Anesthetic Considerations in Robotic Cardiac Anesthesia

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Introduction

Robotic assistance enables cardiac surgery to be performed without a median sternotomy (rCABG). In the case of coronary artery bypass grafting (CABG), the robot is used to harvest one or both internal mammary arteries and the distal anastomoses can then be performed by hand in a procedure called minimally invasive direct coronary artery bypass grafting (MIDCAB) or they can be performed with the robotic instruments, known as totally endoscopic CABG (TECAB) (Poston 2008, Bonaros 2014). In the case of mitral valve surgery, it is used to gain visualization and dexterity around the valve in a way that improves the reliability of complex mitral repairs over what is possible using open techniques (Suri R 2015). In both of these operations, the avoidance of a sternotomy helps minimize blood loss and improve recovery time. Many patients report a quicker resolution of wound pain and cosmetically superior results.

Despite clear advantages of this novel procedure demonstrated at a few expert centers, developing a successful robotic cardiac surgery program has not proven to be an easy task when it has been attempted across the broader cardiac surgery community. Success versus failure of these programs has primarily been about teamwork (Edmundson 2001). It takes a coordinated team effort to perform complex surgical procedures like robotic assisted surgery. An important characteristic of successful teams is that they become good at rapidly learning from and correcting mistakes. Expert teams develop implicit communication and coordination patterns, anticipate needs of the situation, and minimize interruptions. During a crisis, these teams illustrate their skill at “sensemaking”, or the ability to quickly uncover the seriousness of a situation through action. Expert teams are able to quickly interpret the situation and act safely to resolve the current crisis and prevent any additional ones.

Coaching is the antidote to most problems that occur when trying to develop new programs. In robotic surgery, the value of coaching to get through the learning phase as quickly as possible has been underappreciated and largely overlooked. Computer simulation and cadaver dissection have been proposed as useful for team practice but these only teach the basics (Valdis 2015). The fidelity of available models is not adequate to develop or test the types of skills that would influence patient outcome. Until simulation technology improves, actual clinical cases seem to be the only place for learning the more complex skills that are needed for proficiency. Since doing clinical cases prior to gaining proficiency seems to be an optimal way to learn (at least with current training techniques and technologies), there is a moral imperative to shorten this phase as much as possible. In order to accomplish this, the team requires “deliberate practice”, or the focus of day-to-day activities on identifying and improving the specific things needed for robotic surgery to be safe.

The first step for an anesthesiologist to learn robotic heart surgery is to understand a fundamental safety concern. Robotics and minimally invasive approaches influence the safety of cardiac surgery because it handicaps the surgical team's ability to protect the patient from unforeseen adverse events such as cardiac ischemia or other hemodynamic problems (Wang 2014). In an open sternotomy case, once the hemodynamics are identified as being unstable (for a variety of reasons), the patient is quickly and easily placed on cardiopulmonary bypass. Once the heart is decompressed and circulation is supported on bypass, the ongoing cardiac injury and/or systemic hypoperfusion is immediately relieved and the patient is safe from ongoing harm. A slightly longer bypass time than expected is a highly acceptable tradeoff of this approach. In contrast, a typical minimally invasive approach involves a delay before a similar chance to protect the patient quickly with CPB or other maneuvers is going to be available. When the robot is docked, it creates a barrier that reduces both the anesthesiologist's and surgeon's access to the patient. If fibrillation or hemodynamic collapse occurs, the anesthesiologist must coordinate efforts with the surgical team to be able to quickly undock the robot and move it away from the field before implementing corrective action.

Rehearsal and training are very important steps in setting up a robotic or minimally invasive program. Every member of the team must be comfortable with what needs to happen and what their role will be during the procedure. "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. The team should rehearse how to access the patient in a crisis scenario in "dry run" exercises prior to their first case. The anesthesiologist and surgeon should both be present during these exercises. While the surgeon is at the console, the anesthesiologist must monitor for any situations that may occur. If everyone knows their role in an emergency, steps can be carried out in a controlled manner to achieve the best outcome.

