The Heart Surgery Forum #2001-73777
5 (3):294–297, 2002

Online address: www.hsforum.com/vol5/issue3/2001-73777.html

Totally Endoscopic Atrial Septal Defect Repair with Robotic Assistance

(#2001-73777 … March 10, 2002)

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ABSTRACT

Background: The development of minimally invasive cardiac surgery has been characterized by the performance of increasingly complex operations through progressively smaller incisions. Computer (robotic) enhancement has emerged as a potential facilitator of these procedures, initially by providing enhanced endoscopic camera control and, more recently, by allowing the manipulation of surgical instruments through limited thoracic incisions. This report describes the next step in this progression, namely the performance of an atrial septal defect (ASD) repair entirely through thoracoscopic port incisions. This represents the first U.S. application of robotic technology for totally endoscopic open-heart surgery.

Materials and Methods: A 33-year-old woman with a secundum atrial septal defect underwent totally endoscopic repair through four port incisions by means of the Da Vinci™ (Intuitive Surgical, Mountain View, CA) robotic surgical system. Cardiopulmonary bypass was achieved peripherally (femoral Estech endoaortic balloon cannula; femoral and right internal jugular venous Bio-medicus cannulae). The myocardium was protected with antegrade cold blood cardioplegia delivered through the distal port of the arterial cannula. After port insertion, the entire operation, including pericardiotomy, bicaval occlusion, atriotomy, atrial septopexy, and atrial closure, was performed by computer-aided control of a camera and two instrument arms manipulated by a surgeon seated 15 feet away. The fourth port was used for suction and suture passage by the patient-side assistant. The aortic cross-clamp time was 43 minutes, and the postoperative transesophageal echocardiogram demonstrated normal ventricular function and the absence of interatrial shunting. The patient was extubated on the night of surgery, was ambulatory within 15 hours, and was discharged on the morning of postoperative day 3, 63 hours after the procedure. At 30-day follow-up, the patient was well and without complaints, and transthoracic echocardiogram confirmed the continued absence of interatrial shunting.

Conclusions: Computer-aided robotic surgical technology can be used to perform open-heart procedures with a totally endoscopic approach. The benefits of this approach may include decreased perioperative pain, decreased recovery times, and improved cosmesis and patient acceptance. Clinical trials currently in progress will demonstrate whether this technology will be of reproducible value in the management of patients with intracardiac disease on a larger scale.

INTRODUCTION

In the past decade, the face of cardiac surgery has been changed by a number of advances, most notably the development of minimally invasive techniques, including minimally invasive direct coronary artery bypass (MIDCAB), off-pump coronary artery bypass (OPCAB), and minimal access valve surgery. Initial attempts to perform cardiac operations through small incisions were hindered by the absence of appropriate accessory technology, such as visualization systems, retractors, stabilizers, and alternative methods of vascular cannulation and cardiopulmonary bypass. With the development of these technologies, surgeons have been increasingly able to perform complex cardiac procedures, including coronary artery bypass, mitral and aortic valve replacement, and atrial septal defect (ASD) closure, through smaller-than-traditional incisions. Nevertheless, in many cases, the extent to which incision size has been reduced by these minimally invasive approaches has been matched by a corresponding increase in technical difficulty and operative time—and a potentially decreased safety margin—due to the constraints imposed by limited or incomplete cardiac exposure.

Computer (robotic) enhancement has emerged as a potential facilitator of minimally invasive surgical procedures. Initially this technology was used to improve visualization of intracardiac structures by providing enhanced (including voice-activated) endoscopic camera control [La Pietra 2000]. More recently, robotic surgical systems have permitted the manipulation of surgical instruments through limited thoracic incisions [Chitwood 2000]. This report describes the next step in this progression: the performance of an atrial septal defect repair entirely through four thoracoscopic port incisions. This represents the first U.S. application of robotic technology for totally endoscopic open-heart surgery.

Submitted March 5, 2002; accepted March 10, 2002.

