Cardiovascular Surgery

Early Experience of Robotic-Assisted Coronary Artery Bypass Grafting

Chieh-Sung Tsai,[1] Chuan-Nan Su,[1] Chih-Yuan Lin,[1] Gou-Jieng Hong,[1] Guang-Huan Sun,[2] Dah-Shyong Yu[2] and Shih-Hurng Loh[3]

Purpose: Robotics facilitates minimally invasive cardiac surgery, and has been used to perform portions of coronary artery anastomoses via minimal thoracotomy incisions. This report shares our early experience of robotic-assisted coronary artery bypass grafting.

Methods: The robotic-assisted endoscopic coronary artery bypass grafting of the left internal thoracic artery to the left anterior descending artery was performed by using the da Vinci robotic system. Two robotic instruments and one endoscopic camera were placed through three small ports. A robotic system was used to harvest the left internal thoracic artery; anastomoses were performed directly through a left anterior minimal thoracotomy under off-pump coronary artery bypass.

Results: Between January 2005 and September 2005, the new instrumentation was used in 10 patients. The mean age of the patients was 59 years, and mean left ventricular ejection fraction was 62%. Two of the 10 patients received double coronary artery bypass grafts. They had a radial artery graft bridging the left internal thoracic artery to the diagonal branch through a small left anterior thoracotomy. No major complications were encountered in the postoperative period, except for one patient who was admitted because of left-side pleural effusion. The median length of stay in the intensive care unit was 2.2 days. The mdian postoperative hospital stay was 7.1 days.

Conclusion: The results from this prospective clinical trial in our hospital showed favorable short-term outcome with no adverse events. Robotic assistance enables us to perform totally off-pump endoscopic coronary artery bypass.

Key Words: Coronary artery bypass • Robotics • Surgery

INTRODUCTION

Traditional cardiac surgery is performed through a median sternotomy, which provides generous exposure and access to all cardiac structures and the great vessels. During the past 10 years, surgeons have begun to explore strategies to decrease the invasiveness of cardiac surgery. Techniques have been developed to decrease the size of the incision, and some procedures can be performed through small thoracotomies and limited sternotomies.[1-3]

Recently, there has been an interest in using robotics and computers to enhance the surgeon's ability to perform endoscopic cardiac surgery. This interest has stemmed from the rapid advancement of technology and the desire to make cardiac surgery less invasive. With recent advancements in computers and robotic systems, robotics has proved to be an enabling technology for endoscopic cardiac surgery. The aim of this study was to share our early experience of robotic-assisted coronary artery bypass grafting (CABG).

Received: March 21, 2006 Accepted: June 28, 2006
[1]Division of Cardiovascular Surgery; [2]Division of Urology, Department of Surgery; [3]Department of Pharmacy, Tri-Service General Hospital, National Defense Medical Center, National Defense University, Taipei, Taiwan, R.O.C.
Address correspondence and reprint requests to: Dr. Chieh-Sung Tsai, Division of Cardiovascular Surgery, Department of Surgery, Tri-Service General Hospital, No. 325, Sec. 2, Cheng-Gung Road, Neihu 114, Taipei, Taiwan. Tel: 886-2-8792-7212; Fax: 886-2-8792-7376; E-mail: sung1500@mail.ndmctsgh.edu.tw

MATERIALS AND METHODS

Ten patients underwent robotically assisted endoscopic CABG of the left internal thoracic artery (LITA) to the left anterior descending artery (LAD), utilizing the da Vinci robotic system (Intuitive Surgical, Sunnyvale, CA). The da Vinci system comprises three components: a surgeon console, an instrument cart, and a visioning platform. It permits the intracavitary manipulation of various instrument tips through six degrees of excursion, emulating the human wrist. The operative console is physically removed from the patient and allows the surgeon to sit comfortably and with the head positioned in a three-dimensional vision array. The image of the surgical site is transmitted to the surgeon through a high-resolution stereo display, enabling natural depth perception with high-power magnification and helping restore hand-eye coordination. The InSite high-resolution 3D endoscope and imaging processing equipment provide true-to-life, three-dimensional images of the operative field. Six degrees of motion freedom are offered by this combination of trocar-positioned arms (insertion, pitch, and yaw) and articulated instrument wrists (grip, yaw, pitch, and roll). Full X-,Y-, and Z-axis agility is affected by coordinating footpedal clutching and hand-motion sensors. Coordination of these eye-hand-foot movements enables the surgeon to manipulate the articulated wrists smoothly.[4]