Preoperative Evaluation

Prior to any robotic cardiac surgery, the anesthesiologist has many factors to consider in preparing for the procedure. As with any anesthetic, the patient's comorbidities must be carefully reviewed. The patient will require one-lung ventilation for potentially three to five hours or more, so specific attention must be paid to any underlying pulmonary disease. Patients with asthma, COPD, ventilation/perfusion mismatch for any reason, or pulmonary hypertension must be further evaluated. Any patient that has contraindications to one-lung anesthesia will need further evaluation or should forgo the minimally invasive approach in favor of a median sternotomy with two-lung ventilation. We recommend room air arterial blood gas and pulmonary function tests for patients with any underlying pulmonary disease. Careful review of these studies is imperative in predicting potential success for a minimally invasive approach. Patients with severe pulmonary hypertension also need to be carefully screened. During prolonged periods of one-lung ventilation, this may be worsened, possibly forcing the team to abandon the technique in favor of a two-lung approach. Prior thoracic surgery can also affect the ability to gain the exposure afforded by the minimally invasive approach.

As these patients are known to have coronary or valvular disease, their cardiac history also needs to be evaluated. Patients with multi vessel coronary disease may need more revascularization than can be done with a robotic approach. Alternatively, the location of the stenosis may affect the ability to reach the coronary vessel with a conduit, and thereby prevent the approach from being used or may affect where the surgeon will place the mini-thoracotomy incision. Knowing the valvular lesion will also determine where the incision will be made. During the distal anastomoses of a robotic CABG case, the hemodynamics are often stable even though these cases are done off pump without cardiopulmonary bypass. This improved hemodynamic state in robotics is different than with off-pump CABG done via a sternotomy where the need to rotate the heart out of the chest often creates hemodynamic challenges. In robotic cases, the heart remains within the pericardium while the anastomoses are created, allowing the blood pressure to remain more stable.

As with any cardiac surgery, attention must also be paid to other comorbidities. Patients with a history of stroke, diabetes, renal or hepatic disease, to name a few, will all require some specific care. Having an adequate history will allow the anesthesiologist to best care for the patient to achieve the best possible outcome.

Preoperative Preparation and Monitoring

There are several issues specific to robotic and minimally invasive surgery that require advanced preparation. These are all inherent to robotic cardiac surgery. The first issue is that while the robot is docked to the patient, there is limited access to the patient by either the surgeon or the anesthesiologist. Planning of the room must be well thought out in advance. It is important to know the relative positions of the OR table, the anesthesia machine and the perfusion pump, as the robot and its arms will occupy a large amount of space. Once the procedure has begun, it is no small task to undock the robot to access the patient in an emergency situation.

Communication with the surgeon must start prior to the procedure, and include the surgeon's plan and goals for the case. It is important to know ahead of time what invasive monitoring will be needed for each particular patient and any concerns the surgeon may have that might need to be addressed during the case. The discussion should include whether a coronary sinus catheter, PA vent or endoaortic clamp might be needed. Placement of these devices takes time and planning, and their usage affects everyone in the room.

ECG, pulse oximetry, and radial arterial pressure monitoring are all standard anesthesia modalities. We have found cerebral oximetry to be extremely helpful as well. Two temperature measurements are routinely used, a core temperature and a nasopharyngeal or esophageal temperature. Central venous pressure and pulmonary artery pressure monitoring are typically used as well. All minimally invasive procedures have limited access to the patient; therefore we use external defibrillator pads for every case. Placement of the external pads needs to done to avoid the surgical field while still maintaining a vector across the heart for electricity to be delivered. Prior to incision, the pads should be hooked up to the defibrillator and the presence of an ECG trace should be confirmed. In some cases, most often minimally invasive valve surgery, a retrograde coronary sinus catheter, a pulmonary artery vent and possibly an endoaortic balloon clamp may be employed as well. Fluoroscopy and TEE are used in the placement of these catheters. It is important to have good communication with the perfusionists when using these catheters. These lines need to be checked and tested prior to their use on bypass. If a superior vena cava line is to be placed, access is usually obtained at the same time other internal jugular access is acquired.