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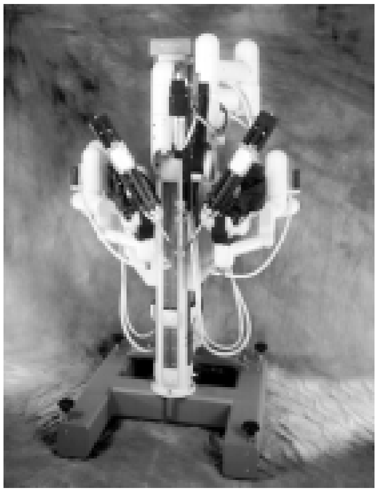

Figure 1. The Da Vinci surgical cart, with a central camera arm and two lateral instrument arms.

MATERIALS AND METHODS

The patient was a 33-year-old woman with an asymptomatic atrial septal defect (secundum type) discovered by echocardiography after a cardiac murmur was noted on routine physical examination. The patient was otherwise in good general health, with no comorbid conditions. The mother of two toddler-aged children, the patient presented to our center requesting a minimally invasive operation because of concerns about the prolonged recovery time associated with more traditional incisions. The patient provided informed consent, and was enrolled in a study entitled "Atrial septal defect closure using Intuitive Surgical Inc.'s Da Vinci Surgical System." This study had been approved by the Columbia University Institutional Review Board and had received an FDA Investigational Device Exemption (IDE # G010156).

Robotic Surgical System

The Da Vinci™ Surgical System (Intuitive Surgical, Inc., Mountainview, CA) consists of two primary components: the surgeon's viewing and control console and the surgical arm unit that positions and maneuvers detachable surgical EndoWrist instruments (Figure 1, ◎). These pencil-sized instruments, which have small mechanical wrists with 7 degrees of motion, are designed to provide the dexterity of a surgeon's forearm and wrist at the operative site through entry ports of less than 1 cm. One port allows access for the endoscope, and the other two ports provide access for surgical instruments. The wrists of the surgical instruments mimic the motions made by the operating surgeon, who sits at a console away from the operating table. The surgeon peers through an eyepiece that provides high-definition, full-color, magnified, 3-D images of the surgical site provided by the endoscope.

Operative Procedure

After induction of general anesthesia, a left-sided double-lumen endotracheal tube was positioned to allow single-lung ventilation. A transesophageal echocardiography probe and bilateral radial arterial pressure monitoring lines were inserted to assist with positioning of the endoaortic balloon later in the procedure. A 17 Fr arterial cannula (Medtronic Bio-Medicus, Eden Prairie, MN) was placed percutaneously into the right internal jugular vein and passed into the superior vena cava with echocardiographic guidance. This cannula was heparinized before and after insertion to avoid thrombus formation. The patient was placed in a modified left lateral decubitus position, with the right arm suspended above the head and the pelvis relatively flat to facilitate femoral cannulation. After sterile preparation and draping, the right femoral vessels were accessed through a 2 cm oblique incision along the inguinal crease. After systemic heparinization, the right common femoral artery was cannulated with a 21 Fr. Remote Access Perfusion cannula with endoaortic balloon (Estech, Inc., Danville, CA). The distal tip of the arterial cannula was passed under echocardiographic guidance into the ascending aorta, approximately 3 cm from the aortic valve. The bypass circuit was completed by inserting a 21 Fr. venous cannula (Medtronic Bio-Medicus, Eden Prairie, MN) into the right common femoral vein and passing it into the inferior vena cava, with its tip just inferior to the IVC-RA junction.

After establishing ventilation of the left lung, a port incision was made in the fourth intercostal space, in the midclavicular line, and a 12 mm endoscopic trocar (Ethicon, Inc., Somerville, NJ) was placed into the pleural space. The endoscopic camera was inserted and, after pleural adhesions were ruled out, the pleural space was insufflated with carbon dioxide to a maximum pressure of 8 mm Hg. Two additional 8 mm port incisions were made in the third and sixth intercostal spaces, in the anterior axillary line. The Da Vinci Surgical Cart was positioned at the operating table, and the left and right robotic arms were inserted into the pleural space. A fourth port incision (15 mm) was made in the fifth intercostal space, in the posterior axillary line, as a service entrance port.

Next, the operating surgeon moved from the operating table to the surgeon's console and began the intrathoracic portion of the operation by manipulating the robotic camera and surgical instrument arms (Figure 2, ◎). A pericardiotomy was made, and pericardial stay sutures placed, with traction provided extrathoracically by passing the sutures out of the chest through needle-sized puncture wounds. Cardiopulmonary bypass was initiated, with kinetically assisted bicaval venous drainage, and the patient was cooled to 32ºC. Caval snares were placed and passed out of the service entrance port, and atrial stay sutures were then placed. The perfusion pressure was reduced, and the endoaortic balloon was inflated to a pressure of 250-300 mm Hg. Antegrade cold blood cardioplegia (4:1) was administered through the distal cannula port, and a satisfactory cardiac arrest ensued. Core temperature was further reduced to 25ºC.