LIMA takedown was performed using the 3-armed da Vinci unit via 3 chest incisions of 1 cm, with a left-sided approach (Figure 1). The patients were intubated with a double-lumen endotracheal tube, allowing single right lung ventilation. The patients were in a supine position, with 30-degree left chest elevation and the left arm placed along the body below the midaxillary line. After deflation of the left lung, the camera port was introduced into the fifth intercostal space (ICS) in the anterior axillary line. Continuous CO_2 insufflation, applying pressures of 5 to 10 mmHg, is mandatory to increase the available space between the heart and the sternum. The robot was then placed to the right side of the patient so that the camera actuator of the robot could be connected to the camera port. The 2 other ports for instrumentation, localized in the third (right arm) and sixth (left arm) ICSs in the midlavicular line, were then introduced, forming a triangle. The LIMA was mobilized from the subclavian artery all the way down to the distal bifurcation with a 30-degree endoscope. The distal end was skeletonized with the concomitant veins and fascia intact to provide countertraction.

After internal mammary artery takedown, access to the heart was achieved via a 6- to 8-cm left lateral chest incision in the fourth ICS. A specially designed retractor that allows a stabilizing device to be attached to immobilize the desired area for anastomosis was used. All anastomoses were performed directly under beating-heart surgery.

RESULTS

Between January 2005 and September 2005, the new wrist-enhanced instrumentation was used in 10 patients (nine men and one woman). The mean age of the patients

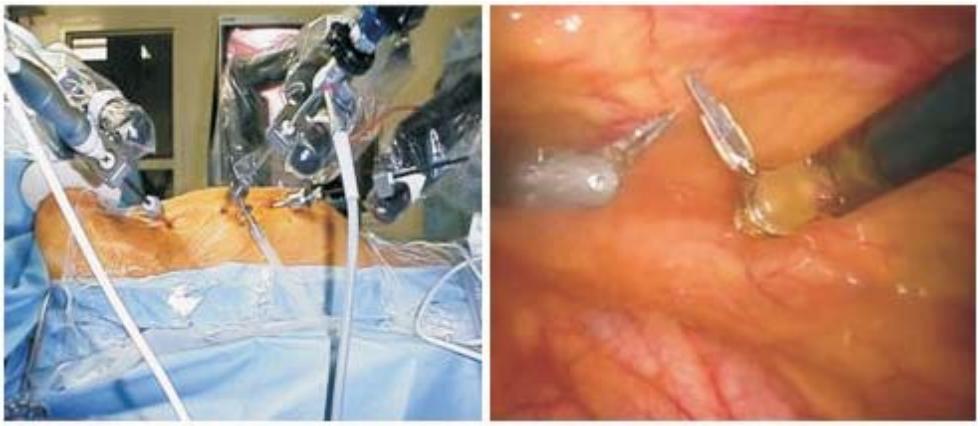

Figure 1. *Left: da Vinci surgical telemanipulation system: patient side cart with three manipulators. Right: Intraoperative view of harvesting the left internal mammary artery.*

was 59 years (range: 38 to 82). Their preoperative left ventricular ejection fraction averaged 62% (range: 35 to 83) (Table 1). Before surgery, all patients had class III or class IV New York Heart Association angina class. There were no intraoperative complications related to the placement of the endoscopic ports. The robotic system functioned without problems in all procedures. There were no intraoperative device-related complications. All patients left the operating room without inotropic agent support, were in sinus rhythm, and were without signs of acute myocardial ischemia.