All patients also require transesophageal echocardiography, TEE. Information obtained from TEE is useful to evaluate the heart prior to the start of the procedure. In valve surgery, it will aid the surgeon in determining the type of surgery to be performed, whether repair or replacement might be necessary, the size of the valve, and the function of the new valve after it is placed. In all surgery it is useful in determining ventricular function and how best to treat any hemodynamic issues that may occur. Due to the limited visual field of minimally invasive surgery, information obtained by TEE can be very helpful, and is often the only way to evaluate the heart. Without a good view of the surface of the heart, most decision making needs to be based on the 'view' from the TEE. This information then needs to be shared with the surgeon as the case progresses.

In robotic or minimally invasive surgery, the visual field is very small and focused. While the surgeon is at the console, the picture from the console is projected in 2-D so the staff in the room can have the best opportunity to anticipate what will be needed next. In our program the surgeon at the field wears a camera attached to the headlight so that after the thoracotomy incision has been made, the picture is projected onto a screen in the room for everyone to continue to observe the progress.

Induction and Maintenance of Anesthesia

The induction of anesthesia should be performed as the anesthesiologist would perform any cardiac induction. One difference is that these patients will require lung isolation, with one-lung ventilation. The non-ventilated lung will need to be allowed to decompress, as this will allow the surgeon the best view to perform the operation. We have found it best achieved with a double lumen tube, as it allows better decompression of the non-ventilated lung and also allows for low flow CPAP to the down lung if needed.

After confirmation of the endotracheal tube position, a thorough TEE exam should be performed. It is important to reevaluate any valvular disease as well as the cardiac function. The left **and** right sides of the heart need to be carefully examined. Comparison of these studies may need to be done at later points during the operation.

Usually ten to fifteen minutes before incision, one-lung ventilation is initiated to assure that the patient will tolerate the extended period of lung isolation that will be required to complete the surgery. It is common to see a decrease in oxygen saturation with the onset of this severe V/Q mismatch; as hypoxic pulmonary vasoconstriction begins to occur, the shunt usually improves to allow the saturation to return to an acceptable level to comfortably proceed. If the saturation doesn't improve, PEEP to the ventilated lung or CPAP to the nonventilated lung may be tried. CPAP to the nonventilated lung must be used with caution as even the small amount of insufflation could affect the surgeon's ability to proceed.

Intraoperative maintenance depends on the postoperative goals of each specific case. Our goal for most robotic single-jump CABG and some double-jump CABG is extubation prior to leaving the OR. In any robotic surgery, it is important to prevent movement while the robot is docked to the patient, as this could cause serious internal damage to the patient. We have found Rocuronium and Remifentanyl combined with inhalational agent and longer acting narcotics, such as Dilaudid, to be an excellent combination to allow for quick extubation in hemodynamically stable and appropriate patients. We strive to fast-track most minimally invasive or robotic valve procedures and other robotic CABG patients with narcotics (fentanyl), muscle relaxants (Rocuronium or Vecuronium) and Propofol infusions at the end of the procedure for transport to the intensive care unit.

In robotic or minimally invasive valve surgery, some other modalities that may be used include the coronary sinus catheter, for administration of retrograde cardioplegia, a PA vent, for maintaining an empty heart and an endoaortic balloon occlusive device. Retrograde cardioplegia is utilized frequently in less invasive cases. Compared to antegrade cardioplegia, this approach provides a convenient and reliable way to deliver myocardial cardioplegia with less need to interrupt the flow of the case. Problems with cardioplegia delivery should be noted by the anesthesiologist because it can predict how easy it might be to wean from cardiopulmonary bypass and maintain stable hemodynamics postoperatively. When used, these devices are all placed and positioned after induction and prior to beginning the surgical scrub. Placement of these devices requires an anesthesiologist with additional training for their use. TEE and fluoroscopy may both be required for their placement. Use of these devices also requires specific communication between the perfusionist and the anesthesiologist as well as the surgeon.

