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Technical Aids to Performing Thoracoscopic Robotically-Assisted Internal Mammary Artery Harvesting

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ABSTRACT

Objective: This report outlines the procedures and technical aids used for performing thoracoscopic internal mammary artery (IMA) harvesting in a series of 308 patients.

Methods: As a part of atraumatic coronary artery bypass (ACAB) operations, thoracoscopic IMA harvests (294 left, 14 right, and 12 bilateral) were performed in 308 consecutive patients. Single-lung ventilation and carbon dioxide insufflation were employed in all cases to facilitate exposure and dissection. A voice-activated robotic arm controlled the camera view, and harvesting was accomplished with the electrocautery on a low setting.

Results: Harvest time decreased from a mean of 58.4 minutes in the first fifty procedures to 29.4 minutes in the last fifty procedures. There were no significant complications as a result of this technique, and no patients required a conversion to sternotomy as a result of IMA injury.

Conclusions: Thoracoscopic internal mammary artery harvesting is an essential basic skill for cardiac surgeons interested in performing minimally invasive and atraumatic coronary bypass procedures. Thoracoscopic IMA harvesting can be successfully performed with the use of the technical aids and procedures outlined in this report.

INTRODUCTION

Thoracoscopic internal mammary artery harvesting has become an integral part of minimally invasive coronary artery bypass procedures. Since previous reports [Nataf 1996, Mack 1997, Duhaylongsod 1998], the technique has undergone significant changes and improvements. There are several justifications for learning thoracoscopic IMA harvesting: (1) it is the most complete and atraumatic method to harvest the IMA; (2) with experience, it can be time-efficient; (3) the technique can be grasped by a majority of cardiothoracic surgeons; and (4) it is an essential technique in future endoscopically assisted or totally endoscopic coronary artery bypass grafting (CABG). We present a comprehensive report of the technique for thoracoscopic IMA harvesting.

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METHODS

Equipment Requirements

There are a number of specialized items of equipment that are essential for thoracoscopic IMA harvesting (Table 1,).

Significant injury to the intercostal nerve can occur with the use of the 10 mm thoracoscope, particularly in the small patient. For this reason, preference is given to the 5 mm scope. The recent improvements in optical quality as well as the greater maneuverability of the smaller scopes make this a better choice. The choice of a zero-degree or 30-degree endoscope is simply a matter of surgeon preference. The 0-degree scope is easier to maneuver, as the movements of the scope are true, whereas the 30-degree scope movement changes the image in two planes simultaneously. The 30-degree scope has the advantage of allowing the scope to operate in a different horizontal plane from the surgeon's two hand-controlled instruments, thereby avoiding collisions. However, this is a rare problem when the 0-degree scope is voice-controlled by a robotic arm. As in all thoracoscopic procedures, it is important to warm the lens to body temperature before use and employ a lens defogger solution.

Carbon dioxide insufflation greatly facilitates harvesting of the left IMA (LIMA), and in most patients, is an absolute necessity. The insufflation safely shifts the heart and its associated mediastinal fat pad medially away from the IMA, allowing complete harvesting to the sixth rib. Insufflation in harvesting the right IMA (RIMA) from the right side is not always required because the heart and associated fat pad are further away. In performing the dissection, one can use either a grasper or an endoscopic kittner to retract the pedicle. In either case, the instrument needs to be at least 30 cm in length to reach the chest wall in all patients.

The tissue is divided with a long cautery extension coupled with a smoke evacuator (Genzyme Surgical, Cambridge, MA). The smoke evacuator tubing is connected to a suction

Table 1. Equipment for Thoracoscopic IMA Harvesting.