Two of the 10 patients received two CABGs. They had a radial artery graft bridged from the left internal thoracic artery to the diagonal branch through the left anterior small thoracotomy. The survival rate was 100%. No major complications were encountered in the postoperative period, except for one patient who was admitted because of left-side pleural effusion. The average length of stay in the intensive care unit was 2.2 days (range: 2 to 5). The average postoperative hospital stay was 7.1 days (range: 5 to 8). All 10 patients were available for short-term follow-up. The mean period of follow-up was 7.4 months (range: 4 to 12). There were no late complications. There were no reinterventions and no major adverse cardiac events. All patients were asymptomatic, without recurrent angina.

DISCUSSION

In the past decade, two strategies have been applied to decrease the invasiveness of coronary artery bypass surgery: (1) elimination of cardiopulmonary bypass and cardioplegic arrest to decrease the systemic inflammatory response and eliminate prolonged global myocardial ischemic injury; and (2) minimization of access trauma through small incisions. Cardiac surgeons around the world are becoming aware of the minimally invasive potential of computer-enhanced robotic procedures. With the installation of a computer-based surgical system at our institution, we were able to treat patients with CAD by using computer-enhanced, partially endoscopic, minimally invasive surgical techniques. We began working with the concept of well-established procedures such as minimally invasive directed coronary artery bypass (MIDCAB) and off-pump coronary artery bypass, and started applying them in combination with robotic instrumentation as an adjunct tool. The ultimate goal is the development of a totally endoscopic, closed-chest port access, multivessel coronary artery bypass procedure on the beating heart without the use of a cardiopulmonary bypass that maintains the same superior outcomes attained with the conventional open, arrested-heart approach.

As of May 2001, the da Vinci telemanipulation system had been used in a total of 1250 endoscopic cardiac procedures, ranging from the harvesting of arteries (1137) to endoscopic CABG and mitral valve repair. This system was clinically introduced in 1998. Dr. Loulmet performed the first total endoscopic CABG using da Vinci in June 1998.[5]

Between May 1999 and January 2001, Dr. Stephan

Table 1. Data for 10 patients

Patient No.	Sex	Age (years)	Post-OP hospital stay (days)	ICU stay (days)	Preoperative EF (%)	CABGx
1	F	50	8	3	75	LIMA to LAD
2	M	48	8	2	64	LIMA to LAD
3	M	81	8	2	55	LIMA to LAD
4	M	77	7	2	50	LIMA to LAD
5	M	48	6	2	66	LIMA to LAD
6	M	78	8	3	81	LIMA to LAD, radial artery to D2
7	M	38	5	2	56	LIMA to LAD
8	M	41	8	2	57	LIMA to LAD, radial artery to D2
9	M	48	6	2	35	LIMA to LAD
10	M	82	7	2	83	LIMA to LAD
Mean		59	7.1	2.2	62	

Abbreviations: LIMA= left internal mammary artery; D2: diagonal branch 2; LAD: left anterior descending artery; EF: ejection fraction; F: female; M: male.

Schueler's group in Dresden used the da Vinci on 201 patients.[3] Group A consisted of 156 patients placed into either a minimally invasive direct coronary artery bypass (MIDCAB) (n = 106) without cardiopulmonary bypass, or a robotically enhanced Dresden technique coronary artery bypass (REDTCAB) group with cardiopulmonary bypass (n = 50). All anastomoses were performed manually under direct visualization. The internal mammary artery (IMA) was harvested endoscopically in these groups. In group B, 37 patients underwent totally endoscopic CABG, 8 on pump and 29 off pump. In group C, 8 patients had endoscopic LIMA takedown with robotically-enhanced CABG via median sternotomy.

The survival rate was 99.4% for all groups. Ten patients (4.9%) were converted intraoperatively to a conventional median sternotomy. Of the 56 patients scheduled for total endoscopic CABG, 19 (33.9%) were converted to a MIDCAB procedure due to several factors, including calcification of the LAD, intramural LAD course, pleural adhesions, and difficulty with stabilization. There were no differences in the length of ICU stay, ventilation time, or hospital stay between any of the groups.

