

TOTAL ENDOSCOPIC BYPASS GRAFTING

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Rationale for Endoscopic Bypass Grafting

The goals of minimally invasive or less-invasive coronary artery bypass grafting are twofold: to reduce the surgical trauma by minimizing access and to obviate the need for extracorporeal circulation. Ideally, coronary artery bypass grafting would be performed endoscopically on the beating heart.

In the early 1990s, some groups developed techniques to perform coronary anastomoses on the beating heart.^{1,2} With the development of mechanical stabilizers that provided sufficient local immobilization of the beating heart, patency rates became comparable to conventional on-pump surgery, and both the minimally invasive direct coronary artery bypass (MIDCAB) operation and off-pump coronary artery bypass (OPCAB) procedures have found widespread clinical application.³⁻⁵

Stimulated by the developments in other surgical specialties, endoscopic techniques were introduced in the field of cardiac surgery in the mid-1990s. Using conventional endoscopic instruments, some groups started with endoscopic harvesting of the internal thoracic artery.⁶ At the same time, cardiopulmonary bypass systems, such as the Port-Access system, were introduced, which allowed for closed-chest cardiopulmonary bypass and cardiac arrest.⁷ Closed-chest bypass grafting was, however, still not possible, primarily because of the limitations of conventional endoscopic instruments. The introduction of computer-enhanced instrumentation systems (robotics) has prepared the ground for true endoscopic bypass grafting. These telemanipulators enhance the dexterity, allow scaling of motions, and provide tremor filtering.⁸ A number of groups have started to expand their minimally invasive programs with an endoscopic approach that uses the two currently available surgical telemanipulation systems. After extensive experimental trials, the first clinical studies have demonstrated the feasibility of total endoscopic coronary artery

bypass (TECAB) grafting on the arrested and on the beating heart.^{9,10}

Telemanipulation Technology

Two telemanipulation systems are currently commercially available, the Zeus (Computer Motion, Goleta, California) and the da Vinci (Intuitive Surgical, Mountain View, California) systems. The da Vinci system consists of two major components: a master console and a cart-mounted manipulator. The console houses the display system, the master handles, the user interface, and the electronic controller. The image of the surgical site is transmitted to the surgeon through a high-resolution stereo display. The system projects the image of the surgical site atop the surgeon's hands, while the controller transforms the spatial motion of the tools into the camera frame of reference. Hereby the system provides a natural hand-eye coordination. Motion scaling allows for various ratios for master and manipulator motions. By activating a foot switch, the operator is able to temporarily uncouple and reposition the masters in the working field, while the instrument tips remain stationary (indexing). A tremor filter is used to minimize involuntary motions. The patient-side cart consists of two instrument manipulators and a central camera manipulator. The instruments (end effectors) attach interchangeably to the two instrument manipulators that feature an automated instrument recognition system. By means of an endowrist, a total of 6° of freedom is provided, allowing for free motion and orientation of the tip in space. The system has been described in detail elsewhere.⁸⁻¹²

Technique of TECAB

In December 1998, the da Vinci system was introduced; its main focus was on endoscopic coronary surgery.¹³ In the majority of cases, the system was used to harvest the internal thoracic artery (ITA) endoscopically. After an initial learning curve that was similar in most centers using this

technology, harvest times for the left ITA are now in the range of 30 to 40 min, and the technique is routinely performed in a number of centers.^{9,14,15}

For robotic-assisted ITA harvest, patients are placed in a supine position with the left chest slightly elevated and the left arm lowered. Single-lung ventilation of the right lung is performed. A 30° scope angled up is inserted at the fourth intercostal space (ICS). Continuous CO₂ insufflation is applied to enhance exposure by increasing the available space between the heart and the sternum. Although insufflation pressures up to 10 mm Hg are usually well tolerated, hemodynamic studies demonstrate an increase in right ventricular filling pressures, a decrease of intrathoracic blood volume index, and a decrease of right ventricular ejection fraction with increasing insufflation pressures. As a result, cardiac index and mean arterial pressure (MAP) may decrease despite a compensatory increase in heart rate.¹⁶ The instrument ports are created in the third and sixth ICS. Depending on the individual's physiognomy, ports are created in a flat triangle (with the central camera port placed a little bit lower than the two instrument ports) or in an almost linear fashion following the anterior axillary line. The ideal position for the set-up joints of the instrument arms is 90° between the primary and secondary axis (shoulder) and 45° between the secondary and tertiary axis (elbow). For the camera arm, the net-sum of angles should be 0°, resulting in straight alignment of the scope and the central column. With this set-up there should be no necessity to move the set-up joints during the procedure. The remote centers should be placed correctly within the ports to provide the highest precision and lowest friction.