Endoscopy Equipment	Alternative
Three chip camera	Single chip camera
Monitor	Head mounted display
Endoscope: 5 mm (0 or 30 degree)	10 mm (0 or 30 degree)
Fiber optic light source	
Optics defogger solution	
Carbon dioxide insufflator machine/tubing	
Ports: 3.5 mm and 5.5 mm (Genzyme)	Same (Core Dynamics)
Video camera-recorder	
Instruments	
Grasper, 3 mm shaft, 30 cm length (Computer Motion)	Endoscopic kittner
Cautery extension with smoke evacuator (Genzyme)	Harmonic scalpel (Ethicon)
5 mm clip applier (Ethicon)	
Robotic arm (AESOP-Computer Motion)	

regulator on its lowest setting. This allows removal of the cautery-generated smoke and yet maintains the pneumothorax and the appropriate level of carbon dioxide insufflation (5-10 mmHg). The cautery setting is always kept low (15-20 watts) because excessive energy for cautery (>25 watts) can result in thermal injury to the IMA as well as splattering of the scope lens, requiring more frequent scope cleaning. Alternatively, the IMA dissection can be performed with the harmonic scalpel (Ethicon) [Ohtsuka, 1997, Wolf 1998]. The advantages of the harmonic scalpel are that it uses mechanical energy rather than thermal energy to divide tissue, which reduces the likelihood of injury to the IMA. The disadvantages of the harmonic scalpel are that it can cause excessive aerosolized particles within the chest cavity, obscuring the view (this tends to occur to a greater extent in patients with a large amount of mediastinal fat), and the division of tissue appears to take longer than with electrocautery. Surgeons experienced with the harmonic scalpel technique will place a needle in the chest on low suction. This allows constant refilling of the chest cavity with new carbon dioxide, which keeps the view clear. Clips are rarely necessary for controlling hemostasis, although a 5 mm clip applier is available.

Voice-activated robotic movement of the endoscope (AESOP-Computer Motion, Goleta, CA) allows for greater precision and efficiency than can be achieved with direct human control. Instrument and tissue collisions are avoided, and delays for scope cleaning are minimized.

Patient Selection and Contraindications

Early in the learning curve, it is best to select patients with a body mass index (BMI) of less than 32. Patients with extremely large hearts in the left chest can also be challenging. For the experienced surgeon, there are very few contraindications to a thoracoscopic approach to IMA harvesting. The presence of pleural symphysis and morbid obesity (BMI >40) are the only major contraindications to this procedure.

Anesthetic Considerations

A central venous catheter and an arterial line are inserted for routine monitoring. If possible, the arterial line should be inserted in the radial artery of the same side as the IMA that is being harvested. The radial artery line can be exchanged to a 4Fr sheath and accessed for intraoperative IMA angiography if so desired.

Single-lung insufflation is necessary for thoracoscopic IMA harvesting. The anesthesiologist places a double-lumen endotracheal tube or a bronchial blocker, and the proper position should be confirmed with fiber optic bronchoscopy.

The lung on the operative side is dropped while the patient is being draped. This allows time for atelectasis to occur. A persistently expanded lung usually signifies malposition of the endotracheal tube or retained air within the lung. Applying low suction to the left bronchus easily rectifies the latter. Oxygen desaturation can also occur on single-lung ventilation. Verifying the tube position can rectify this, but if low saturation levels persist, continuous positive airway pressure (CPAP) is applied to the ventilated side. This is not possible when a bronchial blocker technique is used.

Carbon dioxide insufflation introduced gradually (5 to 10 mmHg at 2-4 mm increments) is safe for the vast majority of patients. Most insufflators administer gas at a pre-set intrathoracic pressure and adjust the flow automatically throughout the procedure. They also have the capability to continuously monitor the insufflation flow and intra-thoracic pressure. One should be particularly cautious in insufflating patients with poor left ventricular contractility (ejection fraction <30%) and in hypovolemic patients (central venous pressure <5 mmHg) [Vassiliades 2000]. The patient should be kept warm with a sterile lower body warmer and the use of warm insufflation.

Preoperative Preparation and Positioning

The patient is positioned to maximize ergonomics for harvesting the IMA thoracoscopically and at the same time to allow full access to perform sternotomy if needed (Figure 1,). The surgeon, the patient's chest, and the monitor should be in a straight line. The surgeon is seated comfortably at the patient's left side and an arm board is used for the surgeon to rest his right arm. This arrangement reproduces the ergonomics of an open IMA harvesting technique and provides maximal operating "comfort" for the surgeon.