Communication

Communication amongst all of the team members is very important throughout the case. Since an even better approach is to avoid the chance for a crisis in an actual robotic case, it is very important to discuss the patient's overall baseline state of stability before docking the robot and starting with a less invasive approach. In ideal cases, the whole team hears the discussion and contributes to a collective judgment about whether proceeding with a less invasive approach is safe in that patient and at that time. The best time to do this is during the universal “Time Out”. The circulating nurse initiates a time out that follows the protocol as described by the World Health Organization. This checklist assures the proper access and functioning of standard equipment and supplies for a routine cardiac surgery case. For robotic surgery, there are other items needed by both the surgeon and anesthesiologist that are unique for these cases and should be discussed at this time. In our practice we have expanded the “Time Out” to include three discussions, led by the anesthesiologist, the surgeon and the perfusionist. The purpose of anesthesiologist’s report is to discuss the patient’s “baseline” stability, specifically from first contact with the patient up until the time out. Verbalizing this information allows group consensus to help establish whether it is safe to proceed with the planned less invasive strategy. Specific findings related to the TEE exam, hemodynamic stability, and tolerance of one lung ventilation can be discussed at this time. Other factors that should be discussed as they may affect patient care or surgical approach could include preoperative anticoagulation, preoperative medication usage or cessation of specific medications with rebound tendencies, and comorbidities such as renal, hepatic, pulmonary disease or diabetes.

After the anesthesia report, the surgeon also summarizes for the team how the less invasive approach to the case is likely to increase the risk of difficulty and complications. The surgeon should have a thorough knowledge about the patient that is being treated on that day. It is the job of the cardiac surgeon to share that knowledge and make sure that all staff in the room understand the unique surgical risks posed by this particular patient and/or the chance for a difficult postoperative course. Everyone should also understand the surgery being proposed by the surgeon at this time.

Finally, during the perfusionist's report, they will discuss bypass strategies, cannula sizes for central or peripheral cannulation and the potential need for cardiopulmonary bypass or intra-aortic balloon pump support. If the plan is articulated clearly, the perfusionist can serve a valuable cross checking role. This discussion will prevent the circulating nurse from having to scramble for this equipment later during a crisis. For instance, if the proposal was to cannulate peripherally and there is evidence of severe peripheral artery disease (i.e. can't cannulate the artery) and or a past history of vena caval filter (i.e. can't cannulate the vein), the perfusionist might suggest that the plan change to an alternative approach.

Communication is also very important during the procedure. As changes are made by the anesthesiologist or the surgeon, they should be announced so everyone is aware. For example, when one-lung ventilation is initiated, everyone should be aware as there may be a change in the tone of the pulse ox or a blood gas may be needed to help evaluate the patient's tolerance. The nurse in the room and the perfusionist would then be aware that they may need to help or even change the plan based on the patient's progress. The surgeon should be aware as he should wait for the lung to be decompressed prior to inserting his trocars. Other situations that may require everyone being made aware include the making of the incision, chest insufflation, and anytime the bovie is used near the heart.

Intraoperative Evaluation

There are three main problems that can occur that are specific to a typical *robotic* case and therefore are helpful to discuss: 1) problems with diagnosing and responding to bleeding, 2) difficulties treating ventricular fibrillation and 3) appropriately managing sudden severe hemodynamic difficulties. Each case will pose different risks for each of these problems. As discussed earlier, diagnosing bleeding can be difficult in minimally invasive procedures. The keyhole opening that exposes the heart for the attachment of the bypass graft does not allow adequate viewing of the entire field. Monitoring for bleeding is an important role for anesthesia during less invasive cases, particularly during the distal anastomosis when the robot is no longer being used. In an open cardiac case, active bleeding that causes hemodynamic abnormalities is rarely left undiagnosed for more than a few minutes. A full sternotomy affords easy visualization of all areas where bleeding might occur. In contrast, there is a far more limited field of view when performing surgery via a minithoracotomy. As a result, there is no easy way to determine if surgical sites (IMA harvest site, port sites, IMA branches etc.) outside this limited view are actively bleeding while the case is underway. It might be necessary to put the robotic camera back in to evaluate for possible bleeding. The field of view of the camera is also limited and has no peripheral vision, so active bleeding within the chest can be missed by the camera unless it is raised as a specific concern. The anesthesiologist can help compensate for these surgical limitations by detecting hemodynamic signs of undiagnosed bleeding like the need for increased doses of vasopressors, fluids or transfusions. The TEE can be used to assess for fluid in the left chest and pericardium. If the surgeon is aware of the concern, a suction catheter can be placed into the pleural space to determine if there is a large collection. If blood is recovered, this would prompt placing the camera back into the chest to reassess surgical sites. The key step is to share concerns about anesthetic management with the surgeon so that appropriate actions can be taken. If a source of bleeding is found, then it can be treated quickly and efficiently by the surgeon.

