Coronary Bypass Grafting With the Computer Motion System

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The ZEUS robotic microsurgical system (Computer Motion, Inc., Goleta, CA) has been used in the United States, Canada, and Europe to perform coronary bypass grafting. Initial procedures were done on the arrested heart using either a median sternotomy and conventional cardiopulmonary bypass, or using the Heartport system (Heartport, Inc, Redwood City, CA) and a minimally invasive incision. Recently, Dr. Herman Reichenspurner and Dr. Douglas Boyd have used the robotic system to perform coronary bypass grafting on the beating heart. Dr. Boyd has accumulated a series of 17 patients who have undergone complete endoscopic coronary bypass grafting on the beating heart using the ZEUS system.

The recommended training regimen with this system includes 80 to 100 hours of practice in inanimate models, live animals, and cadavers. Clinical sites are required to prove their mastery of predetermined skill drills that are carefully reviewed before proceeding to the next developmental stage. Initially, it is recommended that a center without previous robotic experience begin their clinical cases through a full sternotomy. This provides an excellent safety margin for the patient and allows the surgical team to become familiar with endoscopic surgery. Endoscopic experience increases gradually by requiring centers to first perform a series of robotically assisted endoscopic internal thoracic artery harvests. In these initial cases, the surgeon completes the anastomosis by hand. This format increases endoscopic learning and readies the surgeon and surgical team to perform a completely endoscopic case.

Once the surgical team has had sufficient experience and is comfortable with endoscopic internal thoracic artery takedown and the anastomotic technique, the sternotomy and left thoracotomy may be abandoned. The surgeon can then proceed to performing a total endoscopic bypass graft procedure. Here, we describe the steps in performing a robotically assisted endoscopic anastomosis of the left internal thoracic artery (LITA) to the left anterior descending (LAD) coronary artery using either an anterior thoracotomy or a partial or total median sternotomy. We then describe the steps involved in totally endoscopic coronary bypass grafting.
SURGICAL TECHNIQUE

Anterior Approach on the Arrested Heart

1. Patient and robotic arm positioning. The patient is placed supine on the operating room table. After the patient is anesthetized and intubated, he or she is positioned approximately 8 to 10 inches down from the head of the table. This allows room for the upper robotic arm to be positioned correctly. All three robotic arms are attached to the operating table. The AESOP arm is attached at the level of the patient's head on the right side. This arm will hold the endoscope. The two remaining robotic arms, which will hold the ZEUS instruments, are positioned approximately at the mid-thigh level on the left and right sides of the table. The patient is prepped in the normal fashion, and the ZEUS robotic arms are carefully draped with custom-made sterile drapes. The drapes must be loose enough to allow for free up-and-down movement of the robotic arms. The robotic arms can be lowered out of the way if the surgeon chooses to perform a median sternotomy and internal thoracic artery harvest. If the surgeon chooses a minimally invasive direct coronary bypass (MIDCAB) procedure, then a small left anterior thoracotomy can be made and the ITA harvested in the usual fashion. Alternatively, the ITA can be harvested endoscopically and robotically anastomosed using either a small anterior left thoracotomy or a partial lower sternotomy for surgical exposure.
2 After the ITA graft is harvested, the patient is placed on cardiopulmonary bypass. Then three 5-mm ports are placed. The first trocar is used for the endoscope and is positioned in the fifth intercostal space in the midclavicular line. A second trocar is used for the left instrument port and is placed in the subxiphoid position. The final 5-mm port is used for the ZEUS right instrument and is inserted approximately in the sixth intercostal space in the anterior axillary line. The ports should be triangulated and approximately 8 to 9 cm apart.

3 See legend on opposite page.
Because FDA has allowed only one graft to be performed robotically (LITA to LAD), it is our practice to arrest the heart with cardioplegia and perform all other distal anastomoses first. When the surgeon is ready for the distal LAD anastomosis, the endoscope is reattached to the AESOP arm and the robotic instruments are reinserted into their sheaths. At this point, the retractor is usually either removed or unscrewed to allow the chest to approximate a more natural position. The surgeon then takes a seat at the surgical console, and the first assistant stands at the table along with the scrub nurse. The assistant’s role is to position the ITA graft. The scrub nurse changes the instrument tips and also cleans the camera when necessary.

The surgeon begins by ensuring that he or she has full range of motion of the two instruments and that there is no conflict between the instruments and the endoscopic camera. If a problem exists, it is important to reposition the ports before beginning the anastomosis. Creation of the anastomosis begins by performing an arteriotomy. The articulating scalpel and Pott’s scissors are used to open the LAD coronary artery. After exposure, it is helpful if the assistant uses a mister/blower, but great care must be taken to avoid getting fluid on the camera and obscuring the surgeon’s vision. The anastomosis is performed with a specially designed double-armed 7-0 Gore-Tex suture. We have found this suture to be ideal for endoscopic coronary surgery. It is white and easy to visualize and does not have the intrinsic memory of Prolene suture. It also does not slide as easily as Prolene, which is helpful when tying a knot without haptic feedback. The enhanced visualization afforded by endoscopic camera provides for magnification of up to 15× and can be helpful in the creation of the bypass graft. In 20 consecutive cases at our institution, we have had no significant (>50%) anastomotic stenoses or occlusions.¹
The anastomosis begins by taking an outside-in bite on the internal mammary artery (IMA) at the heel, followed by an inside-out bite on the LAD coronary artery using a needle holder in the right instrument port and a ring forceps in the left instrument port.