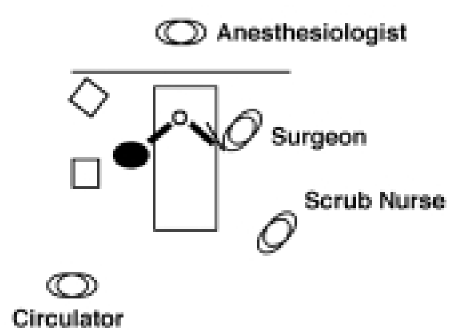

Figure 1. Operating Room Set-up.

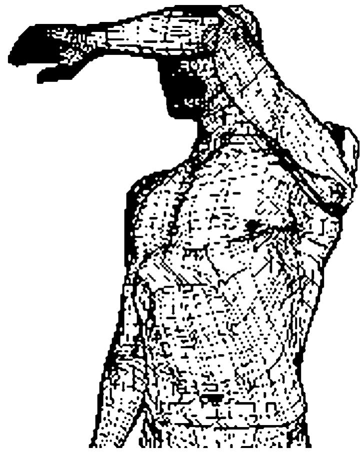

Figure 2. Position of the Patient.

The position of the patient is supine with the thorax rotated approximately 20 degrees off the table by means of folded blankets. Defibrillator pads are placed on the left posterior chest and anterolateral right chest. The left arm is raised over the head with the elbow bent across the patient's face (Figure 2,).

It is extremely important to pad and support the scapula to avoid a brachial plexus palsy. Raising the arm accomplishes several things: it provides more room for the surgeon's right-handed instruments and thins out the soft tissue overlying the anterolateral chest. If so desired, the arm can be returned to the patient's side after the IMA harvesting phase of the operation. The entire chest, abdomen, groin, and legs are prepped. The AESOP robotic arm (Computer Motion, Goleta, CA) is then positioned on the bed rail before placing the sterile drapes.

Technique: (1) Chest Wall Anatomy and Port Placement

Erroneous port placement can make thoracoscopic IMA harvest problematic. The axial (transverse) anatomy of each patient's thorax is unique, but there are primarily two different axial shapes to the thorax that have surgical significance to this procedure: type A: an ovoid shape and type B: a rectangular shape (Figure 3,).

The type A axial chest shape closely resembles a circle, whereas the type B chest shape more closely resembles a rectangle. Thoracoscopically harvesting the IMAs of patients with a type A thorax is technically easier because, as one moves laterally (x axis) along the chest wall away from the IMA, there is also significant change posteriorly (y axis). This provides an expanded and favorable approach angle to the IMA. In contrast, patients with type B axial thoracic anatomy have "flattened" chest walls, and x axis movement results in little y axis movement. Therefore, for type B anatomy, the surgeon must place his ports slightly more posteriorly or be faced with a shallow and problematic approach angle to the IMA. It is also essential to have the chest x-ray in the operating room because the surgeon must know the size and location of the heart before inserting the ports.

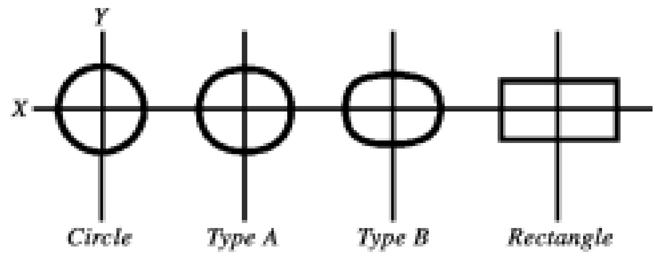

Figure 3. Axial (Transverse) Chest Wall Anatomic Types. x axis: movement in the medial/lateral plane; y axis: movement in the anterior/posterior plane

The z-axis placement of the ports is determined by the interspaces and is not particularly variable from patient to patient (Figure 4,).

The scope port (5.5 mm) is placed in the fifth intercostal space along the anterior axillary line (type A anatomy) or mid-anterior axillary line (type B anatomy). The right-handed port (3.5 mm) is placed in the third intercostal space along the anterior axillary line (type A anatomy) or mid-anterior axillary line (type B anatomy). Keeping the same skin insertion point, the right-handed port is moved back and forth between the third and fourth interspaces for dissection of the superior and inferior portions of the IMA respectively. Therefore, both the scope port and the right-handed port are in the anterior axillary line (type A anatomy) or mid-axillary line (type B anatomy). Regardless of chest wall anatomy, the left-handed port is placed more medially along the chest wall than the other two ports. The third port (3.5 mm) is best inserted in the seventh intercostal space close to the nipple line in type A patients and in the anterior axillary line in type B patients. A small nick in the skin can be made and the grasper or endoscopic kittner may be inserted with or without a port.

