Minimally invasive thoracoscopically assisted coronary artery bypass surgery

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Abstract

Objective: Minimally invasive techniques have been widely used in other surgical fields including video-assisted thoracic surgery (VATS) in thoracic surgery. These concepts are now being applied to cardiac surgery. The opportunities to make cardiac surgery less invasive include elimination of the median sternotomy incision, elimination of cardiopulmonary bypass and no manipulation of the aorta. Materials and methods: From January 1992 through September 1996, various aspects of minimally invasive cardiac surgery have been examined in the inanimate endoscopic trainer, animal model, human cadaver and in human clinical studies. Techniques of endoscopic sutured anastomosis as well as alternatives to suturing were first perfected in the inanimate trainer. Twenty animals then underwent endoscopic coronary artery bypass using the left internal mammary artery to the left anterior descending with circulatory support from an axial flow pump. Fifty eight minimally invasive coronary artery bypass procedures have been performed in humans using thoracoscopic assistance for internal mammary artery harvest. Results: One hundred fifty endoscopic coronary anastomoses were performed in the inanimate trainer with the endoscopic suturing technique being the preferred method. Time required to perform an anastomosis decreased from greater than 60 min to a mean of 20 min as technique and instruments were developed. In animals, methods of access as well as enabling surgical instruments to allow crossclamp of the aorta and performance of the anastomosis were developed. Fifty-eight humans underwent coronary artery bypass using the left internal mammary artery placed to the left anterior descending under direct vision through a limited anterior thordcotomy on a beating heart. The procedure was successful in 52 patients with conversions required in six patients. Techniques were developed for immobilization for performance of the anastomosis. Discussion: The ability to perform an endoscopic anastomosis still remains the rate limiting step for totally endoscopic coronary artery bypass surgery. The present MIDCAB (minimally invasive direct coronary artery bypass grafting) procedure is a significant advance in cardiac surgery, but still has limitations that make performance of an exact anastomosis still somewhat difficult and applicable only to single-vessel disease. Present efforts are directed toward extending the MIDCAB procedure by various immobilization and circulatory support devices and combining the MIDCAB procedure with catheter techniques for treating more advanced disease. © 1997 Elsevier Science B.V.

Keywords: Coronary artery bypass surgery; Thoracoscopy; Video-assisted thoracic surgery; Minimally invasive surgery; Endoscopic coronary artery bypass

1. Introduction

Minimally invasive techniques have been developed for all surgical specialties with cardiac surgery being the last to embrace these concepts. Thoracic surgeons developed significant experience with video-assisted thoracic surgery (VATS) beginning in 1990 and demonstrated that the majority of intrathoracic, non-cardiac
Beginning in early 1992, we began to focus on potential cardiac applications of VATS. Although a number of simple cardiac related procedures including pericardiectomy, patent ductus arteriosus ligation, pacemaker lead and defibrillator patch placement had been performed by VATS, more complex cardiac procedures remained problematic.

Early in our experience, it was clear that three opportunities existed to make cardiac surgery less invasive including elimination of the median sternotomy incision, elimination of or alternatives to cardiopulmonary bypass and elimination of manipulation of the aorta. It became immediately apparent that performance of an endoscopic sutured anastomosis would be the most difficult and therefore, the rate limiting step toward development of a totally endoscopic coronary artery bypass procedure. Therefore, initial research efforts were devoted primarily to this aspect.

2. Materials and methods

2.1. Inanimate trainer

Beginning January 1992, an inanimate trainer simulating an upper human torso was constructed to develop endoscopic surgical techniques. A porcine heart was obtained from a slaughterhouse and human saphenous veins were used to develop an endoscopic sutured anastomosis technique. Alternatives to endoscopic suturing including vascular staples and laser tissue wielding were also examined. Specific instrumentation for endoscopic suturing were developed as well as optimal suture length and needles and a specific suture technique utilizing two sutures was defined.

2.2. Animal studies

When the endoscopic suturing technique was perfected in the inanimate situation, animal studies were performed. The pig model was used to develop techniques of video-assisted internal mammary artery harvest. Access approaches for performance of an internal mammary artery to left anterior descending coronary anastomosis were developed. In some animals, cardiopulmonary bypass by the femoral-femoral technique was utilized. The Hemopump (DLP, Medtronic, Inc., Grand Rapids, MI) axial flow device was used in later experiments for circulatory support. This was a 14 FR catheter placed across the aortic valve into the left ventricular apex capable of augmenting the cardiac output by 2–2.5 l/min.