The robotic ports are placed through the ribs at the start of robotic cases. When inserted near the heart, the ports can manipulate the heart accidentally and cause cardiac ectopy. This 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. Fibrillation during CABG can be due to cardiac ischemia, CO_2 embolism during the distal anastomosis or accidentally touching the heart with the cautery at any point. It is important to discriminate between these different etiologies because they all have a major difference in prognosis and treatment. A heart can develop fibrillation as the result of myocardial ischemia either due to native coronary disease at any point during the case or during the distal anastomosis in an off-pump coronary bypass case. This cause of fibrillation often represents a dire situation that requires an aggressive response. Even if defibrillation is used, it is likely to be successful only temporarily. The underlying ischemic etiology is not treated by defibrillation and therefore fibrillation is likely to recur. 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 as long as defibrillation is quickly used and found to be effective. There are some keys to effective defibrillation during the period of one lung ventilation:

1) The key to effective defibrillation is that it happens quickly. External pads will 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. If the lung is deflated, this can create an empty space within the thorax that does not allow an effective vector to be created between the defibrillator pads.

2) If the external pads don't work after the lung is reinflated, then internal paddles must be used. The machine needs to have the cords changed to the internal paddles and the setting changed to 20J. A thoracotomy often needs to be rapidly made so that the paddles can be inserted into the chest. Usually pediatric paddles are used as they are easiest to place through the minithoracotomy incision. These paddles should be present on the field prior to the start of any minimally invasive procedure.

3) If the internal paddles don't work, then CPB should be initiated in order to decompress the heart so that defibrillation is able to be more effective. 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.

Lung isolation and CO_2 insufflation in order to harvest the LIMA/RIMA causes a period of vulnerability that is not present in traditional open chest CABG. Hypoxia, hypercapnia and a low grade tamponade effect from insufflation can lead to cardiac compromise leading to poor coronary perfusion and myocardial injury. Other changes that can be seen include decreased venous return, decreased cardiac output, decreased mixed venous oxygen saturation and worsening of the V/Q mismatch leading to a shunting situation. If this occurs, it is important to communicate this to the surgeon. Sometimes decreasing the insufflation pressure is enough to resolve the problem; other times a rapid bailout is needed which can range from stopping CO2 chest insufflation all the way to the use of CPB support by peripheral (femoral artery/vein) or central (aorta/atrial) cannulation. Pulmonary hypertension may be present due to underlying cardiac disease or an inability to tolerate one-lung ventilation. Inhaled nitric oxide can be useful in situations where pulmonary hypertension is present. It can lower the pulmonary pressures and reduce the work of the heart enough to complete the procedure.

It is important to monitor for signs of impending hemodynamic collapse and right heart dysfunction on TEE during the lung isolation period. In the case of off-pump coronary surgery, monitoring for ischemia during an off-pump distal anastomosis is an important role for the anesthesiologist. In median sternotomy CABG, the EKG leads are displaced and often provide an insensitive tool to detect cardiac ischemia. During sternal sparing surgery, this is less likely to be a problem. The EKG leads remain in the correct position and provide a more sensitive measure of coronary ischemia. ST changes and TEE changes are very sensitive to ischemia in the off pump situation. ST changes may show up in the first 30 seconds of occlusion. TEE provides a more specific finding of local coronary ischemia by detecting regional wall motion abnormalities in real time during coronary occlusion. In general, the LIMA to LAD anastomosis allows the heart to maintain good hemodynamics. Cardiac subluxation to expose the coronary targets is far less than during off-pump CABG via full sternotomy. A test occlusion of the coronary artery can be performed prior to a LIMA to LAD anastomosis in order to determine whether a coronary shunt will be useful. Shunting can help avoid cardiac compromise due to ischemia during the distal anastomosis on a beating heart, but makes the technical task of the anastomosis more difficult. If the ischemia does not resolve with the coronary shunt in place, this is a major problem that often requires a bail out maneuver – either sternotomy or peripheral access CPB. If ischemic EKG changes don't resolve after the bypass graft is placed and it is associated with wall motion abnormality on TEE, this is another serious situation that often requires a change in the operative approach. These are the events that should be anticipated in order to facilitate rapid corrective action.