The right atriotomy was then created, revealing a large secundum atrial septal defect. Cardiotomy suction was provided by a specially modified instrument (the Flora sucker) passed through the service entrance port by the patient-side surgeon. The septal defect was closed in two layers with a running 4-0 polypropylene suture. Before tying the suture,

Figure 2. The Da Vinci surgeon's console, from which the robotic camera and instrument arms are controlled.

the left atrium was de-aired by inflating the left lung. After the suture was tied, the endoaortic balloon was deflated, the patient was rewarmed, and normal sinus rhythm resumed. Total cross-clamp time was 43 minutes. The atriotomy was closed with two layers of running 4-0 polypropylene, and the patient was weaned from cardiopulmonary bypass. Total bypass time was 174 minutes. Protamine was administered, and after adequate hemostasis was confirmed, two small (19 Fr) flexible drainage tubes were placed in the pericardium and right pleural space through two of the thoracoscopic ports, and the robotic arms were removed from the chest. The femoral vessels were decannulated and the percutaneous catheter removed from the internal jugular vein. All incisions were closed in layers with absorbable suture material.

Post-operative Course

The patient was transported to the intensive care unit in stable condition without pharmacologic support, and there were no subsequent untoward events. The patient awoke three hours after the procedure and was extubated four hours later. Total pleural and mediastinal drainage was less than 500 cc when drainage tubes were removed 24 hours after the procedure. The patient was ambulatory 15 hours after the procedure and was discharged from the intensive care unit the morning after surgery. The patient received no exogenous blood products, experienced minimal incisional pain, and was discharged on the third postoperative morning, 63 hours after the procedure. At 30-day follow-up, the patient was well and without complaints, all wounds were well healed (Figure 3, ◎), and transthoracic echocardiography confirmed normal ventricular function and the absence of shunting at the atrial level.

DISCUSSION

In the past several years, technical advances in peripheral cardiopulmonary bypass access and endoaortic balloon technology have allowed a number of intracardiac procedures to be performed through smaller than usual (but not necessarily small) incisions. The development of these procedures has required the adaptation of surgical instruments and techniques to the challenge of operating "in a deep hole," with less than optimal visualization. The least invasive of these procedures have required small thoracotomy or partial sternotomy incisions [Reichenspurner 2000, Grossi 2001]. Although these approaches employ smaller than traditional incisions, they are still associated with significant perioperative pain, largely due to the division or retraction of intercostal muscles, ribs, and/or sternal bone. For this and other technical reasons, these procedures have been performed predominantly at selected centers and have not gained widespread popularity.

The minimally invasive cardiac surgical movement has more recently been propelled by the introduction of a new category of technological achievement, the computerized telemicromanipulator. Using this device, also known as the surgical robot, surgeons can manipulate small instruments, which are inserted through small chest incisions, in tight spaces and perform many of the technical maneuvers previously possible only with traditional open exposure. In 1997, the first intracardiac procedures—mitral valve repairs—were performed using a prototype of the current Da Vinci system [Carpentier 1998, Falk 1998]. These operations were performed through small thoracotomy incisions, since the "micro-wrists" allowed the surgeons to complete complex maneuvers without placing their hands within the chest. In December 2000, Chitwood and associates reported the first such mitral valve operation performed in the United States, using an infra-mammary minithoracotomy [Chitwood 2000]. Dozens of such mitral valve repairs have subsequently been

Figure 3. The patient, 30 days after surgery, with four well-healed port incisions.

performed by Chitwood and others under the auspices of a FDA-sanctioned multicenter trial.