The IMA is then parachuted down to the LAD coronary artery and the toe of the anastomosis completed. During the anastomosis, the needle holder is held in both the right and left instrument arms to complete the entire circumference of suture. We have found this easier than trying to perform a backhand stitch. The suture is tied using standard intracorporeal technique. The slight curve on the needle holder greatly aids tying the Gore-Tex suture. The IMA is then opened, and the anastomosis is inspected. The remainder of the case is finished in a standard fashion.
Endoscopic Beating Heart Coronary Bypass

Patient and robotic arm positioning. After establishment of general anesthesia with a double-lumen endotracheal tube, the patient is placed in the 30-degree right lateral decubitus position. The three ZEUS robotic manipulating arms are mounted on the operating table as shown. The voice-controlled AESOP arm is used to hold the endoscope and is positioned on the right side of the operating table directly opposite the proposed camera port-access site. The two remaining arms are mounted on the left side of the table opposite the patient's head and at the level of the patient's mid-thigh. These arms are used for positioning the endoscopic instruments. The video monitor is placed directly across the operating table from the first assistant, who is positioned on the patient's left side. The patient's left arm is abducted and free-draped to provide for sufficient exposure of the axilla to allow placement of the access ports. The patient and robotic arms are draped as previously described. In addition to standard monitoring, external defibrillator pads are placed, and warming blankets and a bear-hugger extracorporeal warmer are applied to maintain normothermia.
Endoscopic ITA harvest is performed using three 5-mm ports positioned as shown. After the left lung is collapsed, a 30-degree thoracoscope, held by the robotic AESOP arm, is placed through the insufflation port in the fifth intercostal space at the anterior axillary line. Warmed CO₂ is used for insufflation, with initial pressure limits are set at 8 mm Hg. To vent intrathoracic vapor created by the harmonic scalpel, a Veress needle is inserted through the anterior chest wall in the sixth intercostal space. Once the ITA is identified, two additional 5-mm ports are inserted in the third and either the sixth or seventh intercostal spaces in the mid-to-anterior axillary line. Actual port positions are governed by chest wall anatomy, but a distance of at least 7 cm between ports is necessary to prevent external robotic arm collisions. For the ITA dissection, the harmonic scalpel is initially placed through the upper port, and a Kinter dissector (Ethicon Endo-Surgery, Cincinnati, OH) is placed through the lower port.

Before beginning the ITA dissection, the desired end-effector motion and rotational scalings are set. A motion scale of 3.5 to 1 and a rotation scale of 0.8 to 1 is routinely used. The course of the ITA is identified and marked by scoring the parietal pleura 1 to 2 cm away from the artery between the first and sixth intercostal spaces. The ITA dissection begins over the second rib and progresses distally. We have found that the dissection is easiest when initiated over the ribs, because they provide "safe-zones" free of any intercostal tethering.
After the ITA is separated from the superior and inferior ribs, the intervening intercostal spaces are carefully dissected. During this dissection, the Kitner dissector is often used to provide gentle countertraction and is positioned by rolling the Kitner on the ITA. The intercostal arteries and veins are divided using the harmonic scalpel. Using a power setting of three, gentle pressure is applied with the blunt side of the blade. Coningulating and cutting intercostal vessels require an average of approximately five seconds, but the actual time can vary depending on the size of the intercostal branches being divided. After the dissection reaches the fifth or sixth intercostal space, it is sometimes necessary to change the harmonic scalpel to a lower interspace, although still using the same skin incision. This technique eliminates any excessive instrument torque and avoids maneuvering limitations caused by the surrounding soft tissues or ribs. The port access for the harmonic scalpel and Kitner can also similarly be exchanged to improve distal approach angles for dissection if required.
Once the ITA dissection is completed, the Kitner is exchanged for a grasper and the pericardial fat pad is removed to expose the pericardium. The pericardium is incised vertically, starting 2 cm medial to the phrenic nerve at the junction of the thymus and pericardial fat pad and the anterior descending coronary artery is identified. Heparin is administered, and the activated clotting time ACT is verified to be greater than 400 seconds.
An endostabilizer (Computer Motion, Goleta, CA) is inserted through a 10-mm port in the second interspace at the lateral clavicular line. Articulating instruments (Microwrist, Computer Motion, Inc.) are inserted into the chest cavity through upper and lower ports. The 5-mm endoscope may be exchanged for a 10-mm three-dimensional visualization system (Karl Storz, Culver City, CA) to perform the anastomosis. After the target area is stabilized, silastic tapes are placed around the LAD proximally and distally to the proposed anastomosis site. Using the ZEUS articulating knife and ZEUS Potts scissors, an arteriotomy is made in the LAD and an intracoronary shunt is placed within. The shunts improve hemostasis and provide a valuable needle depth landmark when performing endoscopic anastomoses with two-dimensional cameras.
A table-mounted stabilizer arm is positioned to hold a 3-mm endoscopic grasper passed through the anterior chest wall to position the ITA that has been clipped distally. Proximal ITA control is achieved by inserting a 3-mm transthoracic bulldog clamp (Scanlan, St. Paul, MN). The ITA is then prepared for anastomosis.
The anastomosis is started in a side-to-side fashion using a 7-cm Gore-Tex CV-8 suture. After stitching around the heel area, the distal end of the LITA is cut away and the conduit is parachuted down.
The anastomosis is completed in the conventional end-to-side fashion, the shunt is removed and the suture is tied with the robotic instruments. After the anastomosis is completed, the graft flows are checked with an endoscopic transit-time ultrasonic flow probe (Transonic Systems, Ithaca, NY). Heparin is then reversed with protamine sulfate, and a small chest tube is placed in the left pleural cavity through the camera port site.
REFERENCES


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