption of any high impact innovation.

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