Table 1

<table>
<thead>
<tr>
<th>Current</th>
<th>Proposed</th>
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<tr>
<td>General anesthetic (double lumen tube)</td>
<td>Access-ports only</td>
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<tr>
<td>Limited left anterior thoracotomy</td>
<td>Visualization: 3D video</td>
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<tr>
<td>Video-assisted internal mammary artery harvest</td>
<td>Circulatory support: hemopump axial flow device</td>
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<td>Direct vision mammary–coronary anastomosis</td>
<td>Immobilization: Octopus device</td>
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<td>Adenosine temporary cardiac standstill</td>
<td>Anastomosis: endoscopic suturing</td>
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2.3. Human studies

Beginning in May 1995, our clinical experience began with the minimally invasive direct coronary artery bypass grafting (MIDCAB) procedure using video assistance for internal mammary artery harvest (Table 1) [1]. The procedure is performed through either a 6-cm limited left or right anterior thoracotomy with or without resection of the fourth costocartilage. The internal mammary artery is harvested either through three ports on the lateral chest wall (Fig. 1) or by use of video assistance through a separate port and introduction of instruments through the limited anterior thoracotomy incision (Fig. 2). Complete harvest of the internal mammary artery was attempted in all patients. A pericardial window was then made and the anastomosis was performed between the left internal mammary artery and the coronary artery without cardiopulmonary bypass using a variety of immobilization techniques including vessel loops, sutures and various local stabilization devices. In addition, pharmacologic immobilization with adenosine was used to create a motionless field.

Fig. 1. Technique of video-assisted internal mammary artery harvest.
2.4. Current and future studies

At present, in collaboration with other centers, we are working to extend the current MIDCAB procedure using the Hemopump device for circulatory support, the Octopus local wall motion immobilization device and a totally endoscopic sutured anastomosis in the animal model (Table 1) (Fig. 3). The goal is to perform a totally endoscopic coronary bypass on a beating heart without cardiopulmonary bypass.

3. Results

One hundred fifty totally endoscopic sutured anastomoses were performed in the inanimate trainer. Among the results obtained were a specific endoscopic suturing technique. The technique involves two sutures one each placed at the heel and the toe of the anastomosis with a running back handed suture technique. The time required for performance of anastomosis consistently decreased during the course of the study from greater than 60 min initially to an average of 20–25 min.

Specific endoscopic microvascular instrumentation including Castro-Viejo type needle holders and DeBakey endoscopic forceps were developed. Three-dimensional imaging significantly simplified the endoscopic suturing technique. All anastomoses were examined immediately upon completion for patency. Because of the continual evolutionary changes in the anastomotic technique during the course of the study, success rates are not meaningful. Changes included suture length, needle size and shape, number of sutures used, different needle holder and forceps prototypes as well as vascular staples. It was only when we could consistently complete the anastomosis endoscopically in the trainer model did we embark on animal studies.

In the animal model, the Hemopump axial flow device was felt to be sufficient for circulatory support when local wall mobilization was obtained. However, the Hemopump does not allow for the ability to cross-clamp the aorta and perform ischemic arrest. It also does not allow the technique to be performed on a fibrillating heart due to distension of the right ventricle. Specific access sites were developed for the endoscopic approach as well as cardioplegia delivery devices, and aortic crossclamp instrumentation. The sutured technique that was developed in the inanimate model was...
used in the live animal for anastomosis of the internal mammary artery to the left anterior descending and was significantly more challenging even though it had been perfected in the inanimate trainer.