Another situation to monitor for is tamponade or right heart dysfunction. During open chest surgery, heart surgeons are able to directly inspect the right ventricle and are easily able to detect evidence of dysfunction. In robotic cases, the minimally invasive access eliminates direct visibility of the right ventricle through the surgical wound. Echocardiography therefore is a key tool to monitor the right heart. There is risk of a tamponade-like effect or cardiac ischemia when CO2 insufflation is initiated. It is important to watch for elevations in central venous pressure and pulmonary artery pressures, and decreases in systemic blood pressure (SBP) and cerebral oximetry. If any of these are present or suspected, this should be communicated to the surgeon because it could lead to a change in the operative plan. The most likely problem that would prompt a change to the operative plan is evidence of right heart dysfunction. A TEE exam should be performed continually during the case and can be used to monitor right heart function. It is possible that the surgeon could make changes in the approach that may improve the blood pressure, such as decreasing the pressure of insufflation or making other changes in the operative plan, such as using CPB assistance that will improve right heart function. Many times, a modification in the surgical plan creates a quicker and more definitive treatment for hypotension or hypoxia.

During elective mitral valve and multivessel CABG cases there is no access to the heart directly for cannulation and therefore peripheral access of the femoral artery and vein is used for bypass. The TEE exam becomes very important in determining whether there is evidence of disease in the descending thoracic aorta. This finding could complicate the safety of femoral artery cannulation and the ability to use an intraaortic balloon pump. In general, the main focus for a preop TEE is to identify intracardiac pathology and ventricular function. Femoral access CPB is not used in every case, so the importance of reviewing the descending aorta and making this finding known to the surgeon can be forgotten at times. TEE is then used intraoperatively to assure the arterial wire is in place prior to the insertion of the femoral arterial cannula. Using a bicaval view the TEE is then used to guide the surgeon in placing the femoral venous cannula, assuring its position in the SVC. Prior to the initiation of CPB, the CPB machine will be primed using retrograde autologous perfusion in order to minimize hemodilution. Sometimes the volume depletion this causes leads to difficulties maintaining the SBP in the appropriate range. This requires two way communication between the anesthesiologist and perfusionist, who can adjust how quickly the volume is being removed from the patient to prevent a precipitous drop in SBP.

Weaning from CPB typically occurs within 10-20 minutes of removing the aortic cross clamp. If ventricular fibrillation occurs as bypass is being weaned, it often signifies an air embolism. Such an embolism often occurs in the right coronary artery. Finding EKG evidence of right coronary artery ischemia or focal wall motion abnormality in the right coronary distribution on TEE helps confirm this as the etiology. Defibrillation is the treatment of choice at this time. Elevation of the systemic arterial pressure helps to drive the embolic air from the coronary circulation. After the patient is successfully weaned from CPB, the lungs should be gently re-inflated. When there is a LIMA to LAD done robotically, the surgeon should be closely watching the position of the left upper lobe as it is inflated to confirm that it does not distort the graft. Evaluation by TEE should be done prior to weaning from CPB and removing the cannulas, looking specifically for major problems with valve function or ventricular function that should be addressed prior to attempting to remove bypass support.

Conclusion:

While there are many similarities to open cases, robotic cases provide challenges that are vastly different than the corresponding conventional open approach. Anesthesiologists can contribute to success or failure of the operation by understanding how they can favorably influence the safe completion of the procedure. A great way to get through the learning curve period is to use expert coaches intimately familiar with these steps that can provide feedback to the novice. Ultimately, the culture of safety is a key aspect that allows teams to learn from mistakes made during the early initiation period. By having all personnel available for all cases while early in the learning curve, they can all gain valuable experience needed to successfully transition into an experienced program.

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