The ITA is usually dissected as a pedicle from the first rib to the sixth ICS by using low-energy cautery. Clips are rarely used. In cases of muscle or fat covering the ITA, initial dissection of the tissue, including the fascia, facilitate take-down. The precision of the instruments does also allow for a skeletonized take-down technique. Care must be taken to avoid injury of the subclavian vein and the phrenic nerve while dissecting the proximal part of the ITA. ITA harvesting is now routinely performed and permits the tailoring of the thoracotomy incision necessary for a MIDCAB procedure. Approximately 1,350 cases of robotic ITA take-downs have been reported for the da Vinci system alone. If the ITA is to be used for a TECAB procedure, the vessel is skeletonized distally, cut and trimmed for the anastomosis *in situ* by using the native tissue for countertraction. The pedicle is not detached from the chest wall until the anastomosis is finally performed so as to avoid torsion of the graft and any interference during pericardiotomy. For bilateral ITA take-down, the right pleural space is opened and the right ITA is dissected first, sometimes facilitated by the use of a 0° scope.

The first successful TECAB procedure on the arrested heart was reported by Loulmet.¹⁷ Following ITA take-down, the pericardial fat is removed and a pericardial win-

dow is created. After the left anterior descending (LAD) artery is identified, femoro-femoral bypass is initiated by using the Port-Access system for closed-chest cardiopulmonary bypass and antegrade cardioplegic cardiac arrest. The anastomosis is then performed in a running fashion on the arrested heart through the same ports. More than 100 cases have been reported in the literature, mostly single-vessel revascularization of the ITA to the LAD. Cardiopulmonary bypass time and cross-clamp time are in the range of 80 to 120 and 40 to 60 min, respectively. The conversion rate to a sternotomy is now consistently less than 10%, and the reported patency rate for the TECAB procedure ranges from 95 to 100% prior to discharge and 96% at 3-month follow-up angiography.^{18–20} In a few patients, the right ITA was used to graft the right coronary artery (RCA), and successful double-vessel TECAB to the LAD and RCA, as well as sequential grafting of the LAD and a diagonal branch, has been reported.^{21–23} In addition, both ITAs may be harvested endoscopically, followed by a multivessel arterial revascularization on the arrested heart through a left parasternal minithoracotomy in the second interspace (Dresden technique).²⁴

The development of endoscopic coronary artery bypass grafting on the beating heart required the development of endoscopic stabilizers and methods for temporary vascular occlusion. Complete endoscopic bypass grafting was first achieved in a canine model by using a nitinol-based self-expanding endoscopic stabilizer.^{25,26} More advanced stabilizers have subsequently been developed, allowing articulation of the pads and thus providing easier placement. The last generation of endoscopic stabilizers also features vacuum assistance and an irrigation channel (Figure 13-1).

Vascular occlusion can be achieved by using vascular clamps or, more commonly, by using silastic bands that are either locked into the pads of the stabilizer or used in combination with a self-locking plate.

Complete TECAB procedures on the beating heart were first reported by groups in Leipzig and Dresden that used the da Vinci system and an endoscopic stabilizer that was inserted through a subxyphoidal port (Figure 13-2).^{10,27} After the site for the anastomosis is identified, occlusion snares are placed around the vessel. Rather than pushing the needle through, the motion of the heart is used to passively move the needle through the tissue. Before insertion of the stabilizer, all suture material to be used should be placed into the chest to avoid CO₂ leaks later during the procedure. After the stabilizer is placed, the ITA is placed beneath the stabilizer. Alternatively, a first stitch can already be placed in the ITA while it is still attached to the chest wall. Before starting the anastomosis, instruments should be checked for the possible occurrence of singularities, and changes in set-up made accordingly. The irrigation is placed from behind, aiming at the site of the anastomosis. After occlusion (usually proximal and distal occlusion will be necessary because



FIGURE 13-1. Latest generation of vacuum-assisted endoscopic stabilizer with irrigating channel.