Technique: (2) Set-up and Use of AESOP

AESOP (Computer Motion, Inc., Goleta, CA) is mounted on the right side of the patient at the level of the xiphoid. The

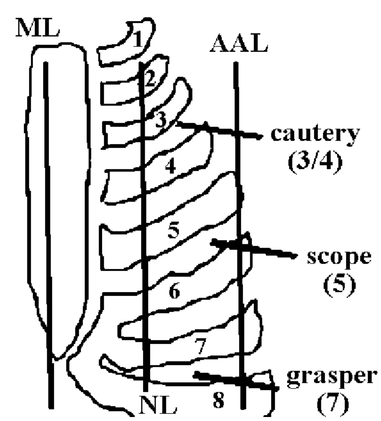

Figure 4. Port Placement. ML = midline; NL = nipple line; AAL = anterior axillary line

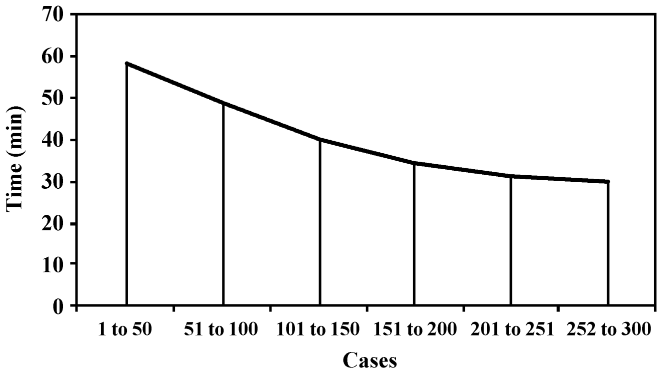

Figure 5. Thoracoscopic IMA Harvesting Times.

elbow is bent toward the head and set at an angle of -2 degrees for most patients. The arm is mounted on the bed rail in a neutral position but can be tilted toward the head or feet up to 15 degrees if necessary during the dissection. Occasionally it is necessary to tilt the base of the arm toward the feet when performing the most inferior IMA dissection. This allows more distance between the scope and the cautery. The lower limit of the arm is set before connecting to the endoscope. It is helpful to save three AESOP positions in at the beginning of the dissection: superior, middle, and inferior points of the IMA. This quickens long distance movements along the IMA.

Technique: (3)The IMA Harvest

Left IMA Harvest from the Left Side

With the lung deflated, the scope port is inserted in the predetermined location as previously described (usually the fifth intercostal space). Carbon dioxide is then started gradually and maintained at a level of 8 to 10 mmHg. The endoscope is inserted and the anatomy reviewed. The remaining two ports are inserted using the guidelines provided above and determined by the patient's particular thoracic anatomy. The key to performing a time-efficient IMA harvest is good surgical ergonomics. The operating table is rotated slightly to the right and the height adjusted to allow the surgeon to be seated comfortably with his hands, shoulders, and head positioned essentially the same as with open IMA harvest. Once the surgeon confirms good port placement and has thoroughly examined the thorax, the dissection may begin. In patients with significant mediastinal and chest wall adipose tissue, it is extremely beneficial to dissect the fat from the endothoracic fascia to see the IMA course clearly. One then dissects the IMA in a manner similar to an open, direct-vision harvest.