CONCLUSIONS

The current case represents the next step in the progression of minimally invasive intracardiac surgery. It is the first U.S. report of a totally endoscopic, robotically assisted open-heart procedure. With femoral cannulation and only four port incisions in the right chest, the Da Vinci surgical system was used to perform every step of an atrial septal defect repair in a 33-year-old woman. By avoiding thoracotomy incisions and rib spreading, this procedure resulted in minimal pain and postoperative recovery time. Despite the impressive results in this case, and the potential advantages of this approach in terms of cosmesis and patient acceptance, it is currently unclear whether these benefits can be expected in all patients. For this reason, additional patients are being enrolled in the FDA-sanctioned clinical trial in order to determine whether this technology will be of reproducible value in the management of patients with intracardiac disease on a larger scale.

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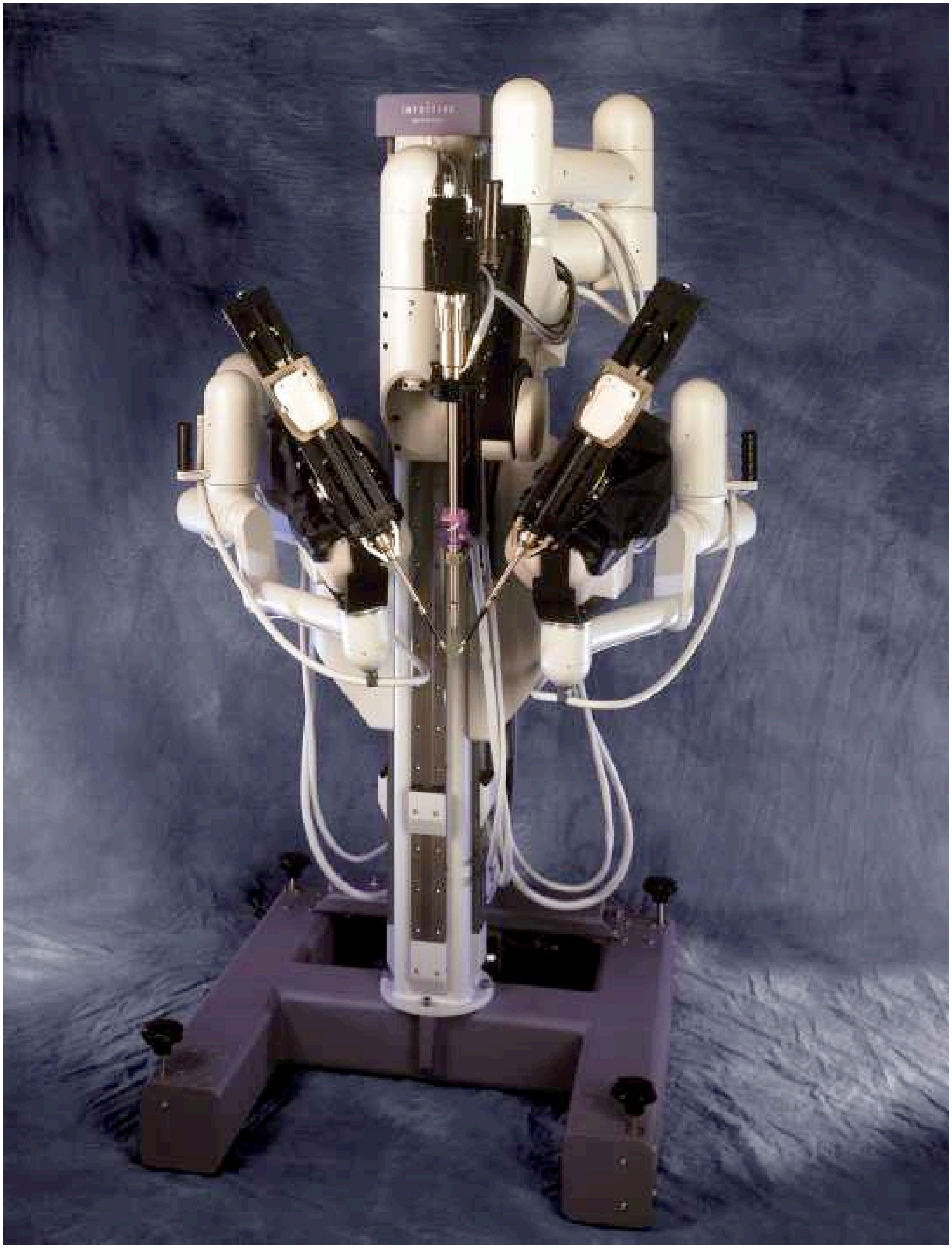

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