At present, these operations are lengthy, technically difficult, and applicable to only a small group of carefully selected patients. The accumulation of surgical experience with this sophisticated instrumentation will eventually improve operative choreography and shorten operative times. This field will continue to advance as parallel technologies continue to develop and facilitate these procedures.

A significant challenge that faces surgeons is the determination of optimal port placement. Surgical experience and computer guidance should facilitate this in the future. Improved instrumentation will aid in the development of this field as smaller, more precise instruments with increased shaft flexibility may simplify port placement in the future. Another challenge is that the lack of fine tactile feedback associated with the current generation of telemanipulators used in surgery requires a new understanding of visual cues such as tissue deformation during dissection of left internal mammary artery (IMA). A substantial learning curve was observed during this early experience, with operating times slowly decreasing from some 120 min in the beginning to 45 to 60 min for recent cases when harvesting left IMA.

At present, the results from the first prospective clinical trial of robotically assisted endoscopic coronary bypass in our institution showed favorable short-term outcomes with no adverse events. These data were our first experience of using robotic telemanipulation systems to perform handsewn endoscopic coronary artery anastomoses. The development of anastomotic devices and further refinements in the telemanipulator technology, optical systems, and image-guided augmented reality scenarios will greatly facilitate endoscopic bypass grafting. As surgeons become more experienced and computer components continue to develop, the safety and efficacy of these procedures will continue to improve. In the future, using robotic assistance is an enabling technology that will motivate us to perform totally off-pump endoscopic coronary artery bypass (TECAB) surgery for the treatment of our patients with coronary artery disease.

REFERENCES

1. Prasad SM, Ducko CT, Stephenson ER, Chambers CE. Prospective clinical trial of robotically assisted endoscopic coronary grafting with 1-year follow-up. *Ann Surg* 2001;233:725-32.
2. Magee MJ, Mack MJ. Robotics and coronary artery surgery. *Curr Opin Cardiol* 2002;17:602-7.
3. Kappert U, Schneider J, Cichon R, et al. Development of robotic-enhanced endoscopic surgery for the treatment of coronary artery disease. *Circulation* 2001;104(suppl):102-7.
4. Diodato MD, Damiano RJ. Robotic cardiac surgery: overview. *Surg Clin North Am* 2003;83:1351-67.
5. Loulmet D, Carpentier A, d'Attellis N, et al. Endoscopic coronary artery bypass grafting with the aid of robotic-assisted instruments. *J Thorac Cardiovasc Surg* 1999;118(1):4-10.

機器人輔助冠狀動脈繞道手術之早期經驗

蔡建松[1] 蘇銓男[1] 林致源[1] 洪國峻[1] 孫光煥[2] 于大雄[2] 羅時鴻[3]
台北市 國防大學 國防醫學院 三軍總醫院 外科部 心臟外科[1] 泌尿外科[2] 藥理學系[3]

目的 機器手臂輔助手術促使微創手術蓬勃發展。且已用在經由小傷口的開胸手術來完成冠狀動脈繞道手術的血管接合。這篇報告主要是分享我們使用機器手臂輔助冠狀動脈繞道手術的早期經驗。

方法 經由達文西機器手臂系統輔助，由左胸前小傷口開胸術完成左內胸動脈至左前降枝冠狀動脈的繞道手術。機器手臂系統是用來取下左內胸動脈，血管接合是在心臟不停跳之下，由左前胸小傷口開胸術完成。

結果 從 2005 年 1 月至 9 月，共 10 位病人。平均年齡為 59 歲，左心室射出分率為 62%。其中 2 位病人接受二條冠狀動脈繞道手術，第二條是由橈動脈橋接左內胸動脈至左前降枝之分枝。術後除了一例是因左側肋膜積水而再次入院外，並無特殊的併發症。平均加護病房住院天數為 2.2 天，平均術後住院天數為 7.1 天。

結論 這篇報告結果顯示出使用機器手臂輔助之冠狀動脈繞道手術有短期良好之預後。且促使我們將來能全程由達文西機器手臂系統來完成冠狀動脈繞道手術。

關鍵詞：冠狀動脈繞道手術、機器人輔助、外科。