The easiest and quickest technique for harvesting the IMA is to mobilize the vessel from lateral to medial as a pedicle with its two accompanying veins. Dissection is performed by gently retracting the IMA pedicle and developing the natural plane between the IMA fat and the intercostal muscle. One then advances up and down the longitudinal axis of the IMA until only the medial fascia remains. Branches of the IMA are divided by using low wattage electrocautery or the harmonic scalpel. The cautery, by virtue of its flexible tip, provides more options for dissecting the IMA under a variety of anatomic conditions. Because cauterizing or clipping in a bloody field is likely to result in IMA injury, bleeding is best managed by gentle pressure for several minutes. Nearly all bleeding resolves without the need for clips or cauterization. The IMA is then separated from all its attachments to the chest wall. Complete mobilization is performed from the subclavian artery origin to the bifurcation (sixth rib). The dissection is not concluded until the target coronary artery is identified and there is confirmation of adequate IMA length for the anastomosis.

Right IMA Harvest from the Right Side

The RIMA harvest from the right side is essentially the same as the left-sided operation, with several important differences. Carbon dioxide insufflation is not as crucial for RIMA harvest because the mediastinal fat pad is primarily left-sided. Nonetheless, insufflation does provide counter traction (medially) during dissection that is extremely helpful. Port placement is the same except that the hand-held instruments are reversed, with the most superior port used for the grasper and the most inferior port used for the cautery.

Bilateral IMA Harvest from Either Side

Thoracoscopic harvest of both the right and left IMA can be performed entirely from one side. The left-sided approach is preferable, as the pericardium will need to be opened from this side for target vessel identification. The ports are placed on the left side and the LIMA is harvested. The mediastinal fat is then completely dissected from the underside of the sternum and the scope and instruments are advanced across the mediastinum. If necessary, the ports for the hand-held instruments can be removed to provide the instruments with some additional working length. If the LIMA has been harvested in its entirety, it will lie on the heart and not obstruct access to the right side. The right pleura is then opened slightly so the lung on that side will partially collapse and be out of the way. Despite bilateral pneumothoraces, the right side is still ventilated adequately and most patients tolerate this extremely well [Vassiliades 2000]. The dissection of the RIMA is then carried out similarly to the LIMA. In contrast to the left dissection, the most challenging part of the RIMA is its most superior portion. Similarly, the inferior part of the RIMA dissection from the left side is easier than the LIMA dissection. This is because the RIMA is further away from the ports, making the angle more favorable.

RESULTS

Between November 1996 and May 2001, 320 thoracoscopic internal mammary artery harvests were performed in 308 patients (300 left harvests and 20 right, of which 12 were bilateral harvests in the same patients from the same side). The mean IMA harvest time (from origin to sixth rib) for the last 50 cases was 29.4 minutes (range 17 to 61 minutes), (Figure 5,).

Six patients underwent thoracoscopic RIMA harvest followed by LIMA harvest from the right side and six patients underwent thoracoscopic LIMA harvest followed by RIMA harvest from the left side. In these 12 bilateral thoracoscopic IMA harvest patients, the mean harvest time of the contralateral IMA averaged 11.5 minutes longer than the ipsilateral IMA harvest. With respect to the entire group of 320 IMA harvests, there were two iatrogenic injuries to the distal IMA, neither one requiring conversion to sternotomy. Both patients underwent end-to-end extensions of the IMA proximal to the injury using the reversed saphenous vein. Eleven patients were redo-CABG procedures.

DISCUSSION

Pitfalls

In addition to correct port placement, one of the keys to a successful thoracoscopic IMA harvest is careful and gentle dissection in the proper plane between the endothoracic fat around the vessel and the intercostal muscle. Staying in the natural planes simplifies the harvesting technique. It is preferable to use the flexible cautery tip to bluntly dissect the planes rather than cauterizing, which tends to create unnatural planes. The electrocautery is reserved for dividing the branches once they are dissected for a safe distance. The branches are then cauterized close to the chest wall and outside of the area between the mammary veins. A second key is to maintain a clear and dry field as much as possible. Even a small amount of bleeding endoscopically can obscure the view significantly.

If the IMA is injured, or unusable, the following options are available: (1) open the pericardium to determine if the injury is beyond the point where the IMA will be divided and continue the operation as planned, (2) resect the mammary from the point of injury distally and add a saphenous vein or radial artery end to end, (3) abandon the injured LIMA and harvest the RIMA thoracoscopically (using the same ports) and graft it in-situ to the LAD, (4) abandon the injured IMA and connect an alternative conduit to the subclavian artery, adding an infra-clavicular incision, (5) convert to a sternotomy and use a free IMA or other conduit as a free graft.