In our human experience between May 1995 and September 1996, a total of 58 minimally invasive coronary artery bypass procedures were performed (Table 2). These included the left internal mammary artery (LIMA) to the left anterior descending in 51 patients. The LIMA was placed to the diagonal in two patients, the right internal mammary artery to the right coronary artery in three and right gastroepiploic artery was placed through the diaphragm to the posterior descending branch of the right coronary artery in two patients. Fifty patients (86%) had single vessel disease while the remainder had two or three vessel disease with a culprit lesion. Twelve patients (20%) had previous coronary artery bypass surgery. The procedure was successful in 52 patients with six patients requiring conversion to either cardiopulmonary bypass, median sternotomy or both. Three patients required conversion to sternotomy only, one to cardiopulmonary bypass only and two to both sternotomy and cardiopulmonary bypass. Reasons for conversion included hemodynamic instability in two patients with right coronary artery procedures being performed, inadequate internal mammary artery for conduit in two patients, an intramyocardial left anterior descending that could not be located through the limited access technique in one patient. A thick chest wall in an obese patient with extensive pleural symphysis precluded performance of the anastomosis in one additional patient. In the 52 successful patients, the operative results are listed in Table 2. There was a consistent trend toward shorter operative times although the hospital stays have gradually increased due to an older cohort of patients with more comorbidities being selected for the less invasive procedure. Twelve patients (20%) who represented with chest pain were restudied angiographically. One patient had a stenosis distal to the anastomosis and one patient had a large diagonal isolated from the left anterior descending inadvertently bypassed. All other grafts were patent and the unstudied patients are all clinically asymptomatic.

### Table 2

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<thead>
<tr>
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<th>Total</th>
<th>Successful</th>
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<tr>
<td>Operating room time</td>
<td>158 min (range: 96–224)</td>
<td>13.61 min (range: 11–32)</td>
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<tr>
<td>Anastomosis time</td>
<td>1.4 h (range: 0–72)</td>
<td>1.3 min (range: 11–32)</td>
</tr>
<tr>
<td>ICU stay</td>
<td>3.61 days (range: 1–8)</td>
<td>3.61 days (range: 1–8)</td>
</tr>
<tr>
<td>Hospital stay</td>
<td>3.61 days (range: 1–8)</td>
<td>3.61 days (range: 1–8)</td>
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4. Discussion

As anticipated, when our efforts in minimally invasive cardiac surgery began in 1992, the rate-limiting step for development of a totally endoscopic coronary bypass procedure is still performance of an endoscopic anastomosis. All other aspects of the operation can be addressed and accomplished with less difficulty. The current MIDCAB technique is a significant advance in cardiac surgery allowing both the elimination of cardiopulmonary bypass and the median sternotomy incision [2–5,7,9]. However, significant limitations to the procedure still exist. These include limited application for the most part to only single-vessel coronary artery disease, and the use of a still somewhat painful limited anterior thoracotomy incision. The most concerning part of the procedure is the performance of an internal mammary artery coronary artery anastomosis on a moving target vessel. It has not been yet proven that the long-term results of a left internal mammary artery to left anterior descending coronary artery anastomosis performed under ischemic arrest in a motionless field are able to be duplicated by the MIDCAB technique, and our results presented here are incomplete and therefore conclusive patency rates cannot be assessed. We are currently prospectively performing immediate postoperative angiography on all patients to answer this concern.

Numerous enabling devices have been developed to help simulate a motionless field. These include various mechanical stabilization devices developed by a number of commercial manufacturers, including the development of the Octopus immobilization device by the Utrecht group. We currently perform all beating heart anastomoses using a stabilization device and feel that the procedure is significantly facilitated.

Alternative forms of circulatory support to extend the procedure yet avoid the morbidity of cardiopulmonary bypass are also being examined at the present time. These include various mechanical stabilization devices developed by a number of commercial manufacturers, including the development of the Octopus immobilization device by the Utrecht group. We currently perform all beating heart anastomoses using a stabilization device and feel that the procedure is significantly facilitated.
Current clinical studies for extending the current MIDCAB procedure include use of the procedure in older patients with significant co-morbidities who are not candidates currently for conventional coronary artery bypass grafting. In addition, numerous centers including our own are combining the MIDCAB procedure with catheter techniques as a ‘hybrid’ approach for treatment of coronary artery disease. The goal is to reproduce the long-term results of the left internal mammary artery to the left anterior descending by the MIDCAB procedure and manage the remaining disease in other vessels by catheter technique (angioplasty or stent placement).

Future enabling technologies include development of other alternatives to cardiopulmonary bypass, including various left ventricular assist devices including some that have no contact with blood. The development of surgical robotics may ultimately facilitate development of a totally endoscopic technique performed on a beating heart using ‘virtual immobilization’ and without cardiopulmonary bypass. This is an exciting time in the field of cardiac surgery and a field very much in a state of flux. The MIDCAB procedure, although a significant contribution, is only an intermediate step in the arena of minimally invasive coronary artery bypass surgery.

References