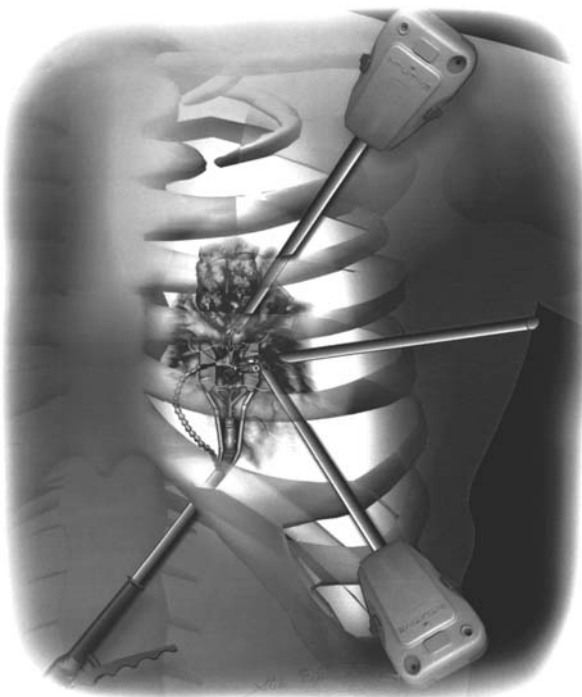


FIGURE 13-2. Set-up for endoscopic beating-heart bypass grafting of the left internal thoracic artery to the left anterior descending. The stabilizer is inserted through a subxyphoidal port.

even a little bleeding from the anastomotic site is not well tolerated), the anastomosis is performed in the usual fashion. Approximately 80 closed-chest beating-heart procedures, including 3 double-vessel beating-heart TECABs using the da Vinci system, have been reported in the literature.^{18,28} Based on an intention to treat, the conversion rate (elective conversion to a MIDCAB procedure) with this approach is currently in the range of 30 to 50%. LAD occlusion times are in the range of 25 to 40 min, and thus exceed those reported for MIDCAB procedures.

Others have used the Zeus system for closed-chest bypass grafting. Because of the lower level of dexterity of the Zeus telemanipulator, five to seven ports plus an additional working port (minithoracotomy) for assistance are needed. Because insufflation pressure cannot be maintained throughout the procedure, a sternal hook is used to provide additional space between the chest wall and the heart. Due to longer anastomotic times, a coronary shunt is used. A harmonic scalpel is usually used for ITA take-down, and the stabilizer is inserted parasternally in the second intercostal space.^{29,30}

Discussion

Based on the experience presented here, it can be concluded that the use of telemanipulation systems is safe and allows for true endoscopic coronary artery bypass grafting. The use of the systems is currently restricted to a few indications (single-vessel bypass grafting of the LAD; occasionally, double-vessel grafting), but it is conceivable that they may be used for endoscopic multivessel procedures in the near future. Ergonomic human-machine interfaces and multilevel servo controlling allow for precise tissue handling despite the lack of fine tactile feedback.

However, operating times are still long and conversions to MIDCAB or open surgery are frequently necessary. A lot of steps that occur between ITA take-down and performing the anastomosis are hampered by the lack of assistance, limited space, the lack of fine tactile feedback, and a limited number of instruments. Among the difficulties are the handling of excessive epicardial fat, determination of the optimal site for an anastomosis, target vessel calcification, and backbleeding from septal branches. In addition, difficulties with positioning of the stabilizer or incomplete immobilization render beating-heart closed-chest bypass grafting difficult. Although removal of pericardial fat, identifying the target vessel, temporary vessel occlusion, delivering material inside the chest, and many more parts of the procedure are trivial in an open-chest scenario, they require a certain choreography to be mastered endoscopically. A low threshold for conversion is mandatory to avoid any risk for the patient. Elective conversion is safe and should not be considered a failure.

As with all new technologies, a learning curve has to be overcome and structured training is considered essential

for the procedural success. This includes a principal understanding of the system architecture of telemanipulation systems and the underlying human-machine interface technology. A team approach is crucial for success, and it is important that the table-side surgeon understands the basic mechanisms of joint motion of the manipulators in order to provide a set-up that allows an unrestricted range of motion. Take-down of the ITA should be routinely accomplished, before aiming at a complete TECAB procedure. For multivessel revascularization, endoscopic devices for exposure of the back wall of the heart need to be developed. Alternatively, different access routes (transabdominal, right chest) need to be explored. Endoscopic ultrasound probes may help to identify coronary pathology and to define the ideal location for an anastomosis in the absence of tactile feedback.³¹

With refinements in telemanipulator technology and the development of adjunct devices to enhance exposure, the technique of computer-enhanced endoscopic cardiac surgery will further evolve and may prove beneficial for selected patients. Smaller and more flexible modular robotic arms will be developed, and new control algorithms will eventually allow one operator to control multiple arms. Three-dimensional high-definition television (3D-HDTV) systems will provide even better optical resolution in the near future.³² The application of multimodal 3D imaging and computational modeling of the range of motion of the robotic arms in an individual patient dataset may optimize preoperative planning of the procedure.³³ The use of preoperative imaging may also help to better identify suitable candidates for an endoscopic approach. Multidetector computed tomography (CT) scanning may help to preoperatively identify intramyocardial LADs, decreasing the risk of conversion or grafting to a diagonal branch.³⁴ New devices for facilitated anastomosis, such as the Ventrica magnetic coupling device, may facilitate endoscopic coronary artery bypass grafting in the future.

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