The Educational Process

A logical progression for learning thoracoscopic IMA harvesting would be: (1) acquiring familiarity with the basic principles of thoracoscopy, (2) operative experience with thoracoscopic pulmonary surgery, (3) didactic training in thoracoscopic IMA harvesting, (4) laboratory experience on cadavers and/or animals, (5) live case observation, and (6) mentoring by an experienced surgeon. With enough experience, the harvest times come down to an acceptable level. Eventually, one is able to endoscopically harvest the IMA in nearly all patients who are candidates for a minimally invasive approach. Although the learning curve may be shorter for fully robotic IMA harvesting, such as with the Zeus (Computer Motion, Goleta, CA) or DaVinci (Intuitive Surgical, Mountain View, CA) robotic devices [Loulmet 1999], it is probably a more logical progression to perform thoracoscopic IMA harvests manually (with robotic assistance of the endoscope) before proceeding with robotic dissection [Boyd 2000]. However, a discussion of this topic is beyond the scope of this report.

Another technique for acclimating to endoscopy is to perform open IMA harvesting through a sternotomy using the endoscope and an alpha port (Computer Motion). The alpha port is a device that attaches to the bed and then provides a "virtual" port in space. The surgeon can then harvest the IMA endoscopically using his/her own conventional instruments. This has the advantage of teaching the surgeon how to recognize visual cues of the procedure endoscopically. It allows practice with the use of AESOP (Computer Motion) and provides the surgeon the opportunity to "check" his work throughout the procedure by looking at the IMA directly. It is important for both the surgeon and the team to practice this technique regularly (twice per week) to become familiar with the set-up and function of the equipment as well as the actual performance of the procedure. The next phase in this plan would be to perform an IMA harvest endoscopically in a patient for whom a sternotomy is planned. At the beginning, the surgeon may want to set a time limit (e.g., one hour) for the endoscopic portion of the procedure and then convert to a sternotomy and continue the operation conventionally as originally planned. This method allows the surgeon and the team the opportunity to train without placing the patient at any risk and without delaying the operating room flow significantly. More importantly, the surgeon is able to inspect his work when converting to the sternotomy. One can then confirm that the IMA is being dissected atraumatically and completely.

Regardless of the individual technique used, thoracoscopic IMA harvesting has a shorter learning curve today than it had five years ago. The quality of the image and the instruments has improved, the port placement has been better defined, and several acceptable techniques of dissection have proven to be successful. The procedure is not overly complicated, technically challenging, time-consuming, or expensive. Furthermore, the difference in chest wall trauma between the thoracoscopic approach and the direct vision method are very apparent in the operating room. In light of these developments, arguments against employing an endoscopic approach to IMA harvesting no longer seem valid.

The Future

In addition to the recent advancements mentioned above, ideas now under development will further shorten the learning curve for thoracoscopic IMA harvesting. Image-guided surgery, employing computed tomography or magnetic resonance imaging that would permit pre-selection of favorable port placement, could potentially simplify the entire operation. Robotic or hand-held instruments with greater degrees of freedom (>4) would also assist the surgeon in the entire dissection process. Both of these potential developments would have the effect of lessening the influence of each patient's unique chest wall anatomy on the IMA harvest. Port placement, which is absolutely critical in this operation, could potentially have more flexibility.

CONCLUSION

Thoracoscopic IMA harvesting can be learned by a majority of cardiothoracic surgeons, and several educational plans are available. Unfortunately, its usefulness as a tool in minimally invasive coronary artery bypass operations has yet to be fully appreciated by the cardiac surgery community. Perhaps this is because many cardiac surgeons believe it is useful only for patients with single-vessel disease. The future of hybrid therapy, combining the ACAB technique [Vassiliades 2001] or the TECAB technique [Falk 2000] with the most successful catheter-based procedures, will have a significant influence on the long-term value of this procedure. It seems clear that in the future, minimally invasive bypass procedures, whether ACAB or TECAB, with or without some form of facilitated anastomosis, will require that the IMA be harvested endoscopically. This technique should be learned by any surgeon interested in performing minimally invasive coronary artery operations.

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